Eastern Research Group, Inc.

Evaluation of Remote Sensing for Improving California's Smog Check Program

FINAL REPORT
Version 11

For peer review and public comment

Prepared for:

California Air Resources Board and California Bureau of Automotive Repair

Prepared by:

Eastern Research Group, Inc.

May 4, 2007

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Disclaimer

Table of Contents

List of Tables

List of Figures

1.0 Executive Summary

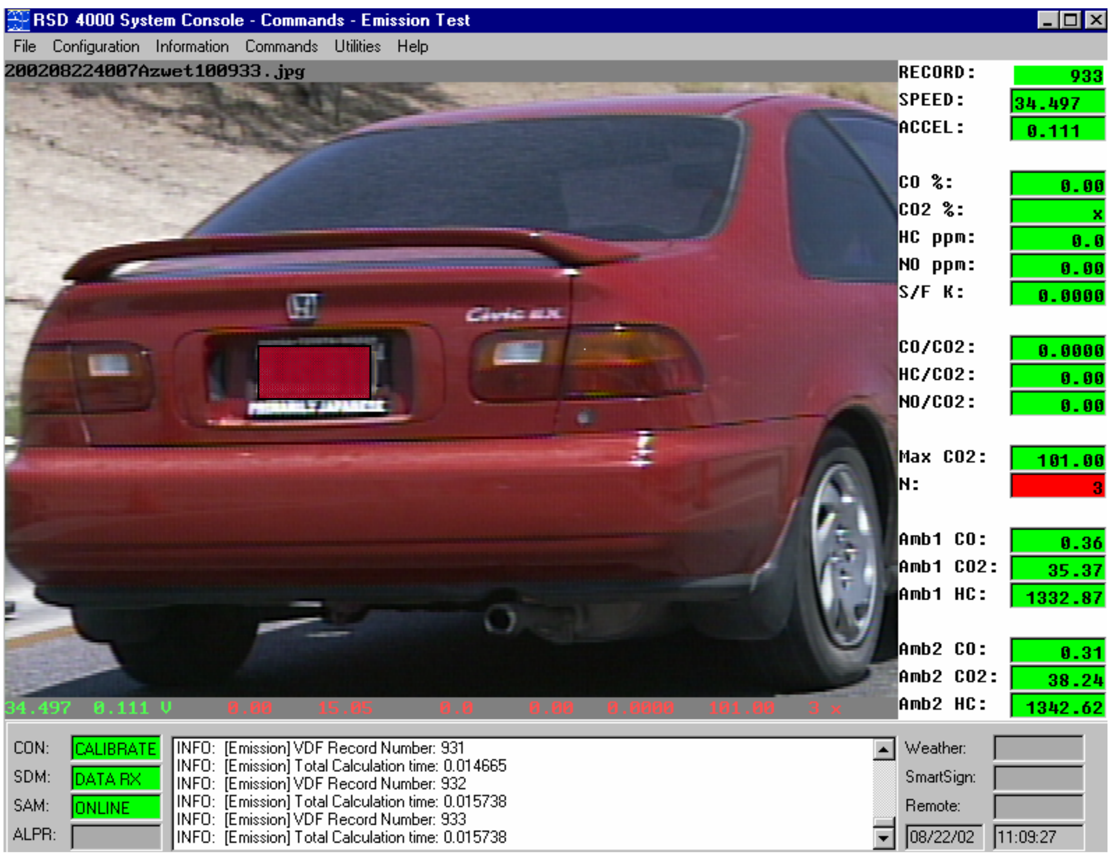
An August 2000 evaluation of California's Smog Check program found the program to be reducing vehicle emissions, but falling short of the reductions set forth in the State Implementation Plan (SIP). To increase the emission reductions of the Smog Check program, the California Air Resources Board (ARB) and the California Bureau of Automotive Repair (BAR) adopted recommendations for improvement based on the evaluation. Most of these recommendations have been implemented. One recommendation was to conduct a pilot program to evaluate whether use of on-road emissions measurement systems, commonly known as Remote Sensing Devices (RSD), could improve the effectiveness of the Smog Check program. This report presents the results of the pilot study.

Remote sensing technology measures pollutants in vehicle exhaust from the side of the roadway. Figure 1-1 shows a vehicle approaching RSD measurement equipment during a test program. Vehicles driving past the measurement site pass through beams of light. The light is partially absorbed by the carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxide (NO) present in the vehicle's exhaust gases, and is partially blocked and scattered by particulate matter (PM) in the exhaust. Measurement of the effect of the exhaust on the light beams can therefore be correlated to vehicle emission levels at the instant the vehicle passes the measurement site. Less than one second's worth of data is captured. The roadside setup also captures vehicle speed and acceleration to aid in the measurement and analysis of the emission data. A photograph of the license plate is taken to facilitate identification of screened vehicles through Department of Motor Vehicles (DMV) records. Figure 1-2 shows an example of the information collected during an RSD measurement.

The principal objective of the pilot study was to determine whether RSD can be used to cost effectively increase emission reductions and improve the efficiency of the Smog Check program. Therefore, the study focused on the cost effectiveness of an RSD program that would be an addition to California's existing Inspection and Maintenance (I/M) program, not one that would replace it. ARB and BAR staff developed a set of specific questions upon which the evaluation was to be based, and refined them through a public workshop prior to the start of the study. The questions, which are presented and answered below, are focused on the ability of RSD to identify specific vehicles for strategies such as "calling-in" for off-cycle inspections or targeting vehicles for "clean-screening", and also on the potential use of RSD data to help evaluate the benefits of Smog Check and characterize emissions from the on-road fleet.

Figure 1-1. Vehicle Approaching RSD Test Setup

Figure 1-2. Sample RSD Data Record



The study consisted of two primary tasks. The first task was a literature review led by Eastern Research Group (ERG) of existing RSD studies and publications. Remote sensing technology experts reviewed and evaluated data and reports covering 12 previous RSD programs relative to the objectives of the pilot study. Existing research gaps and the need for further studies were identified. The team of experts also gleaned to the extent possible information that would help answer the questions of this study and shape its second task. Overall, it was determined that RSD offers potential for identifying vehicles that would benefit, for example, from off-cycle emission inspections, and could also be useful for fleet characteristic and Smog Check performance evaluations. However, the cost of implementing remote sensing in California was cited as a concern. Another issue that was highlighted is the difficulty of using the brief snapshot of emissions performance that RSD provides to assess the overall emission performance of individual vehicles.

The second study task was to generate a large RSD database to be used as the basis for a thorough review of the potential benefits of currently available RSD technology relative to California's Smog Check program. ARB and BAR staff completed this task by collecting over two-million RSD measurements. The data collection effort began in 2004 and continued into 2005. The measurements were taken primarily in the following areas of California: the South Coast region, San Diego, San Francisco, San Joaquin Valley, and Sacramento. In all, valid, registration matched data were obtained for approximately 420,000 vehicles. Approximately 1,000 of the vehicles were randomly selected to receive a roadside Smog Check test immediately following the RSD reading.

ERG used the field data along with California's Smog Check database, known as the Vehicle Information Database (VID), to develop models that directly answer the study questions. The models analyzed the benefits and costs of targeting vehicles for the strategies identified in the study questions based on RSD measurements alone, RSD measurements used in combination with VID data and, for purposes of further comparison, the use of VID data by itself.

The primary focus in designing the analysis was to determine the maximum statewide emission reductions realistically achievable through a large-scale RSD program. Such a program would field about 50 remote sensing devices to collect approximately 50 million valid remote sensing records per year over the five largest air quality districts in California. One of the findings of the study is that conditions restricting the location of remote sensing devices on various roads and freeway on-ramps practically limits the portion of the California fleet for which RSD measurements can be obtained to about 50%.

The percentage of on-road vehicles that can be targeted for special action is further limited in two ways. First, only the portion of the screened fleet for which the RSD measurement was taken while the vehicle was operating with moderate load on the engine can be considered for targeting. RSD readings taken while a vehicle is decelerating or rapidly accelerating are not useful for predicting vehicle performance at a Smog Check station. Therefore, engine loading was determined through the calculation of Vehicle Specific Power (VSP) as each vehicle was driven through the test lane, and only vehicles with a VSP reading falling into an acceptable range were considered for targeting. Second, the study focused only on vehicles subject to California's Smog Check program that were beyond the six-year new vehicle exemption.

Table 1-1 shows the impact of these limitations on the portion of the fleet that can be qualified for targeting through the use of RSD technology. The values are based on the vehicle fleet traveling in the five largest air quality districts in California. For purposes of comparison, small- and medium-scale RSD programs sharing the same basic design as the large-scale program were also modeled. These vehicle population figures are for calendar year 2004.

Table 1-1. Estimated RSD Fleet Coverage

		Program Size		
		Large	Medium	Small
Statewide Fleet Screened by RSD (within 5 major AQMDs)	Percentage of Fleet	50%	30%	10%
	Number of Vehicles	9,491,440	5,694,864	1,898,288
Screened Vehicles with RSD reading within acceptable power range (VSP) for targeting (within 5 major AQMDs)	Percentage of Fleet	20%	12%	4%
	Number of Vehicles	3,796,576	2,277,945	759,315
VSP qualified vehicles subject to I/M	Percentage of Statewide I/M Fleet	16.97%	10.18%	3.39%
	Number of Vehicles	2,271,613	1,362,968	454,323

The data indicate that a maximum of about 17% of the statewide fleet subject to Smog Check can be qualified by RSD for targeting consideration. This percentage excludes vehicles still within the 6-year new vehicle exemption period. The fraction of the fleet that can be targeted using smaller scale programs decreases proportionately. Vehicle targeting using VID data can cover a much larger portion of the fleet because it contains vehicle description information for every vehicle subject to California's Smog Check program along with data from all previous inspections. As such, essentially 100% of the I/M fleet that is beyond the six-year new vehicle exemption can be considered for targeting.

A few key assumptions were employed concerning RSD fleet coverage and costs. First, the use of manned RSD units was assumed. Second, the calculations do not try to account for the fact that some motorists may take alternate routes to their destinations in an attempt to avoid passing through an RSD test lane. Third, it was assumed that the RSD siting restrictions during rush hour that were experienced during the data collection portion of this project would be eliminated through coordination with CalTrans. Lastly, no enforcement costs were included (i.e., it was assumed that all motorists receiving notices following an RSD screening responded as intended without having to be further compelled).

ERG developed and applied ranking parameters to select the best candidate vehicles from the fleet for the special I/M strategies under study. The ranking parameters that were used focused (depending on the strategy) on reducing the number of miles driven by vehicles while they are in a condition that would cause them to fail a Smog Check ASM emissions test, or on reducing the expected mass emissions per vehicle as a result of applying the strategy. As discussed in detail in Section 6.4 of the report, program administrators could choose to employ other ranking variables with the understanding that each parameter presents trade-offs with respect to the type of program benefit that will be maximized. When both VID and RSD data are used by the model, RSD data was used to enhance the ranking calculations for the portion of the fleet for which adequate RSD data can be obtained.

Answers to the study questions, summarized below, were based on the three RSD implementation sizes presented above. The percent of vehicles targeted for a particular strategy is with respect to the portion of the fleet that is both subject to I/M and for which valid, DMV-matched[1] RSD readings were taken that fall within the acceptable VSP range. Questions 1 through 4 focus individually on the benefits and costs of using RSD to call-in high emitting vehicles for off-cycle Smog Check inspections, to exempt clean vehicles from their next scheduled Smog Check, to improve High Emitter Profile (HEP) databases used to direct vehicles to high-performing Smog Check stations, and to identify high-emitting vehicles that would be good candidates for early retirement. For Question 5, the benefits of a program that combines the strategies identified in Questions 1 through 4 are evaluated. Questions 6 and 7 address whether RSD data can be used to collectively evaluate the general emission performance and trends of large groups of vehicles (in contrast to using RSD to select individual vehicles for specific emission-related programs).

[1] DMV-matched refers to the successful matching of a license plate observed during an RSD measurement with a license plate in the Department of Motor Vehicle’s vehicle registration database.

The benefits are for calendar year 2004, and the analysis takes into account that a substantial portion of the emission reductions that RSD technology may otherwise provide are already being obtained by the Smog Check program. The calculated benefits, therefore, are those above and beyond the emission reductions already realized by the Smog Check program. This is an important point to remember considering that other studies often look at the entire benefit of a program that includes RSD instead of just the incremental gain. Further, the study focused on statewide implementation of RSD technology. The results, therefore, may not necessarily reflect the relative costs and benefits of small-scale local programs designed to meet local goals and objectives.

<u>Overview of Study Questions and Findings</u>

Question 1: Can remote sensing technology be an effective tool to identify high-emitting vehicles between regular inspection cycles (i.e., calling-in), and to document the emission reduction benefits of such a program?

Answer: No, not when a follow-up I/M station inspection is required

The call-in program modeled under the study would notify vehicle owners of the need to bring their vehicles in for off-cycle inspection if high RSD emission levels were measured. Called-in vehicles would still be subject to their next biennial inspection. For such a program, the study found that there was an insufficient agreement between remote sensing device readings and the results from follow-up ASM tests conducted at a later date. The study found that the Smog Check station ASM failure rate for vehicles with high RSD emissions was less than 50 percent. This means that vehicles predicted to fail an ASM test based on RSD readings would actually pass a follow-up ASM test more than half of the time.

Table 1-2 summarizes the results of the pilot study for three specific targeting percentages when using RSD to call-in vehicles for off-cycle Smog Check inspections. Estimated failure rates for high emitter call-ins (as identified by RSD) were only 43.5%, 37.2%, and 32.7% (for 5%, 10%, and 15% call-in rates, respectively). To the extent that vehicles that pass the off-cycle inspection are construed to represent errors of commission, the error of commission rates would be far beyond the 5 percent limit for the Smog Check program as set forth in California’s Health and Safety Code. When using the VID to select candidate call-in vehicles, the analysis indicates that only approximately one-third of the vehicles would fail the follow-up ASM test.

Table 1-2. Using RSD to Target Vehicles for "Call-In" Off-Cycle Inspections

Percent of qualified vehicles called-in	Program Size	Large	Medium	Small
5	Number of Called-In Vehicles	113,581	68,148	22,716
	Benefits (tpd HC+NOx)	0.76	0.46	0.15
	Costs ($/2years)	$80,692,952	$35,056,656	$11,988,378
	Cost Effectiveness ($/ton)	$144,822	$104,862	$107,579
10	Number of Called-In Vehicles	227,161	136,297	45,432
	Benefits (tpd HC+NOx)	1.33	0.80	0.27
	Costs ($/2years)	$91,985,532	$41,832,203	$14,246,894
	Cost Effectiveness ($/ton)	$94,902	$71,931	$73,493
15	Number of Called-In Vehicles	340,742	204,445	68,148
	Benefits (tpd HC+NOx)	1.77	1.06	0.35
	Costs ($/2years)	$102,197,934	$47,959,644	$16,289,374
	Cost Effectiveness ($/ton)	$79,133	$61,893	$63,065

Apart from the low predicted follow-up ASM test failure rate for call-in vehicles, the cost of using RSD technology for calling-in was found to be high in comparison to the emission benefits yielded. Cost effectiveness was calculated to be between approximately $61,000 to $145,000 per ton of emissions reduced, depending on the program size and the percent of qualified vehicles targeted. The benefits and costs of using the VID to call-in high emitting vehicles were also considered when answering Question 5, and are discussed in Section 7.1 of the report.

Agreement between the RSD readings and an immediate roadside ASM test was significantly better. The data indicate that the dirtiest vehicles with valid RSD readings can be expected to fail an immediate follow-up inspection with certainty ranging from 80% or better depending on the stringency of the RSD cutpoints. This suggests that factors such as test station performance and repair work conducted after the RSD reading but before the follow-up inspection play a role in reducing the Smog Check failure rate of called-in vehicles. Therefore, notwithstanding consumer acceptance and other practical implementation issues, a program wherein a binding roadside inspection is given immediately following the RSD measurement would likely yield greater quantifiable emission reductions in possibly a more cost effective manner.

Question 2: **Can remote sensing technology be an effective tool to "clean screen" vehicles and exempt them from the next scheduled Smog Check inspection, thus reducing program costs?**

Answer: **No. The costs to administer such a program would exceed the benefits.**

The primary benefit of a clean screen strategy is to reduce Smog Check program inspection costs by exempting vehicles that are highly likely to pass their next scheduled Smog Check. However, the analysis indicates that RSD data collection to identify clean-screen candidate vehicles would actually cost more to the state in program expenses than motorists would save through fewer inspections, defeating the purpose of the strategy. Table 1-3 shows the magnitude of the net expected cost increases when using RSD to clean-screen 20% (selected solely for demonstration purposes) of targetable vehicles. As a result, using RSD to clean-screen vehicles appears practical only if RSD data is also being collected for other purposes. In the answer to Question 5, the benefits and costs for clean-screening using RSD are evaluated in combination with other targeting strategies.

Table 1-3. Program Costs/Savings when Using RSD for Clean-Screening

Program Size	Large	Medium	Small
Number of Clean Screened Vehicles	454,323	272,594	90,865
Inspection Cost Savings	$14,084,001	$8,450,401	$2,816,800
RSD Data Collection and Administration Costs	$66,309,209	$25,977,502	$8,213,815
Net Additional Program Costs	$52,225,208	$17,527,101	$5,397,015

Using the VID instead for clean screening would not require further data collection and could result in substantial inspection cost savings. As is the case with virtually any clean screen strategy, a small fraction of the exempted vehicles will not be as clean as expected, and would have in fact benefited from the scheduled inspection. The impact on benefits and costs with respect to using the VID for clean screening are discussed as part of the answer for Question 5 below and also in Section 7.3 of the report.

Question 3: Can remote sensing technology be an effective tool to identify vehicles that would be, based on the vehicle emission levels (and overall condition), candidates for early retirement (scrappage)?

Answer: Yes, but not cost effectively.

Emission benefits and costs for scrappage (Table 1-4) were based on a hypothetical early retirement program with varying available funding to purchase and scrap high emitting vehicles over a two year period. Candidate vehicles were ranked based on the ratio of expected emission benefits to vehicle value. Vehicles with the highest expected emission benefits per dollar of value were targeted first. Although estimated benefits reached as high as 2.79 tons per day of hydrocarbons and oxides of nitrogen for a large scale RSD program, the corresponding cost of more than $81 million results in a cost effectiveness of approximately $40,000 per ton reduced. The cost effectiveness of using smaller scale RSD programs to identify vehicle scrappage candidates is improved, primarily due to decreased RSD data collection costs. However, the cost effectiveness was found to remain above $20,000 per ton. Cost effectiveness was calculated using estimated vehicle values as opposed to a cost per vehicle that includes participation incentives, and the analysis assumes that 100% of targeted vehicles "participate" in the scrappage program. Such a program would be less cost effective to the extent the participation rate is actually less than 100% and higher per vehicle purchase offers are necessary to achieve a participation rate that is considered acceptable.

Table 1-4. Using RSD Data to Select Candidates for Early Vehicle Retirement (Scrappage)

Scrappage Funding Level (approximate)	Program Size	Large	Medium	Small
$8M	Number of Scrapped Vehicles	9,014	7,461	5,680
	Average Value ($/vehicle)	$875	$993	$1,386
	Benefits (tpd HC+NOx)	1.83	1.47	1.03
	Total Costs ($/2years)	$74,256,998	$33,506,323	$16,308,625
	Cost Effectiveness ($/ton)	$55,479	$31,144	$21,745
$12M	Number of Scrapped Vehicles	11,431	10,380	7,572
	Average Value ($/vehicle)	$963	$1,130	$1,572
	Benefits (tpd HC+NOx)	2.27	1.97	1.33
	Total Costs ($/2years)	$77,286,919	$37,736,447	$20,314,941
	Cost Effectiveness ($/ton)	$46,573	$26,293	$20,936
$16M	Number of Scrapped Vehicles	14,384	12,751	9,186
	Average Value ($/vehicle)	$1,053	$1,230	$1,712
	Benefits (tpd HC+NOx)	2.79	2.37	1.58
	Total Costs ($/2years)	$81,325,746	$41,622,176	$24,132,360
	Cost Effectiveness ($/ton)	$39,978	$24,011	$20,989

Question 4: Can remote sensing technology be used to improve the State's high emitter profile (HEP), used to direct vehicles to test-only stations?

Answer: Yes, but not cost effectively.

To answer this question, a HEP model separate from that currently used to direct vehicles under Smog Check was developed based on data available within the VID, and the incremental benefit of adding RSD data to the model was evaluated. The results are shown in Table 1-5 for an example program where 40% of the vehicles are directed to high-performing stations based on the HEP (40% was selected solely for demonstration purposes). The analysis indicates that **adding** RSD data to the HEP would slightly increase the percentage of directed vehicles expected to fail an ASM test (by about 3 percent for a large RSD program). However, the resulting increase in emission benefits was found to be minimal (0.12 tons per day, or less). When compared to RSD program costs necessary to implement the HEP improvements, the calculated cost effectiveness was extremely high at $330,000 or more per ton.

Table 1-5. Using RSD to Improve Directing of Vehicles to Test Only Stations

Program Size	Large	Medium	Small
Incremental Benefits (tons/day)	0.12	0.07	0.02
Incremental Costs ($/2 years)	$64,184,057	$23,633,020	$5,650,002
Cost Effectiveness ($/Ton HC+NOx)	$765,450	$469,740	$336,906

Question 5: Can a permanent remote sensing technology program be cost-effectively implemented in California, and what would be the most cost-effective design for such a program?

Answer: No, not cost effectively.

The best opportunity for implementing a cost-effective RSD program is to simultaneously use collected data for multiple purposes. However, as indicated in Table ES-6 below, cost effectiveness for the three program sizes considered is still beyond generally accepted cost-effectiveness thresholds, varying from about $22,000 per ton to $40,000 per ton depending on program size. The cost figures include RSD data collection costs, Smog Check testing and certificate costs, program administration expenses, and the cost or savings associated with the impact of each strategy on repairs and number of vehicles inspected. They represent the RSD program costs that would be incurred over a two year period. RSD data collection and program costs are discussed in more detail in Section 6.5 of the report.

Table 1-6. Costs and Benefits of Using RSD for Multiple Strategies

Program Size	Large	Medium	Small
Targeting Strategy	**Emissions Reductions (tpd HC + NOx)**		
5% Off-Cycle Call-In	0.76	0.46	0.15
40% HEP Improvement	0.12	0.07	0.02
20% Clean Screen	-0.72	-0.43	-0.15
$16M Scrappage	2.79	2.37	1.58
Total Reductions	**2.94**	**2.47**	**1.61**
Program Costs ($/2yrs)	**$86,054,087**	**$44,748,009**	**$25,655,686**
Cost Effectiveness ($/ton)	**$40,100**	**$24,860**	**$21,891**

* Negative emission reduction numbers represent an increase in emissions.

These estimates assume that 100 percent of the vehicles targeted for each strategy have owners that actually participate as intended. In reality, participation rates are likely to be significantly lower. Therefore, achieving the level of emission reductions presented in the table would require targeting of a larger number of vehicles and penetrating deeper into the vehicle rankings for each strategy. The added expense of doing so would raise the cost per ton of emissions reduced. In this regard, the cost and benefits in the table can be considered best-case estimates.

Although the data indicate that a large RSD program will yield more emission benefits, smaller implementations were found to be more cost effective because RSD collection costs per unique vehicle receiving a valid, DMV-matched, RSD reading are less for smaller programs. Per vehicle costs are less for smaller programs because duplicate readings on the same vehicle occur less frequently, and because smaller RSD programs can receive a greater percentage of their data from the most productive test locations (i.e., streets with high vehicle volumes and conditions that yield a high percentage of valid readings). RSD data collection costs were estimated to vary from 50 cents for a small program to one dollar for a larger program per unique vehicle identified with a valid, DMV-matched RSD reading.

The benefits and costs of using VID information to carry out the I/M strategies evaluated are presented in Table 1-7. The results when using RSD data in combination with the VID are also presented, but represent only the incremental benefit and incremental cost of adding the RSD data to the analysis. As stated earlier, VID data is available for all vehicles subject to Smog Check. Therefore the targeting percentages shown are with respect to the entire portion of the California fleet that is subject to I/M and is beyond the 6 year new-exemption period.

Table 1-7. Costs/Benefits of Using VID Information for Multiple Strategies

Strategy	% of I/M Fleet Targeted	Number of Vehicles Targeted	Emission Benefits (tpd HC + NOx)	
			VID	VID + RSD (Incremental Benefit)
Off-Cycle Call-In	5%	669,403	6.29	0.18
Clean Screening	20%	2,677,614	-3.23	0.20
Scrappage	0.44% ($16M)	58,908	4.76	0.07
Totals	**25.44%**	**3,405,925**	**7.83**	**0.44**
Costs			$10,274,169	$64,224,950
Cost Effectiveness			**$1,798**	**$198,068**

* Negative emission reduction numbers represent an increase in emissions.

Costs to implement the strategies using the VID alone are only a small fraction of the costs associated with using RSD data for the same purposes because no additional data collection costs are required to take advantage of the VID. When combined with the larger emission reductions resulting from the ability to target a much larger portion of the fleet, the combined-strategy benefits using the VID without RSD were found to be very cost effective at just under $1800 per ton of HC + NOx reduced. Adding RSD data to the ranking models was found to produce a small incremental benefit; however, the high associated RSD data collection costs result in a very poor incremental cost effectiveness of approximately $200,000 per ton of emissions reduced.

Question 6: Can remote sensing technology be used as a tool to periodically verify the emission reductions achieved by the Smog Check program?

Answer: Yes, but with some limitations

Although RSD would generally be unable to quantify the benefits of Smog Check on a per vehicle basis, differences in vehicle emission levels taken before and after regular Smog Check inspections on a fleet-wide basis were observed within the RSD database. The differences were successfully used to demonstrate that sufficiently large RSD databases (which help minimize operating condition, traffic pattern, site selection, ambient conditions, and other variables) can be used to make estimates related to the benefits of the Smog Check program. However, the sizes of the estimated benefits were not always statistically significant. Also, the RSD data is limited to tailpipe emissions, and does not provide information about tampering, evaporative emissions, or on-board diagnostics results. An improved understanding through additional research of the relationship between RSD, ASM, and Federal Test Procedure (FTP) emission rates, and the influence of factors such as vehicle operating conditions and traffic patterns on RSD readings, would likely lead to more accurate estimates of the benefits of the Smog Check program using RSD. Further discussion on the methods used to estimate Smog Check benefits and the results of the analyses can be found in Section 8.1

Question 7: Can RSD be used to characterize the California fleet with regard to Basic/Enhanced Smog Check areas, daily commute/weekend vehicle emissions contributions, magnitude of emissions from the entire in-use fleet to be used for emission inventory verification, and criteria for directing specific vehicles to test-only stations?

Answer: Yes, to a limited extent

Results from the study indicate that RSD can be used to correlate various vehicle usage patterns with emissions, to assess differences in vehicle emission levels by region, and to compare weekday/weekend emissions contributions from the fleet, although the sizes of the effects were not always statistically significant. The study results also indicate that RSD data can be used to estimate tailpipe emissions from the in-use fleet without having to estimate vehicle populations and annual miles driven. However, resulting estimates for the South Coast Air Basin were found to be significantly different than estimates created using California's EMFAC model. Further detail on the usefulness of RSD data to characterize fleet emissions can be found in Section 8.2.

The conditions under which the RSD data is collected impact the usefulness of the resulting database in terms of carrying out the type of fleet characterizations discussed with respect to Questions 7 and 8. Like a photographic portrait that is taken while the subject is blinking, the momentary emission data provided by RSD for a given vehicle may not fairly represent the vehicle's normal emission performance unless RSD data are appropriately taken and analyzed.

Summary

The pilot study revealed that, unless costs associated with the implementation and administration of an RSD program can be reduced, the cost of using RSD to select individual vehicles for special action **within the Smog Check program** generally outweighs the estimated benefits. Because the study was conducted in the context of the existing Smog Check program, RSD must be capable of predicting the future Smog Check ASM emissions test results of individual vehicles in order to generate emission benefits. Thus, sources of variability impacting the results include, along with variability associated with RSD measurements and actual vehicle emission performance, variability introduced by the Smog Check program itself (e.g. vehicle owner behavior and inspection station accuracy). As a result, an elevated RSD reading becomes more of an ASM failure risk factor rather than a reliable predictor of future ASM test results. Overall, the study found that the use of vehicle information and historic Smog Check data included in the VID can accomplish the same objectives far more cost effectively than RSD, because the VID covers virtually the whole fleet of vehicles subject to Smog Check without the need for additional data collection, and has predictive power comparable to RSD in targeting vehicles for special strategies.

RSD data was successfully used within the pilot program to generate relevant, but limited, information on the effectiveness of the Smog Check program and characteristics of the California fleet. An RSD program that collects approximately 5 million records per year (at an estimated cost of approximately $3 million) would provide a database of sufficient size to carry out such analyses. The study did not evaluate the comparative costs and benefits of using RSD for fleet characterization in relation to other emissions data collection methods.

2.0 Introduction

The State of California has conducted a pilot study to evaluate whether vehicle remote sensing devices (RSD) can be used to enhance the California Smog Check program. The study was co-managed by the Air Resources Board (ARB) and the Bureau of Automotive Repair (BAR). Information for the conclusions of the study came not only from data collected in California, but also from existing RSD programs in the U.S. and from other recent RSD studies. The main goals of the project were expressed by ARB and BAR through a set of seven questions:

1) Can remote sensing technology be an effective tool to identify high-emitting vehicles between regular inspection cycles, and to document the emission reduction benefits of such a program?

2) Can remote sensing technology be an effective tool to "clean screen" vehicles and exempt them from the next scheduled Smog Check inspection, thus reducing program costs?

3) Can remote sensing technology be an effective tool to identify vehicles that would be, based on the vehicle emission levels (and overall condition), candidates for early retirement (scrappage)?

4) Can remote sensing technology be used to improve the State's high emitter profile (HEP), used to direct vehicles to test-only stations?

5) Can a permanent remote sensing technology program be cost-effectively implemented in California, and what would be the most cost-effective design for such a program?

6) Can remote sensing technology be used as a tool to periodically verify the emission reductions achieved by the Smog Check program?

7) Can RSD be used to characterize the California fleet with regard to Basic/Enhanced Smog Check areas, daily commute/weekend vehicle emissions contributions, magnitude of emissions from the entire in-use fleet to be used for emission inventory verification, and criteria for directing specific vehicles to test-only stations?

This report answers those seven questions and makes specific recommendations about how RSD might effectively be used by California. Before answering those questions, we first discuss the events leading to this pilot study, the technology of RSD, and how the study was conducted.

2.1 History of Commitment to Perform RSD Study

The technology of RSD has been investigated in California since 1989[1]. Some of those studies have resulted in recommendations for how RSD could be used to reduce vehicle pollution, including ways to improve the Smog Check program as it existed at that time.

Recommendations for using RSD to improve Smog Check have been repeated in other types of projects. The ARB/BAR's first Smog Check evaluation report, in 2000, recommended improving the program's effectiveness through the use of RSD, primarily to identify high emitters and to "clean screen" vehicles. In another Smog Check Evaluation report from 2004, the contractor suggested that RSD might also be useful for testing some 30-year old and older vehicles that are exempt from I/M, but are still being used frequently. ARB and BAR wanted to evaluate these recommendations in a California context, which led to the current contract.

2.2 RSD Technology Discussion

Short History - Vehicle remote sensing is an adaptation of a laboratory analytical technique called long path photometry. This technology has been adapted for on-road use to determine the concentration of pollutants emitted by vehicles as they are normally driven on streets and highways. Although it has been used in limited ways since the 1970's, it has only been intensively developed for on-road vehicle emissions measurement since the late 1980's. During the mid-1990's the technology matured to the point that it was being used as a tool for gathering large amounts of emissions information for vehicles in a given area. As of 2006, the states of Virginia, Missouri, Texas, Colorado, and Georgia had year-around RSD programs of various sizes and purposes.

Since the development of vehicle RSD technology, several companies were formed to sell RSD technology. RSTi (Remote Sensing Technologies, Inc.), Hughes-SBRC (Santa Barbara Research Center), and MDLasertech each offered RSD systems for sale beginning in the mid-1990's. However, as the market matured, it also consolidated. Each of these companies left the business, sold their technology to a competitor, or merged with a competitor. As of the time of this report only ESP (Environmental Systems Products) is a significant presence in the United States RSD market.

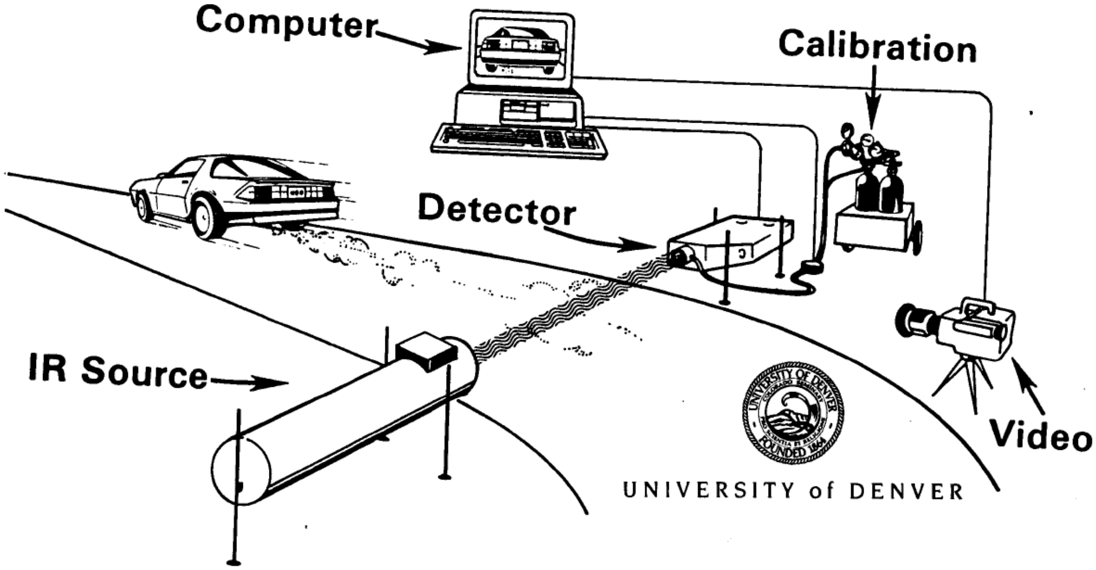
Current State of RSD Technology - Vehicle remote sensing devices (RSD) measure the ratio of pollutants in vehicle exhaust to the carbon dioxide (CO_2) in the exhaust. The measured ratios are used to calculate the concentration of pollutants in the exhaust. Those calculations are based upon basic chemistry assumptions for the combustion of gasoline. RSD units do this in less than a second, as the vehicles are driven past an RSD site on the side of the roadway. RSD can measure up to one vehicle each second. So, at a site with high traffic volume, it is possible for RSD to compile a large number of emissions “snap-shots” from many vehicles in a short period of time.

Vehicle RSDs use infrared and ultraviolet light beams, transmitted across the roadway, to make the measurements. A picture of a typical RSD set up used during this project is shown in Figure 2-1. A sketch of the concept of RSD is shown in Figure 2-2. As vehicles pass through the invisible beams, the changes in the transmitted light are an indication of the concentrations of the pollutants. The measured pollutants are usually carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxide (NO), but some systems can be configured to measure other pollutants. The opacity of the exhaust (i.e., how much smoke particles in the exhaust block and scatter light) can also be monitored.

Figure 2-1. Photo of RSD Measurement Site from This Study

Figure 2-2. Sketch of the RSD Concept

(Source: University of Denver, http://www.feat.biochem.du.edu/whatsafeat.html)



In the case of high ambient pollution levels, the relative concentrations detected by RSD are corrected for the ambient pollutant levels measured just before the vehicle passed. The corrected ratios of the other pollutants to CO_2 are used in an equation derived from basic combustion chemistry to report undiluted, dry pollutant concentrations in the exhaust. This is the way pollutants in California's Smog Check program are also reported. In other words, these are approximately the pollutant concentrations that would be measured at the exit of the vehicle's tailpipe if the water vapor in the exhaust were removed.

Average speed and acceleration are also measured to help determine the operational mode of the vehicle. This helps analysts determine when "off-cycle" operation is occurring (for example, aggressive acceleration, when vehicles can be expected to have higher than normal emissions). This also helps reduce analysis errors caused by wrong assumptions about how the vehicle was being driven when the measurement occurred. The average speed is calculated from multiple speed measurements taken as the vehicle passes. A typical system uses lasers across the roadway to determine the time it takes for the tires of a vehicle to travel from one laser to another. The multiple speed measurements are also used to calculate the acceleration of the vehicle. In other words, the acceleration is how much the speed of the vehicle changes as it passes by the RSD site.

Images of the license plates are also typically recorded for matching the vehicle to registration records. A picture of the license plate is usually obtained by a digital camera that is triggered by the RSD system as it measures the vehicle's speed. Add-on systems exist to automatically read the license plate of the vehicle from the digital image. However, when data were collected for this project, these systems were still in development and did not prove to be useful. Therefore, in this project, it was necessary to visually examine each digital image and manually enter the license plate characters into a database.

3.0. Project Overview

3.1 ARB/BAR Cooperative Project

The study was co-managed by the ARB and the BAR through an interagency agreement. The contracting agency was ARB. Both agencies managed the technical aspects of the project. Both ARB and BAR provided crews to collect RSD data. ARB helped manage encroachment permits and coordinated the schedules of the RSD crews. BAR managed the maintenance of the RSD equipment and fielded a crew to pull over vehicles (with the help of the California Highway Patrol) for the purpose of conducting roadside ASM inspections.

3.2 ERG Contract Elements

The contract was organized into two tasks. Task 1 was a field data collection and analysis task to collect RSD data and test and repair data in California. Task 2 was a literature review of relevant results from previous studies and existing RSD programs.

Task 1 Overview - The field data collection task was to collect at least one-million valid, unique RSD measurements on vehicles registered in California. These were to be a valid representation of vehicles registered in the different I/M area types (e.g., Basic and Enhanced) that fairly represent all model years in the fleet, and cover all socio-economic strata of vehicle owners in California.

In addition to the RSD emissions data, other types of emissions data were to be collected to help evaluate the impact of using RSD to augment the Smog Check program. For example, inspections were to be performed on some vehicles immediately after they had received an RSD measurement, and regular Smog Check data for some vehicles were also to be obtained. Other data such as responses to incentives for test and repair, incentives for scrappage, and public opinions were to be collected to help answer questions about the feasibility and cost of various possible forms of an RSD program in California.

Task 2 Overview - The literature review task was to review previous and current studies on relevant remote sensing programs. The report resulting from the review was to provide an organized synthesis and critical assessment of the results and findings of the studies.

To the extent possible, the literature review was also to answer the seven objectives of this study, define research gaps in the RSD field, establish the need for further RSD studies, and resolve controversies about RSD, if any.

We describe these tasks in greater detail below. Task 2, the Literature Review, is described first because it began first and its results helped influence how Task 1, the Field Study, was conducted.

3.3 Literature Review

The studies assessed in the Literature Review included several relatively large-scale efforts, as well as several papers that looked at the capabilities and limitations of RSD technology. Generally, we limited our review to more recent studies that used newer generation equipment, measured vehicle speed and acceleration, and used improved quality assurance procedures relative to earlier studies. In parallel with the literature review, several existing RSD programs were reviewed to obtain actual operating results relevant to this study.

The results of the literature review are detailed in a report titled, "Review of Literature on Remote Sensing Devices" [2]. In that report twelve studies are summarized with regard to how they relate to the questions being asked by ARB and BAR in this study. The literature review report was co-authored by several RSD experts with widely varying opinions on the abilities and appropriateness of using RSD to improve Smog Check. Each author contributed significantly to the report's findings. The authors debated their interpretations of the results from the studies until they reached common ground and could agree on how to present the results and recommendations.

3.4 Field Data Collection

Teams from ARB and BAR used equipment owned by BAR to collect over two-million raw, single and dual-hit RSD measurements in the major metropolitan areas of the state. Single hit RSD measurements are obtained when one full emissions, vehicle, and speed measurement system is in place at any RSD site. A dual hit consists of two separate full RSD systems capturing two separate emissions, license plate, and speed readings for each vehicle going by the site. This resulted in about 1.4 million valid measurements on vehicles registered in California.

The full RSD sample was used by ERG to develop answers to the questions posed in the contract. We used the data to develop a simulation of the California I/M fleet (described in Reference 3) to estimate emissions reduction and cost effectiveness for various strategies that could enhance the current I/M program. Details on the construction of these estimates are presented in Reference 4. We also used the data to characterize the emissions of the California fleet from just the RSD readings and to evaluate the I/M program.

To evaluate the fleet emissions benefits that could be achieved with RSD data, we needed to quantify the benefits to individual vehicles. Finding a low-cost method for collecting emissions reduction measurements of a large sample of vehicles without biasing the results was a major challenge of the field data collection effort. Initially, many owners of vehicles measured by RSD were mailed invitations to have their vehicles inspected, and repaired if necessary, at no cost. Others were offered a $50 incentive to have their vehicle simply inspected at various types of I/M stations. An extremely low response rate to these types of mailings inspired new strategies that allowed various aspects of an RSD program to be evaluated in a more cost-effective way. As a result, ERG developed a way to estimate benefits using I/M results that occurred naturally, that is, as vehicles participated in the I/M program in their normal course, after they received an RSD measurement.

In addition, more than 1,000 of the vehicles that were measured by RSD were also pulled over and given a roadside ASM inspection by BAR. These vehicles were chosen using stratified random sampling to make sure the data could be used for projecting the results to the fleet of the entire state. The drivers of nearly 500 of the pulled-over vehicles were invited to have their vehicle voluntarily inspected at a Referee station in return for a $50 incentive. The data from those who participated were useful for helping compare voluntary inspection results to mandatory Smog Check inspection results. Some of the results of that effort are described in Section 9.3.

Other important data collected and analyzed include nine years of Smog Check data, the physical configuration and traffic pattern data for every on-ramp in the Sacramento area, and large samples of data from Missouri's RSD program and from Virginia's latest Pilot RSD program.

4.0. Evaluation of Other RSD Programs and Reports

The Paper Study was an assessment of recent studies on relevant remote sensing programs. Information from the Paper Study helped answer the objectives specified for the field data collection (Task 1), defined research gaps in RSD knowledge, established the need for further RSD studies, and where possible, resolved controversies about RSD.

Still, using a paper study of earlier studies has its limitations. The goals of past studies did not necessarily coincide with the goals of this new study. While past studies generally contain useful information, most do not include a comprehensive analysis that looks at the incremental benefit and incremental cost effectiveness of an RSD component that is supplemental to an existing IM program, as was sought in this study. Many of the reviewed reports do not include a complete analysis of all of the costs of operating a program. In addition, many do not look at other alternatives and compare those alternatives to RSD. Some studies were sponsored by or written by an RSD company. Nevertheless, with appropriate objectivity, this review of existing work did provide a basis for beginning this major new study in the field of RSD application. The reader should keep in mind that the Paper Study was performed at the beginning of this project, which was long before any of the results of the analysis of field data were known.

ERG chose the experts to perform the paper study to represent a wide set of viewpoints on the merits of RSD.[2] Since the merits of RSD are still being debated in the vehicle pollution control field, we felt it was important that a wide range of views be weighed in interpreting the results of other studies. Each reviewer contributed significantly to the report’s findings through their participation in the iterative process of debating important issues and helping revise how agreed upon interpretations were presented.

4.1 Reports Reviewed

The literature reviewed in the Task 2 report focused on several relatively large-scale studies as well as several papers that assessed the capabilities and limitations of remote sensing. Generally, we limited our review to more recent studies that used newer technology equipment, measured vehicle speed and acceleration, and used the most current quality assurance procedures for both data collection and data analysis. The reports reviewed in Task 2 covered the following programs:

1) Denver Pilot Study of Remote Sensing for Clean Screening (1999)

2) Infrared Remote Sensing Of On-Road Motor Vehicle Emissions In Washington State (1999)

3) Oregon Remote Sensing Study (2003)

4) Virginia Pilot Remote Sensing Device Study (2002)

5) Evaluation of On-Board Monitoring Devices for Qualifying Taxis in California (2003)

6) Gateway (St. Louis, Missouri area) Clean Air Program Annual "Rapid Screen" Report (2002)

7) Remote Sensing Device High Emitter Identification With Confirmatory Roadside Inspection in California (2001)

8) The Coordinating Research Council's E-23 Program (multiple reports, such as "On-Road Remote Sensing of Automobile Emissions in the Chicago Area") (1997 -- 2004)

9) Evaluation of Remote Sensing in Arizona (2002)

10) Using Remote Sensing Devices (RSD) to Evaluate the California Smog Check Program (1997)

11) On-Road Emissions Changes Due to IM240 Inspection/Maintenance and Oxygenated Fuel Program in Denver (1997)

12) Analysis of Data from the California I/M Pilot Program/Assessment of RSD (1995).

Our team reviewed these reports to find information relevant to the situation being studied in California. Although none of the studies were researching RSD in the same way as required in the California Pilot study, most of them provided information useful in answering some parts of the primary questions of this study. After having reviewed the reports, assessed their relevance to the current study, and debated the interpretation of their results, ERG's team of RSD experts agreed that:

1) RSD can be used to "clean screen" vehicles. (It is currently used in Missouri and Colorado for clean screening.) Compared to equally effective methods based upon vehicle characteristics and/or I/M inspection histories (often called "vehicle profiling"), RSD has the advantage of providing an on-road measurement. However, compared to those same methods, which do not require an on-road measurement, RSD is costly and complex to perform.

2) RSD has potential for the following tasks, but further study is needed to determine if it would be effective (especially cost-effective) for:

a. Identifying high emitters for immediate testing;
b. Identifying vehicles for scrappage programs;
c. Improving the accuracy of the "high emitter index" used to identify vehicles that are likely to fail the Smog Check test;
d. Evaluating the overall effectiveness of the Smog Check program; and
e. Characterizing emissions from subcategories of the California fleet.

Therefore, the reviewers recommended further study in the field data collection task for all but the first of the above questions.

4.2 List of RSD Programs in Other States/Areas

During the course of this study, ERG discussed existing RSD programs with their administrators in other states. As of the time of the study, four other states had large, on-going RSD programs: Colorado, Missouri, Georgia, and Texas. Virginia was beginning an RSD program, but did not yet have significant results. Several other states collect a small amount of RSD data every year to comply with EPA requirements for an enhanced I/M program, but these programs are not large enough nor of a design to merit discussion here.

The four programs are summarized in Table 4-1. The Colorado and Missouri programs are using RSD to clean screen vehicles from their I/M programs. These programs are similar in that both are run by a contractor, they advertise the location of RSD equipment, and they send eligibility notices by mail. Vehicle owners who receive a notice and choose to be clean screened, pay a fee for the convenience. In the first year of the Colorado program, RSD measurements and owner responses to eligibility notices were obtained for only approximately 4% of the vehicles eligible for an RSD clean screen. In Missouri, the clean screen program has been running longer and has a higher participation rate. There, owners of approximately 19% of the vehicles eligible for RSD clean screen responded to the clean screen notice.

The Georgia RSD program, which has been in operation since 1996, was started to collect on-road emissions information and to evaluate the I/M program operating in the Atlanta area. The data are collected and analyzed by researchers from the Georgia Institute of Technology. Although the data collection is funded through the I/M program fees, coordination with the I/M program is minimal. Every year the RSD data are used to evaluate the I/M program by comparing RSD measurements on vehicles in non-I/M areas of the state to vehicles in the Atlanta I/M area.

Texas' RSD program was set up to identify vehicles that regularly drive into an I/M area, but are not required to have an I/M inspection because of where they are registered. About four years after the program began, under a new contractor, Texas started to identify a small fraction of the fleet as gross-emitters using the RSD data. They began sending notices to some of the owners of the suspected gross-emitters to have their vehicles ASM inspected, and repaired if necessary. A few years later, even though the number of notices remained small, Texas began a strict enforcement program to fine those who were not responding to the notices. The strict enforcement had recently begun as the California Pilot RSD project was being conducted, so the final results of the Texas gross-emitter program were not available for this report.

Table 4-1. Summary of RSD Programs in Other States

State	Type	Decision Method	Program Year	Annual Valid RSDs	Participation Rate*
CO	Voluntary Clean Screen	2 measurements less than HC and CO cutpoints	1st	>1-million	4%
MO	Voluntary Clean Screen	2 measurements less than HC, CO, and NOx cutpoints	3rd	5-million	19%
GA	Program Evaluation	n/a	12th	350,000	n/a
TX	Mandatory Dirty Screen	2 measurements greater than HC, CO, or NOx cutpoints	6th (1st year of strict enforcement)	12-million	80% (approx.)

* The fraction of notice recipients who participated.

5.0 Summary of RSD Data Collection in California

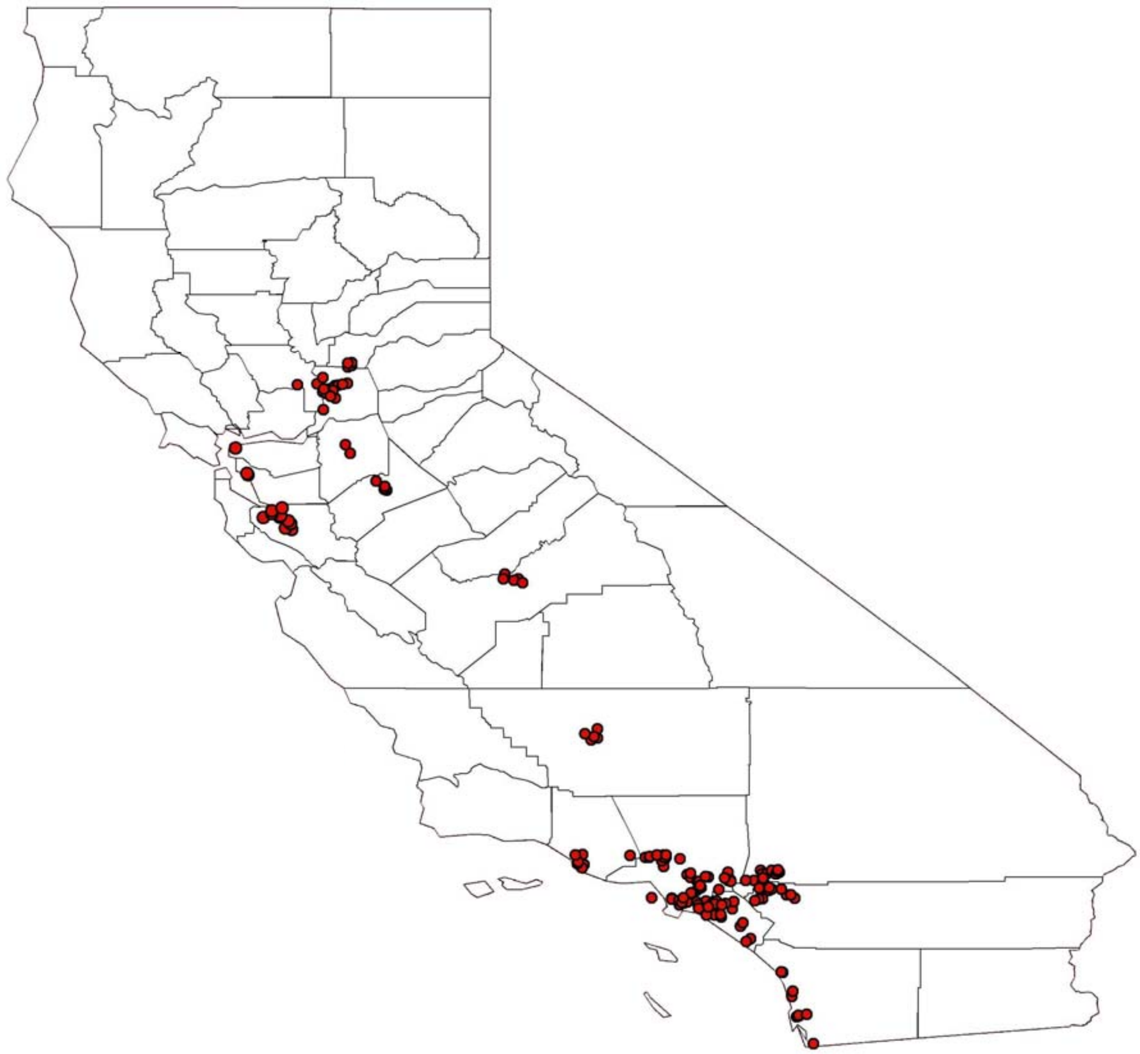
The contract specified that California RSD data be collected in a way that is representative of the California fleet. Therefore, it was important that RSD data be collected from specific locations around the state, during various times of the year. ERG proposed a draft data collection plan in response the RFP for this project. Several revisions to the data collection plan were necessary after consultation with ARB and BAR and after performing the literature review. Only the final data collection plan is referred to in this section.

5.1 Description of RSD Data Collection Plan

The RSD data collection plan called for the collection of over one-million unique, valid data points from around the state. These data were to be collected continuously over a 12-month to 18-month period beginning in October, 2003. On a typical day two or three RSD crews would collect data (i.e., at two or three data collection sites per day). Data were to be collected in both northern and southern California in areas where nearly 90% of registered vehicles are located. Less populated areas of the state, outside of the five largest Air Quality Management Districts, were not targeted in the data collection plan. We relied on the facts that the data were to be collected from a wide range of areas and over a long time period to make the sample representative of the California fleet.

In southern California, data were collected by ARB and BAR crews from the San Diego area up to the Bakersfield area. In the central part of the state, the Fresno/San Joaquin valley area, staff from BAR collected the RSD data. In northern California, crews from BAR and from a subcontractor to Eastern Research Group collected data in the Stockton, Sacramento, and San Francisco Bay areas. Figure 5-1 shows the location of the RSD measurement sites for this study.

Figure 5-1. Location of RSD Measurement Sites for the Study



5.2 RSD Records Collected

Nearly 2.2 million "raw" remote sensing records were collected from March 15, 2004 through January 24, 2005. This does not include the data collected before some RSD equipment problems were resolved (described later). These raw data were quality assured in two phases — in the field and after the data were processed. In the field, calibration gases were frequently used to assess the accuracy of the instruments, and adjust them if necessary. Sometimes a special audit truck was driven past RSD equipment to see if its simulated exhaust would be accurately measured. As vehicle exhausts were measured, software controls applied filtering formulas to categorize the data as either "valid" or "invalid." After the data were processed and delivered to the ERG team, the license plate images were transcribed and the data were matched to recent California registration data and to California's I/M program Vehicle Information Database (VID). Then, the data were further processed to apply a second tier of data validity assessments. Finally, the data were ready to use to help answer the seven questions of the project. [3]

Table 5-1 summarizes the reduction of the California RSD data for this project. 71% of the raw records were successfully merged with registration data from the California Department of Motor Vehicles (DMV), using the vehicle license plate. Visual inspection of the video of a sample of the vehicles indicated that the majority of remote sensing records that could not be merged with registration data had obstructed license plates (by a trailer or hitch) or unreadable license plates (because of extreme contrast or glare). The unmatched 29% of RSD measured vehicles were classified as being of unknown origin. This seemingly high unmatched rate is commonly seen in other RSD programs[2]. The table indicates that about 65% of the matched-with-registration-data measurements were flagged by the RSD equipment software as valid (valid emissions, speed, and acceleration results). This fraction also applies to the raw measurements, so about 1.4-million of the raw measurements (2.2-million * 65%) were flagged as valid by the RSD equipment software (not shown in Table 5-1).

Table 5-1. Reduction in Remote Sensing Measurements for Analysis (RSD Data Collected March 2004 – January 2005)

	Number	Percent of total	Percent of previous category [a]
Raw measurements	2,196,274	100%	NA
Matched with registration data	1,562,618	71%	71%
Valid RSD emissions measurement	1,010,794	46%	65%
Matched with previous Enhanced Smog Check	555,937	25%	55%
Matched to Roadside Pullover Inspection	1,040 [b]	0%	N/A [c]

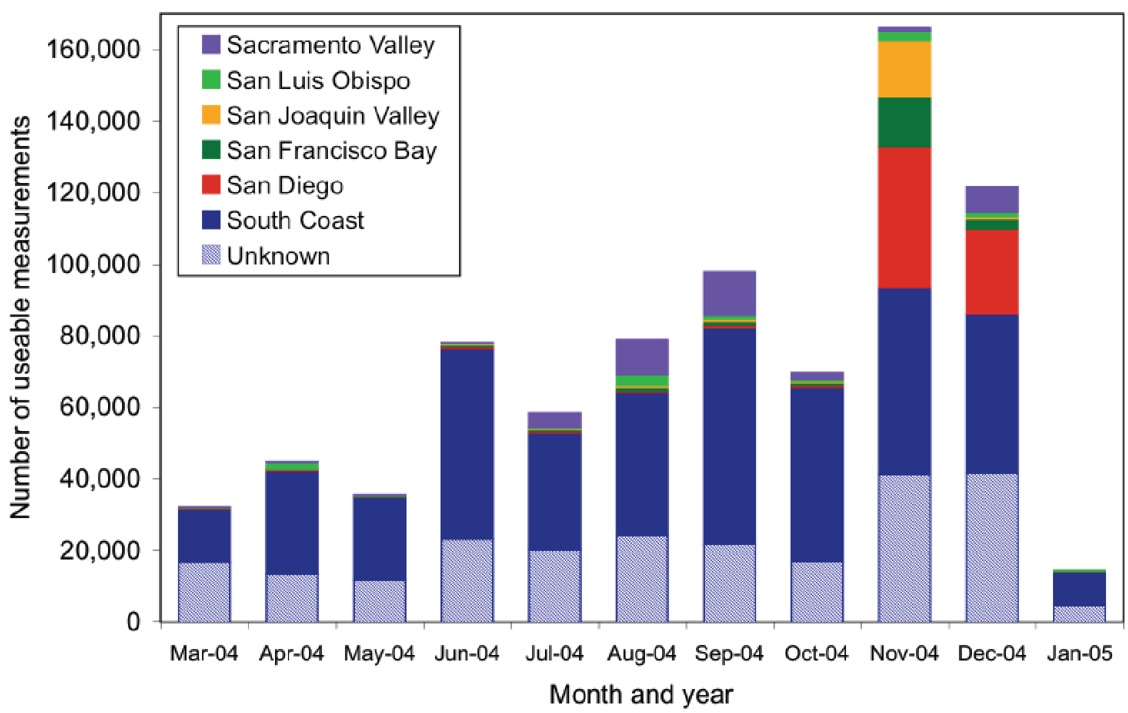
Notes:
[a] The last column of Table 5-1 shows the percent of the previous category; for example, 55% of vehicles with valid emissions measurement also had a previous Enhanced Smog Check record. These vehicles represent 25% of all raw measurements (55% * 65% * 71% = 25%).
[b] Subsets of these 1,040 vehicles subsequently received emission inspections at I/M stations as described in Section 9.3.
[c] Roadside pullover vehicles were not chosen based upon Smog Check history, so they were not a subset of vehicles "Matched with previous Enhanced Smog Check."

[2] For example, in an annual report by Environmental Systems Products for the Missouri Clean Screen program the percentage of raw RSD readings that produced a license plate match to Missouri registration records was 56% (Peter McClintock, "Gateway Clean Air Program Annual Rapid Screen Report January – December 2002." Final report by Applied Analysis on behalf of ESP – Missouri for the Missouri Department of Environmental Resources, Jefferson City, MO, July 2003).

Figure 5-2 shows the distribution of RSD records for each month of data collection by the air basin in which the vehicle was registered for those RSD records that had valid RSD measurements, could be matched to the vehicle registration database, and whose speed and acceleration indicate they were driving in a way that produces representative vehicle emissions (VSP = 5 to 25 kW/Mg)[3], which our fleet characterization analysts called "usable" measurements. As mentioned above, 29% of all remote sensing records could not be matched with registration data; these are the "unknown" category in the figure.

To meet the objectives of field data collection while staying within the project budget, the number of RSD sampling teams was limited to three to four teams collecting RSD data at any one time. An individual team was assigned to work in a given area for certain periods to avoid excessive time traveling between areas. As a consequence, all areas were not sampled at all times. Figure 5-2 shows that on-road measurement of vehicles registered in the South Coast and Sacramento air basins occurred throughout the analysis period, whereas the measurement of vehicles registered in the San Diego, San Francisco Bay, and San Joaquin Valley basins occurred mostly in November and December 2004. A small number of vehicles registered in other air basins were also measured on road because they happened to be driving in one of the larger air basins.

Figure 5-2. RSD Distribution by Month and Basin



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3 1 Mg = 10^6g = 10^3 kg = 1 metric ton

5.3 Difficulties Encountered During Study

As in most projects that include a field data collection component, operational difficulties were encountered. Some of these difficulties caused longer than expected delays and data quality problems. But none of the difficulties was large enough to cause insurmountable problems in schedule or data quality. The most significant difficulties had to do with: 1) obtaining encroachment permits that are usually required for setting RSD equipment on the roadside, 2) working out software and equipment problems related to the new equipment, and 3) weather that prohibited the collection of RSD data.

Encroachment Permit Problems - Temporary encroachment permits are usually required before RSD equipment is allowed to be set up on the roadside. Unfortunately, two significant types of problems were encountered in the permitting process during this project — refusals and time restrictions. Permit refusals by CalTrans occurred mainly in the Fresno area, and prevented our teams from collecting any highway ramp data. Permit time restrictions occurred statewide. Our data collection teams were unable to collect both morning and evening rush-hour data at highway ramp sites due to the restrictions. These refusals and time restrictions caused data selection biases that had to be corrected for in various ways. For example, to estimate the fleet coverage RSD could attain in California, our analysts had to make assumptions based upon data from other states' existing RSD programs. In a research setting, these were not insurmountable problems, but if California ultimately decides to implement an RSD program of some kind, these permitting problems should be addressed.

Equipment Problems/Limitations - Equipment problems mainly related to the deployment of new, customized systems resulted in the rejection of a significant amount of data that was collected in the early part of the project. The RSD data collection systems used in this project were systems purchased by BAR in the summer of 2003. When the project began these systems were operational, but had not yet received their full acceptance tests from BAR. Due to the uncertain schedule of acceptance testing and the urgent schedule of the project, a decision was made to start data collection before the completion of the acceptance tests. This decision resulted in our having to reject data collected from October 2003 until March 15, 2004. We determined through our quality assurance of the data and consultation with BAR and the equipment manufacturer that the software running the equipment until that time had caused several data quality issues. The two unacceptable issues were: synchronization of license plate photos with exhaust measurements and correction of pollutant measurements for changes in ambient temperature and pressure. These two issues were resolved with an RSD equipment software update implemented during the first two weeks of March 2004.

There was another, less serious equipment problem that reduced productivity and increased costs, but did not result in the rejection of any data. It had to do with the automatic license plate reader systems supplied with the RSD equipment. These were manufactured by Pulnix and are commonly used in a more controlled setting. These systems required setting additional equipment on the roadside, so set-up and take-down of RSD sites took longer when the Pulnix systems were used. This extra effort turned out not to be well-spent because the accuracy of the Pulnix systems of reading license plates was never consistent enough to rely upon. Consequently, all plates had to be transcribed manually.

Weather Problems - Current technology RSD measurements cannot be accurately obtained through air with liquid water in it. So RSD data quality will be questionable when the weather is foggy or when the roadway has enough standing water for vehicle tires to create a mist as they drive past. This was an expected data collection difficulty, so the work plan allowed for weather delays, especially during the fall and winter months. Due to seasonal rains and fog, this will always be an issue if California adopts a year-round RSD program.

6.0 Evaluation of RSD's Ability to Select Individual Vehicles for Special Strategies: Cost-Benefit Analysis Approach

The first five questions of this project direct the study to evaluate the incremental benefits of using RSD measurements to select individual vehicles to improve Smog Check. This section describes the approach to performing the cost-benefit analysis. The next section, Section 7, describes the results of the cost-benefit analysis.

The approach to determining the incremental benefits of using RSD to select individual vehicles for special strategies can be summarized by the following four steps:

- Select and formulate strategies that will answer the questions. (Section 6.1)
- Simulate the response of vehicles to the I/M program and strategies (Section 6.2)
- Calculate the fleet performance of a vehicle ranking method for a strategy:

  Rank vehicles based on probable individual vehicle benefits (Section 6.3)
  Estimate fleet benefits of the strategy (Section 6.4)
  Estimate fleet costs of the strategy (Section 6.5)

- Evaluate the effectiveness of RSD by comparing the fleet performances of a vehicle ranking method that uses RSD and a vehicle ranking method that does not use RSD (Section 6.6)

Each of the activities described above are discussed in more detail in the sections indicated at the end of each item in the list.

In the analysis for this study, we chose the ASM emissions test as the focus of the calculations for estimating the emissions benefits of the special strategies. The reason for our decision is that the ASM test is used during Smog Check for the majority of vehicles participating in the program. However, the analysis approach that has been used in this study for the ASM test could have just as easily been used for the Two Speed Idle test, which is used for the portion of the vehicle fleet that cannot be tested according to the ASM procedure. Beyond this point, this report will refer only to the ASM test.

As Section 6.1 will discuss, the analysis uses four strategies that are supplemental to the existing I/M program as a test bed for evaluating the incremental effectiveness of RSD (i.e., the benefit offered by RSD that is above and beyond the current program). The purpose of each strategy is to target vehicles for a special treatment that intervenes in their normal participation in the I/M program. Before a targeted vehicle is eligible for participation in Calling-In or

Scrapping strategies, the emissions performance of the vehicle will be verified by performing an ASM emissions test on the vehicle. These targeting verification tests are named after the strategy in which they are used (e.g., call-in ASM test and scrappage ASM test). While the targeting verification tests are regular Smog Check inspections, and we assume that they are performed at regular I/M inspection stations, they are used only for vehicles that are targeted for special strategies.

The discussion frequently refers to ASM failure probabilities (Fprobs). Several years ago, the concept of I/M emissions test failure probability was developed to assist in directing high-risk vehicles to high-performing inspection stations when they were due for an upcoming I/M inspection. Using historical VID data, failure probabilities were calculated as the fraction of all vehicles of a given description that failed their initial I/M emissions test. Vehicle description was defined by model year, make, model, and engine family. The notion was that if 20% of all vehicles of a given vehicle description failed their initial emissions tests, then the probability that an individual vehicle of the same description would fail its next initial emissions test would also be 20%.

In work that ERG did for BAR after the development of those first Fprobs and before this project, we saw that additional factors also influenced the ASM failure probability. These included the ASM cutpoints, the age of the vehicle, the time since the previous I/M certification, and the previous-cycle initial ASM test result. In this study, we have extended ASM failure probabilities to encompass these additional dependences. Adding these dependences greatly improved the usefulness of ASM failure probabilities while still maintaining the fundamental basis on which failure probabilities are based. The meaning of ASM failure probability remains unchanged. However, because of the added dependences, especially the time and cutpoint dependences, we have developed new ways in which failure probabilities can be used, including forecasting the probable mass emissions of individual vehicles.

6.1 Description of Special Strategies

In the analysis, the effectiveness and cost-effectiveness of adding RSD to Smog Check was evaluated in four different contexts as represented by the first four questions in the study. As a preliminary discussion for the description of the cost-benefit approach, we need to define the environment in which the RSD information will be used. Since the questions all involve supplementing the existing I/M program with an RSD measurement component, it is a given that all vehicles will be participating in the I/M program. For the 2004 calendar year (the year used for this study), the I/M program required biennial inspections on vehicles with model years from

1976 through 1998. All 1976 and newer vehicles were subject to change of ownership inspections.

The approach that we took was to codify each of the four questions into four different strategies that could supplement the normal I/M process: Calling-In, Directing, Exempting, and Scrapping. The correspondence between the questions and the strategies is shown in Table 6-1. The table also shows alternative terms commonly used for the different strategies. The alternative terms are used in the Executive Summary of this report. However, to be consistent with the modeling report [3] and the implementation report [4], the body of this report uses the terms listed under Strategy in Table 6-1.

Table 6-1. Four Strategies to Evaluate RSD's Individual Vehicle Selection Performance

Question	Strategy	Alternative Term
Can remote sensing technology be an effective tool to identify high-emitting vehicles between regular inspection cycles and to document the emission reduction benefits of such a program?	Calling-In	Off-Cycle Call-In
Can remote sensing technology be used to improve the state's high emitter profile (HEP), used to direct vehicles to high-performing stations?	Directing	HEP Improvement
Can remote sensing technology be an effective tool to "clean-screen" vehicles and exempt them from the next scheduled Smog Check inspection thus reducing program costs?	Exempting	Clean Screen
Can remote sensing technology be an effective tool to identify vehicles that would be, based on the vehicle emission levels (and overall condition), candidates for early retirement (scrappage)?	Scrapping	Early Retirement

A special strategy is any effort that is used to enhance the effectiveness or cost-effectiveness of the I/M program. It is important to understand that all of these special strategies can operate with or without RSD information. For example, it is quite simple to select vehicles for all four strategies based simply on model year. The overall question in this study is if RSD information is available, does it cost-effectively provide any incremental benefit to enhance the performance of the special strategies. Therefore, to evaluate the benefits and costs of adding RSD to the special strategies, we need to determine the difference in costs and the difference in benefits of performing the special strategies with RSD and without RSD. If the benefits of using

RSD for identifying vehicles for special strategies can be obtained at reasonable cost, then routinely acquiring the RSD measurements on individual vehicles will be attractive. One benchmark for judging cost-effectiveness is the Carl Moyer criterion of $14,300 per ton of HC + NOx emissions.

We had to clearly specify the details of each strategy in order to perform engineering calculations that would produce costs, benefits, and cost-effectiveness. While we chose the specific details of each strategy to represent likely characteristics, other choices for the details are certainly possible and would produce somewhat different numerical results. The strategies as described below are intended to convey the basis of the analysis results and are not intended to represent recommendations for optimally designing strategies. Nevertheless, we believe that given the wide range of types of strategies that we investigated, the general results of other analyses would be substantially the same as the results presented here. The descriptions that follow provide more detail about the four special strategies used in this analysis.

Calling-In – In this analysis, we considered Calling-In at any time in the I/M program cycle. We performed benefit calculations for one Calling-In option. This chosen option is called Calling-In No-Sticker in which vehicles that are a high risk to the I/M program would be targeted mid-cycle for a call-in ASM test (the targeting verification test) at any I/M station. If the vehicle failed the test, the vehicle would be required to be repaired and to pass a follow-up ASM test. However, the vehicle would not be given an emissions certification but would be required to continue on its existing regular I/M program schedule. The other policy option, which was not used in this analysis, is called Calling-In Sticker. In this case, the vehicle would also be subject to a call-in ASM test and would be required to be repaired and to pass a follow-up ASM test if it failed. However, the vehicle would then be issued a new biennial certification. This would put the vehicle in a new regular I/M schedule. We chose to present the results of Calling-In No-Sticker in this analysis because we found that this option produced larger benefits than the Calling-In Sticker option.

Directing – Directing would occur for vehicles that are a high risk to the I/M program and are expected to soon receive their biennial inspection. For Directing, vehicles would be required to be inspected at high-performing stations instead of average-performing stations. Directing, which is now being performed within Smog Check, is currently based on gross polluter assignments or the current HEP. The notion of Directing is based on the premise that high-performing stations are less prone to inaccuracies than are average-performing stations.

Investigating the benefits and costs of Directing was done to answer the question "Can RSD be used to improve the High Emitter Profile (HEP), which is used to direct vehicles to high-performing I/M stations?" In this study we developed eleven different methods that can be used to rank vehicles for Directing. Each of these eleven different ranking methods is an HEP. Some methods use individual vehicle RSD measurements as inputs; some do not. We worked hard to make all eleven HEPs as effective as possible based on the inputs being used. By comparing the best method for Directing that includes RSD information with the best method for Directing that does not, we can answer the question of how much the best RSD HEP exceeds the best non-RSD HEP.

Exempting – Like Directing, Exempting would also occur shortly before vehicles are expected to appear for their biennial inspection. Vehicles that are expected to be a low risk to the I/M program would be ranked higher on an Exempting list. Vehicles that are exempted would be given a certification without coming in for a regular I/M test. Exempted vehicles would be expected to appear two years later for their next biennial inspection in accordance with their new certification unless they were exempted again. Exempting is expected to always slightly increase emissions of the I/M fleet because a few vehicles will inevitably be incorrectly exempted. The goal of the vehicle prioritization is to preferentially exempt vehicles that represent the smallest risk.

Scrapping – In this analysis, we considered Scrapping for vehicles at any point in their I/M program cycle. For these calculations, scrappage candidate vehicles would be called in for a scrappage ASM test (the targeting verification test) that would be performed at a regular I/M station. If the vehicle failed the test, the State would offer to purchase the vehicle from the owner. If the vehicle passed the scrappage ASM test, the vehicle would be released without issuing a new certification. Scrappage candidates would be selected from the fleet based on their estimated FTP mass emissions over 24 months per dollar of vehicle value. By using this ranking variable, the state will come close to maximizing the total mass of emissions that are reduced through the purchase and scrapping of candidate vehicles.

An example will serve to demonstrate how the Calling-In strategy could be implemented in the context of the existing I/M program. Suppose that the existing California I/M program were supplemented by a regular RSD measurement program. Each week, the previous week's RSD measurements that were declared valid and matched to registration records by the RSD vendor would be provided to a central office. The job of the central office would be to target the vehicles in the set that would be expected to benefit most from being called-in off-cycle. The central office would use software that would rank the vehicles from those that would benefit most to those that would benefit least from the call-in using the available information on each vehicle. The available information would be the RSD measurements, historical inspection records as documented in the VID, and a description of the vehicle in terms of model year, make, model, engine, and emission control equipment. The central office would target the highest ranked vehicles starting at the top of the list and moving down until a specified percentage of the vehicles were targeted. In this analysis, we refer to this percentage as the **targeting percentage** or the **penetration**. The central office would instruct the owners of the targeted vehicles to go to an I/M station for a call-in ASM. Those vehicles that failed the call-in ASM would be required to be repaired until they passed a follow-up ASM.

The discussion above about the details of the strategies and how they could be implemented demonstrates that the ability to rank individual vehicles is key. Methods that can rank vehicles better will produce better-performing strategies. If RSD can help rank vehicles better, then RSD can improve a special strategy. Many different approaches can be used to rank vehicles for special strategies but the one piece of information that is most desired is a measure of the benefit of targeting each vehicle. The benefit is just the difference in a desirable quantity when the vehicle participates in the special strategy versus when the vehicle remains in the normal I/M process.

The problem with ranking vehicles based on the expected benefit of the special strategy is that the calculation of the size of the benefit is based entirely on future quantities. These include the targeting verification ASM pass/fail result, the monthly ASM failure probability over the next two years, the monthly mass emissions of the vehicle over the next two years, repairs made to the vehicle as the result of ASM failures, and any future emissions degradation caused by abrupt failure or gradual degradation of emission control system components on the vehicle. In addition, to calculate the expected benefit of targeting, we would need to know these quantities for both paths: if the vehicle is targeted, and if the vehicle remains in the normal I/M process.

Obviously, there is no way to know these quantities for a given individual vehicle. However, we have found, using the capabilities of the extended ASM failure probabilities that we discussed earlier, that while we cannot know for certain the exact future of a vehicle, it is possible to calculate the <u>probable</u> future quantities that we need to calculate the expected benefits of an individual vehicle participating in a special strategy. Once we have developed the ability to forecast the future probable emissions and the ASM failure probability as a function of time, we can use this capability to rank vehicles and to evaluate the benefits and costs of different methods for ranking vehicles in different specifically formulated strategies.

Calculation of benefits and costs of different strategies requires information about the effects of the strategies on individual vehicle emissions. However, during the planning phase of field data collection, we found that it was impractical to call-in, direct, exempt, or scrap vehicles in sufficient quantities and at low enough cost to produce the monthly emissions information that would be required to evaluate these special strategies. In addition, we believe that imposing such "pilot" strategies would likely produce answers that would not be representative of the performance of real-world strategies that would be realized after implementation. Accordingly, the approach that we took for calculating benefits, costs, and cost-effectiveness was to simulate the four strategies. We created an I/M simulator based on nine years of California I/M program inspection records and the 2.2-million RSD measurements taken in this pilot project. A description of the I/M simulator is provided in Section 6.2.

6.2 Estimating the Benefits of the Participation of an Individual Vehicle

We have developed a mathematical method for forecasting the three FTP emissions rates, the six ASM mode/pollutant concentrations, and the ASM failure probabilities for almost any individual vehicle in the California I/M fleet. The forecasts are time dependent, which is critical for quantifying emissions reductions and costs in this study. Time is a key variable for making good decisions about the disposition of a vehicle in any specific strategy. In addition, the forecasts can be made for a variety of I/M program configurations, including the use of different strategies. This I/M simulator was necessary for us to calculate the benefits and costs of different special strategies since no vehicles actually participated in a special strategy during the field program. We developed two relationships with these properties.

VID-Alone Relationships[4] – The VID-alone relationships forecast the six ASM mode/pollutant and overall ASM failure probabilities of individual vehicles using only a vehicle's I/M inspection records. The forecasts are time-dependent, which means that the forecasts change as the time since the previous inspection gets longer and as the vehicle ages. These relationships were built on nine years of historical California ASM inspection data from the VID. This dataset contains about 200-million observations that contain information on the effects of vehicle description, age, ASM cutpoints, previous-cycle ASM pass/fail results, and time since the previous I/M certification. No RSD information is required to make forecasts using the VID-alone relationships.

[4] Known as VID History in the implementation report [4].

VID+RSD Relationships[5] – When an RSD measurement on a vehicle is available in addition to VID data, we want to use both types of data to forecast ASM failure probabilities. Accordingly, we built a second set of relationships, the VID+RSD relationships, which use an individual vehicle's RSD measurements in addition to the individual vehicle's I/M inspection records to forecast the six ASM mode/pollutant and overall ASM failure probabilities. The forecasts from these relationships are also time-dependent. These relationships were built on a dataset that is the intersection (see Table 6-2) of the 200-million record historical VID and the 2.2-million RSD observations measured in this pilot study, to predict the failure probability of the 69,629 initial-cycle I/M-station ASM inspections that occurred after the RSD measurements.

Table 6-2. Selection of Data Records for Models that Use RSD as Inputs

Cumulative Attributes	Number of Records
All RSD records	2,231,515
+ Valid RSD measurements	1,456,274
+ Moderate engine load (5 ≤ VSP ≤ 25 kW/Mg)	843,867
+ No duplicate RSD records	827,487
+ Non-Error VIN decodes	486,286
+ Initial-cycle ASM after the RSD	90,574
+ I/M cycle before RSD has been completed	76,982
+ Record produces output from all Fprob models	69,629

We discovered that certain calculus manipulations of the VID-alone and the VID+RSD time-dependent failure probability relationships and statistical relationships that connected ASM emissions concentrations to FTP mass emission rates led to new relationships that could estimate the probable FTP emissions rates of an individual vehicle as a function of vehicle description, age, previous-cycle ASM pass/fail results, and time since the previous I/M certification. These relationships can be successfully applied whether or not RSD measurements are available. They predict the ASM failure probabilities and the probable FTP emissions rates for an individual vehicle after completing an I/M inspection cycle. After a vehicle experiences an I/M inspection, the vehicle "relaxes" toward its natural higher-emitting state. These relationships describe the time dependence of this relaxation, which occurs in the absence of any further I/M program activity.

Therefore, to quantify the effects of the I/M program and special strategies, we needed to modify the forecasts. An I/M program causes the ASM failure probabilities and FTP emission rates to change when a vehicle gets an I/M inspection. That's the whole point of the I/M inspection. Of course, we do not know when the next inspection cycle will be because it is in the

[5] Known as VID/RSD + VID History in the implementation report [4].

future. However, through an analysis of the 200-million observation historical VID, we calculated the I/M completion probability, which gives the probability that a vehicle will receive its next-cycle I/M certification in a given month as a function of vehicle age, previous-cycle ASM pass/fail result, and the date of the previous-cycle inspection.

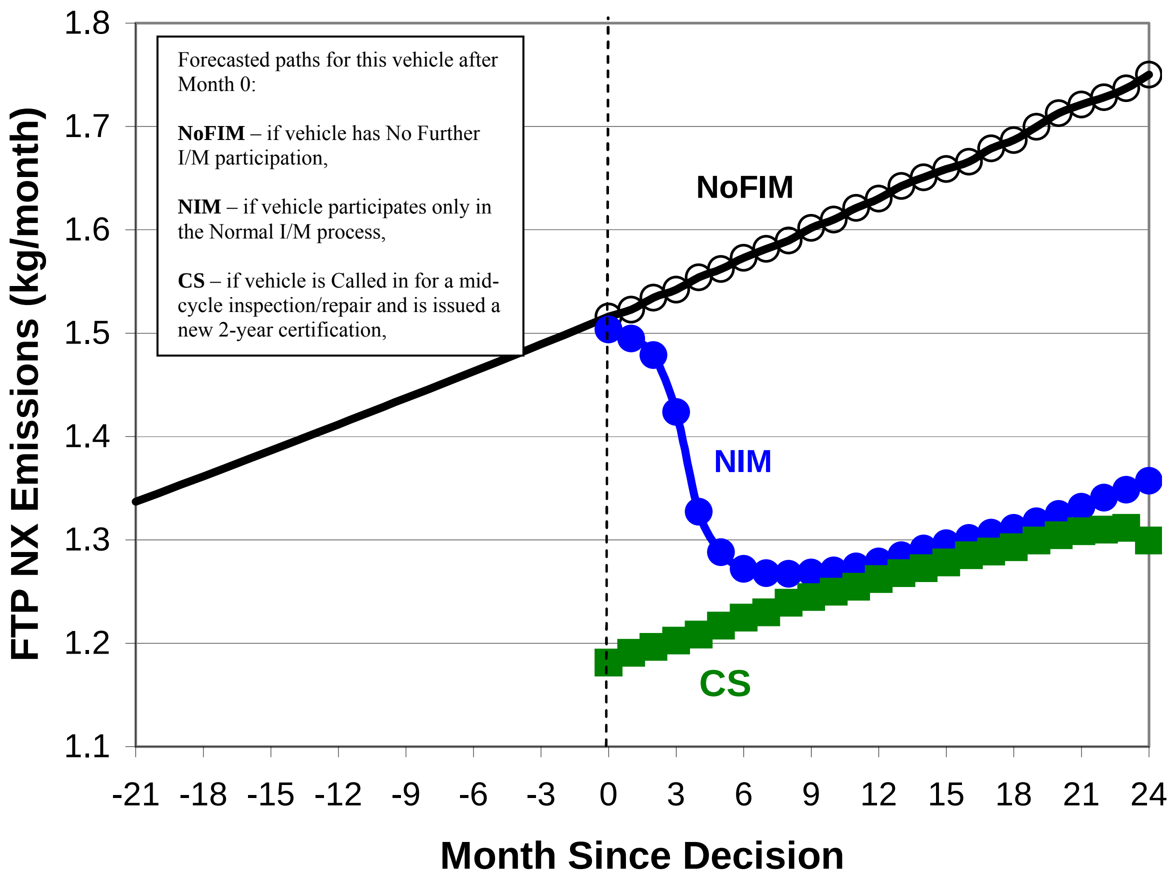
We put together the forecasted time-dependent failure probability, the forecasted FTP emissions rates, and the I/M completion probability in the context of an I/M program (with or without special strategies) using probability theory to produce forecasted time-dependent FTP emission rates and ASM failure probabilities for the vehicle as if it were participating in the I/M program or strategy. Using the monthly vehicle miles traveled for the vehicle, we can then forecast the monthly FTP-basis probable mass emissions for an individual vehicle over the future twenty-four months.

Since the forecasts are a function of time and I/M program configuration, we can forecast the two-year FTP mass emissions for a vehicle for different strategies. The difference in mass emissions calculated for an individual vehicle, if it participates in a strategy and if it does not, reveals the size of the emissions reduction benefit that would be realized by having the vehicle participate in a particular strategy. The I/M simulator can make the calculations that forecast the emissions benefits of an individual vehicle's participation in a special strategy.

An example will help demonstrate the I/M simulator. A particular 1988 Ford Taurus with a 3.0 liter engine received its previous-cycle initial test on February 15, 2003 in which the vehicle failed the ASM2525 NO and passed the other five mode/pollutant tests. The vehicle was repaired and four days later it passed all six ASM mode/pollutant tests and was certified. Twenty-one months later on November 22, 2004, the vehicle received an on-road RSD measurement in the California RSD pilot study. Based on odometer readings recorded in the VID for consecutive I/M inspection cycles, the vehicle is known to drive about 1,000 miles per month. What would be the two-year FTP mass emissions benefit of calling-in the vehicle for an early I/M-station ASM emissions inspection and possible repair? Because of the RSD measurement, the vehicle has come to our attention on November 22, 2004. We call this date the **Decision Point** since we must decide whether to call-in the vehicle or to let it remain in the normal I/M process.

Figure 6-1 shows the I/M simulator forecasts for this vehicle's most probable FTP NOx emissions for three situations: if the vehicle would no longer participate in the I/M program (NoFIM), if the vehicle participates in the I/M program without any calling-in intervention (NIM), and if the vehicle is called in immediately for a regular I/M station ASM emissions test and possible repair (CS). The vertical dashed line denotes the month of the RSD. Months to the left of that line are in the past. The line from -21 to 0 months shows that in past the emissions have likely been increasing. The vehicle is due for its next I/M inspection in Month 4. The NIM curve shows that the emissions are expected to drop because of the inspection process around Month 4 and then will later begin to increase again as the vehicle ages and as the benefits of a repair degrade. If the vehicle does not come in, the emissions will follow the NoFIM line. The size of the area between the NoFIM line and the NIM curve, -7.5 kg NOx, is the biennial benefit of the I/M program for this vehicle. The size of the area between the NIM curve and the CS curve, -1.8 kg NOx, is the biennial benefit of the calling-in strategy for this vehicle.

Figure 6-1. Demonstration of FTP Mass Emissions Forecasting



Keep in mind that the forecasted values of FTP mass emissions are <u>probable</u> values. Some vehicles will have actual emissions greater than and some will have actual emissions less than these probable values. However, the sum of the probable values for a large set of vehicles will be close to the sum of the actual emissions for those vehicles. This makes the probable values useful because the special strategies will be applied to a large set of vehicles in the I/M fleet. From the perspective of the I/M program, the benefits of a strategy estimated using probable values will approximate the actual benefits that will be achieved. The use of time-dependent, probable emissions values to calculate the probable emissions benefit of calling in a vehicle is conceptually no different than the current practice of using standard, non-time-dependent ASM failure probabilities (Fprobs) to direct vehicles. The probable forecasted FTP mass emissions are just more useful because they are time-dependent, are specific to the VID history of the vehicle, and provide emissions estimates.

RSD-Alone Relationship[6] – We also developed a third relationship for the case where only RSD measurements were available. Like the VID+RSD relationship, it was built on the 69,629 observations described in Table 6-2. This relationship is needed so that the analysis can determine the incremental benefits of a strategy when using RSD measurements but without any information about where the vehicle is with respect to its I/M activities. Not having VID information on a vehicle turned out to be a disadvantage. The RSD-alone relationship can predict, but cannot forecast, the six ASM mode/pollutant and overall ASM failure probabilities. These predicted ASM failure probabilities are not time-dependent, but are instead constant. This means they cannot reflect the effects of vehicle aging or the effects of elapsed time since the previous inspection. Also, because they have neither time dependence nor ASM cutpoint functionality, they cannot be combined with I/M completion probabilities (as VID-alone and VID+RSD can be) to produce time-dependent emissions trends like those shown in Figure 6-1. Accordingly, the RSD-alone relationships cannot be used to calculate the mass emissions benefits of an individual vehicle's participation in a special strategy.

Given the above list of all of the things that RSD-alone cannot do, it might seem that RSD-alone is of very limited value. This is not the case. Individual vehicles can still be ranked based on the predicted overall ASM failure probability as calculated by the RSD-alone relationship. This is an important capability for RSD users to have. Traditionally, researchers applied arbitrary RSD "cutpoints" to the RSD HC, CO, and NO measurements to determine if the vehicle was an RSD passer or failer. However, using cutpoints and measured emissions on three pollutants cannot be used directly to rank vehicles, since ranking can be done only on a single quantity. Our new RSD-alone relationship, which combines the ASM failure probabilities derived from each of the three RSD pollutant measurements, is a single quantity. When vehicles are ranked by RSD-alone, they are being ranked in the order of their ASM failure probabilities.

[6] Known as RSD + Nothing in the implementation report [4].

6.3 Methods of Ranking Individual Vehicles for a Strategy

The I/M simulator, which was described above, provides a way to calculate the benefits for an individual vehicle's participation in a special strategy. But what is the best way to prioritize or rank vehicles for targeting by a strategy? What criterion should be used? The ranking methods that produce the largest improvement in quantities that are important to I/M will be those that are favored. To help answer this question, we evaluated three basic vehicle ranking methods.

ASM Failure Probability at Decision Point (FprobDP) – The simplest ranking method is to use the ASM failure probability at the time of the decision to include the vehicle in a strategy or not, that is, at the Decision Point. This method selects vehicles that are most likely to fail an immediate I/M-station ASM test. This is the method that has traditionally been used to select vehicles for Directing and Scrapping. It can be used for Calling-In, and if vehicles are reverse-ranked, it can be used for Exempting. The problem with using ASM failure probability at decision point is that it ranks vehicles only on the ASM failure probability at a single point in time even though we know that a vehicle has emissions over the long period of time between I/M inspections. It completely ignores the time aspects of the interaction between the vehicle and the I/M program, and it completely ignores the vehicle miles traveled by the vehicle. For example, if a vehicle that is being considered for Calling-In is expected to begin its next I/M cycle in only one month, the vehicle will soon be tested by the regular I/M program anyhow. If the vehicle's miles traveled are low, then the vehicle is not a large risk to the airshed unless its FTP emission rate is quite high.

Change in biennial Failed Miles Driven (ΔFMD) – This basic ranking variable makes up for the deficiencies of an ASM failure probability at the decision point. Failed Miles Driven integrates the time-dependent ASM failure probabilities over two years and accounts for vehicle miles traveled. The difference in failed miles driven (ΔFMD) for a vehicle proceeding through the normal I/M path, versus the same vehicle taking a Directing, Exempting, or Calling-In path, can be used to estimate the benefit that would likely be realized by taking the alternate path. By ranking vehicles by the size of their forecasted ΔFMD, the vehicles with the highest potential benefits over a two-year period can be selected for special strategies. While the goal of the I/M program is to reduce total fleet emissions, the means by which the I/M program approaches the problem is by trying to ensure that all vehicles are in an ASM-passing status at all times. Of course, Failed Miles Driven is related to the emissions of the vehicle since vehicles with higher emissions will tend to drive more miles in an ASM-failing status. By selecting vehicles with large forecasted ΔFMDs, vehicles that both emit more than they should and drive more over a biennium are better identified in comparison with selecting vehicles simply on the ASM failure probability at the decision point.

Change in biennial FTP mass emissions per dollar of vehicle value (ΔFTP/$) – I/M program designs recognize that simply minimizing the total emissions is not a practical goal because the logical conclusion of that goal is the crushing of all vehicles. On the other hand, crushing vehicles is the stated goal of Scrapping. Accordingly, the ranking variable for selection of vehicles for Scrapping is based on the forecasted change in FTP mass emissions (ΔFTP) over two years if the vehicle were scrapped versus if it remained in the normal I/M process. However, the ranking variable is not exactly the ΔFTP. Instead, the ranking variable is ΔFTP divided by the value of the vehicle in dollars. By ranking vehicles by ΔFTP/$, the state of California can target those vehicles for scrappage that will provide the largest decrease in FTP emissions for the limited budget that the state has to spend on purchasing scrappage vehicles.

For each strategy and for each of the failure probability relationships (VID-alone, RSD-alone, or VID+RSD), which are based on different types of vehicle information, we ranked vehicles by giving highest priority to those that were likely to have the largest benefits consistent with the working objective of the I/M program. The working objective of the I/M program is that all vehicles on the road should be in an ASM-passing status at all times during the two-year period.

We have chosen ranking methods for each strategy that are consistent with the working objective of the I/M program and the capabilities of the available vehicle information. The ranking methods that we have used in this analysis are shown in Table 6-3. The goals for Calling-In and Directing are to maximize a reduction in Failed Miles Driven over the two-year period after the Decision Point. The goal of Exempting is to minimize the increase in Failed Miles Driven over the two-year period. The goal of Scrapping is to reduce the fleet FTP mass emissions over the two-year period by as much as the vehicle purchase budget will allow. If vehicles are ranked in this manner, regardless of how far vehicle targeting penetrates the ranking, the largest benefit for the fleet will be achieved.

As Table 6-3 indicates, these goals can be realized with the VID-alone and VID+RSD relationships. However, as described earlier, the RSD-alone relationship does not have the capability to calculate the change in failed miles driven or the change in FTP mass emissions for a vehicle's participation in a strategy. Accordingly, the next best method for vehicle ranking for RSD-alone is to rank by the ASM failure probability at the decision point.

As we will see later, ranking vehicles by ASM failure probability at the decision point as calculated by RSD-alone will provide substantial fleet emissions benefits. However, the benefits are not nearly as large as those provided by VID-alone and by VID+RSD. We believe the reason for this is that VID-alone and VID+RSD take into account the point the vehicle is at in its I/M cycle, which is a reason that centers on timing. Thus, it appears that knowing the timing of a vehicle's RSD measurement with respect to the vehicle's I/M cycle is an important piece of information when considering the effectiveness of adding an RSD component to an I/M program.

Table 6-3. Ranking Criterion Used for Strategy/Information Combinations

	Individual Vehicle Ranking Method		
Strategy	**VID-alone**	**RSD-alone**	**VID + RSD**
Calling-In	ΔFMD	FprobDP	ΔFMD
Directing	ΔFMD	FprobDP	ΔFMD
Exempting	ΔFMD	FprobDP	ΔFMD
Scrapping	ΔFTP/$	FprobDP	ΔFTP/$

As an aside, we have been asked what we mean by high emitters and low emitters per se. The reader may have noticed that we do not talk about high emitters and low emitters. The reason is that in this study we are taking a different approach – a probabilistic approach. When a decision needs to be made to either target an individual vehicle for a special strategy or to let it remain in the normal I/M process, it is based on the probability of the vehicle failing a future ASM test. Whether or not that vehicle is an actual ASM high emitter is not certain. As we will see in Section 9, this is not known conclusively even if RSD measurements on the vehicle have been taken.

Different investigators casually speak about high emitters without defining the term. For example, a high emitter could be defined as:

- A vehicle that has emissions concentrations that are higher than current technology vehicles,
- A vehicle whose tailpipe concentrations exceed at least one of the its I/M cutpoints at the I/M inspection, or
- A vehicle whose tailpipe concentrations exceed at least one of its I/M cutpoints at any point during a two-year period.

In this study, we are trying to find the high emitters by selecting vehicles that drive a large number of miles over the biennial period and that simultaneously have generally high ASM failure probabilities over the biennial period. When these two concepts of "miles driven" and "failure probability" are put together, we arrive at the notion of identifying vehicles that are more likely to be driving a large number of miles in an ASM-failing status during a two-year period, that is, Failed Miles Driven. We think that this approach is consistent with the goal of the I/M program and with the goal of reducing emissions to the airshed while acknowledging the variety of emission control technologies in the fleet.

Accordingly, for this study and for Calling-In, Directing, and Exempting, we would define high emitters as those vehicles that drive a large number of miles in an ASM-failing status over a two-year period and low emitters as vehicles that drive few or no miles in an ASM-failing status over a two-year period. For Scrapping, we would define high emitters as those vehicles that are more likely to emit a large mass of emissions over a two-year period and low emitters as vehicles that emit a small mass of emissions over a two-year period.

6.4 Estimating Fleet Benefits of a Strategy

The previous section described the methods used to rank vehicles for each special strategy. Once the vehicles are ranked, the next step is to evaluate the ranking in terms of the benefits and costs to the I/M program.

The benefits and costs for a ranking depend on the vehicles that are targeted and on those that participate in the strategy. Vehicles that are not targeted do not contribute to the benefits because those vehicles remain on the normal I/M process path. If no vehicles are targeted, there will be no benefits. Because the vehicles have been ranked from those that would provide the largest benefits to those that would provide the smallest benefits, vehicle targeting starts from the top of the ranking and ends when the desired penetration or targeting percentage of the vehicles in the ranking has been reached. As a group, the targeted vehicles would provide the largest benefit to the I/M program for that strategy and that vehicle ranking method.

The fleet benefits for the strategy at the penetration rate used would simply be the sum of the benefits for the individual vehicles that are targeted. Therefore, for the 69,629-observation dataset, the individual vehicle benefits of the targeted vehicles need to be summed. Now, we have an obstacle, because for no vehicles in the study do we have measured emissions and failure probabilities for vehicles for each of the 24 months after the RSD measurements were obtained. That is, there are no measured benefits to sum.

How then do we evaluate the performance of these two different rankings? Here is the solution. As a surrogate for these measurements, we use the forecasted ASM failure probabilities and probable FTP mass emissions using the best forecasting model that we have developed – the VID+RSD relationship. To consistently use the same benefits for each individual vehicle, we always use VID+RSD to calculate the forecasted benefits regardless of the models that were used to rank the vehicles for the strategy. Accordingly, we have a case here where we are using one model to evaluate the performances of other, competing models. This introduces a bias in the results of the evaluation. However, because RSD information is in the evaluation model, the bias will always be in favor of models that contain RSD information. If under these circumstances, the RSD information is found to be not cost-effective then in the real-world situation, RSD will be even less cost-effective.

Additionally, we need to make an assumption about the participation of targeted vehicles in the strategy. Simply because a vehicle is targeted does not mean that the vehicle will participate. Participation rates will depend on the procedural and enforcement details of each strategy. Because we have not quantified actual participation rates for the strategies in this study, we have assumed that participation rates are 100% for all strategies. Again, if under these circumstances, a strategy is found to be not cost-effective then in the real-world situation the strategy will be even less cost-effective.

In the case of Directing, it should be possible to achieve near 100% participation since I/M procedures can be developed that would disallow inspections of directed vehicles at average-performing I/M stations. Exempting participation rates will be less than 100% because vehicle owners may simply forget to respond to a mailing that offers them Exempting. Calling-In participation rates will probably be substantially lower than 100% since the strategy requests owners to come in off-cycle for the call-in ASM inspection. Enforcement action may be necessary. Finally, for Scrapping, not only will owners need to respond to a mailing and come in off-cycle for a scrappage ASM, if the vehicle fails they will also need to accept an offer to purchase their vehicle before they can be considered a participant in Scrapping.

To evaluate an individual vehicle ranking method for a strategy and the ability of RSD measurements to improve the strategy, we needed to consider a number of different fleet quantities. Value is ultimately determined by considering costs and effectiveness, however, we also considered some other quantities that are important to an I/M program. Each of the following fleet quantities is presented in the cost-benefit analysis results for each strategy in Section 7:

- ASM Fail Rate at Decision Point (%);
- ΔFailed Miles Driven (miles/2years);

- Total ΔFTP HC + NOx (tons/2years);
- Total Costs ($/2years); and
- Cost-Effectiveness ($/ton HC + NOx).

ASM Fail Rate at Decision Point – This value is the fraction of vehicles that would fail an I/M station ASM test on the day that the decision was made to select or to not select a vehicle for a strategy. We do not regard the decrease in ASM Fail Rate at Decision Point as a benefit because it occurs at just a single point in time. The decrease in fail rate is a consequence of repair; however, as the benefits of repair degrade between I/M cycles, the ASM fail rate increases. The benefits of a repair accrue over the entire biennial period. Nevertheless, ASM Fail Rate at Decision Point is an important quantity because, without a failing result for Directing, Calling-In, and Scrapping or a passing result for Exempting, the benefits of the strategy will not be realized. The ASM Fail Rate at Decision Point does not reflect the level of failure for a vehicle over a two-year period. This is the reason that we developed the idea of Failed Miles Driven over the two-year period.

Δ Failed Miles Driven – Δ Failed Miles Driven is the calculated change in Failed Miles Driven for the fleet over two years that would result from the use of a special strategy. We regard a decrease in Failed Miles Driven as a benefit to the I/M program. Failed Miles Driven extends the notion of ASM Fail Rate at Decision Point to an entire biennial period because the ASM failure probability changes with the vehicle's participation in the I/M program, with the time elapsed since the vehicle's previous Smog Check inspection as a consequence of emission control system wear and failure, and with vehicle aging. In addition, Failed Miles Driven takes into account the level of usage of the vehicle. Vehicles that are not driven a large number of miles are a lower risk to the I/M program than vehicles that are driven many miles per month. Because the approach of the I/M program is to identify vehicles that fail the ASM emissions test, reductions in Failed Miles Driven are a benefit to the I/M program just as reductions in tons of FTP HC + NOx emissions are a benefit to the airshed.

Total Δ FTP HC + NOx – ΔFTP is the calculated change in the mass emissions of the fleet over two years that would result from the use of a special strategy. We regard a decrease in FTP mass emissions as a benefit to the I/M program. Just as for Failed Miles Driven, the mass emissions of a vehicle change with the vehicle's participation in the I/M program, with the time elapsed since the vehicle's previous Smog Check inspection as a consequence of emission control system wear and failure, with vehicle aging, and with the level of usage of the vehicle. The acronym "FTP" signifies that the mass emissions are on an FTP basis. The FTP mass emissions for a given month for an individual vehicle is the average FTP emission rate (g/mile) for the month times the number of miles that the vehicle drives in the month. We use the Δ FTP HC + NOx over a two year period for the I/M fleet as a measure of the effectiveness of a special I/M strategy. The I/M simulator has the capability of calculating time-dependent probable FTP mass emissions for HC, CO, and NOx for individual vehicles in the normal I/M process or in the normal I/M process supplemented by a strategy.

Total Costs – The cost for each strategy is built up from estimates of costs for central office, RSD measurements, notices, inspections, certificates, repairs, purchase of scrappage vehicles, and model update and maintenance. The I/M simulator provides the information that is needed to calculate these costs for a given strategy and for any given level of vehicle targeting within a strategy. Costs will be discussed in detail in Section 6.5.

Cost-Effectiveness – We defined the cost-effectiveness of a strategy as the total cost to run a strategy over a two-year period divided by the reduction in tons of FTP HC + NOx over the same two year period.

When we estimate the value of a strategy or the value of adding RSD to a strategy, we need to consider all five of the above quantities. Only Δ Failed Miles Driven and total Δ FTP HC + NOx are benefits. Traditionally, strategies have gone after maximizing ASM Fail Rate at Decision Point. However, we found that this approach causes the accrued benefits of the I/M program over a biennium as measured by Δ Failed Miles Driven and Total Δ FTP HC+NOx to be smaller than they would otherwise be.

As a result of investigating the benefits of special strategies, we found that trade-offs exist among important I/M program performance measures. Since the I/M simulator can quantify these trade-offs, as an aside, we will examine some of them.

When individual vehicles are ranked for a given strategy, the ranking must focus on a single quantity that is being optimized. However, in an I/M program, there are several quantities that are of interest to program administrators. We believe that there are at least five quantities that administrators should be interested in:

- ASM Fail Rate at Decision Point,
- Failed Miles Driven,
- FTP HC,

- FTP CO, and
- FTP NOx.

When vehicle rankings focus on one of these five quantities, the other four are not improved to the maximum extent possible. Thus, there are trade-offs among the five quantities. It is important that I/M program administrators recognize these trade-offs and make a conscious decision about which of the quantities they would like to use as the focus of special strategies.

As an example, we provide Table 6-4, which demonstrates the trade-offs between ranking vehicles by ASM failure probability at decision point and probable Δ Failed Miles Driven for three different strategies. Consider the first strategy in the table, which is Directing. If we rank individual vehicles by ASM failure probability at Decision Point for 40% fleet targeting, we see that the Δ Failed Miles Driven and Δ FTP emissions are reduced by a specific amount. The ASM Fail Rate at Decision Point is 21.8%. On the other hand, if we rank the vehicles by their probable Δ Failed Miles Driven, we get a different vehicle ranking and therefore different reductions in Δ Failed Miles Driven, Δ FTP emissions, and a different ASM Fail Rate at Decision Point. When vehicles are ranked by ASM failure probability at the decision point, the ASM Fail Rate at Decision Point is the highest that it can be of any possible individual vehicle rankings. Therefore, when we rank the vehicles by a probable Δ Failed Miles Driven, the ASM Fail Rate at Decision Point decreases. The table shows it decreases to 20.1%. In a similar manner, when we rank by a probable Δ Failed Miles Driven, the observed Δ Failed Miles Driven is -17.5%. No other individual vehicle ranking for Directing will produce larger Δ Failed Miles Driven than this ranking.

In the table, we show the more attractive values for the five quantities in bold font. In general, we see that when individual vehicles are ranked by the probable Δ Failed Miles Driven, the observed Δ Failed Miles Driven and the FTP emissions drop by larger amounts than when individual vehicles are ranked by ASM failure probability at decision point. However, the trade-off is a lower ASM Fail Rate at Decision Point.

Individual vehicles could also be ranked by specific types of FTP emissions or combinations of FTP emissions. For example, if certain areas of California had an ozone problem that was determined to be NOx limited, then vehicles could be ranked for the strategies using the probable decrease in FTP NOx emissions. In this study, we did not investigate rankings based on the forecasted Δ FTP emissions of individual types of pollutants. Nevertheless, the I/M simulator is capable of producing these rankings. Thus, rankings based on

Δ FTP emissions could be examined to determine the trade-offs that could be expected and the resulting values for Δ Failed Miles Driven and ASM Fail Rate at Decision Point.

Basically, it all comes down to I/M program administrators deciding what quantity is most important for their I/M program in a particular area. Is it ASM Fail Rate at Decision Point, which is a one point in time value, or would a better goal be to maximize the reduction in failed miles driven or the reduction in mass emissions to the airshed?

6.5 Estimates of Fleet Costs of a Strategy

When the existing I/M program is supplemented with special strategies, the total cost of the I/M program changes. In some cases, the rationale for implementing a special strategy is to reduce the total cost of the I/M program while keeping it as effective as it had been or even improving the overall effectiveness of the program. We estimated the changes in costs for each of the special strategies as a function of the scope and attributes of the strategies. The time-dependent ASM failure rates calculated by the I/M simulator made the calculation of the various types of special strategy costs possible.

The incremental cost to the existing I/M program produced by the special strategies are made up of the following categories:

- RSD measurement costs;
- Central office costs;
- Scrappage vehicle purchase costs;
- Vehicle repair costs;
- Vehicle owner notification costs;
- Inspection certificate costs;
- Inspection costs; and
- Model update and maintenance costs.

In the discussion below, each of these costs is described and the special strategies which influence the costs are pointed out.

Table 6-4. Example of Trade-Offs

Strategy	Individual Vehicle Ranking Method	Percent Fleet Targeted (%)	Fleet Δ Failed Miles Driven (ΔFMD) over 2 years (% of I/M Fleet FMD)	Fleet Δ FTP Emissions over 2 years (% of I/M Fleet FTP Emissions) HC	CO	NOx	ASM Fail Rate at Decision Point (%)
Directing		0%	0.0	0.0	0.0	0.0	100.0%
	Failure Probability at Decision Point	40%	-16.5	-8.0	-5.3	-4.2	**21.8%**
	Probable Δ Failed Miles Driven	40%	**-17.5**	**-8.6**	**-5.6**	**-4.8**	20.1%
		100%	-20.2	-11.3	-7.6	-7.3	10.2%
Exempting		0%	0.0	0.0	0.0	0.0	0.0%
	Failure Probability at Decision Point	20%	0.38	0.82	0.57	0.86	**0.6%**
	Probable Δ Failed Miles Driven	20%	**0.10**	**0.34**	**0.29**	**0.45**	2.0%
		100%	20.2	11.3	7.6	7.3	10.2%
Calling-In No-Sticker		0%	0.0	0.0	0.0	0.0	100.0%
	Failure Probability at Decision Point	5%	-2.4	-0.96	-0.56	-0.42	**51.8%**
	Probable Δ Failed Miles Driven	5%	**-3.6**	**-1.21**	**-0.65**	**-0.64**	40.0%
		100%	-8.4	-4.2	-2.9	-2.8	10.2%

RSD data collection costs – To estimate the RSD data collection costs, it was necessary to make some assumptions about how RSD data collection would be implemented. For the purposes of costing, we assumed that all RSD measurements would be collected by manned RSD units located only in the five largest AQMDs. We assumed that the RSD measurement effort was largely accepted by the public and that drivers did not try to avoid RSD sites or try to invalidate the measurements. In addition, we assumed that the restrictions that CalTrans placed upon our RSD measurement teams would be lifted so that RSD measurements could take place during rush hour traffic. Finally, we assumed that there would be no costs for enforcement, for example, to fight legal challenges on the validity of RSD measurements.

RSD data collection vendors typically charge clients for RSD data collection based on the number of valid, DMV-matched RSD measurements provided. The vendor ensures that the RSD measurement is valid according to the RSD instrument software, and they match the RSD reading to a vehicle registration record using the vehicle's license plate information, which is captured at the time of the RSD measurement. The vendors do not consider the operating mode of the vehicle when counting RSD observations to determine their fees for measurement or when determining coverage of the fleet. For their purposes, vehicles can be operating at any VSP[7]. Therefore, we refer to the RSD vendor's definition of coverage of a fleet as the any-VSP RSD coverage. Any-VSP RSD coverage is discussed more in Section 9.4 and is contrasted with usable-VSP RSD coverage.

The unit cost of a valid, DMV-matched RSD reading provided by the vendor is dependent on the RSD fleet coverage because getting RSD measurements on the increasingly difficult-to-find unique vehicles means that RSD equipment must be set up at more and more, less-than-ideal RSD sites. Figure 6-2 shows the RSD unit price as a function of the RSD coverage of the geographical area. The coverage is measured by the percent of the fleet that gets at least one valid, DMV-matched RSD reading. The costs in the figure were developed from the real-world experience of other jurisdictions that have RSD programs.

Using the estimated unit costs from Figure 6-2 and estimates of the number of unique I/M and non-I/M vehicles with valid, DMV-matched RSD readings for different sized RSD programs we were able to calculate the total annual RSD data collection costs shown in Table 6-5.

The table shows that annually the large RSD program costs more than $31.6 million to obtain 2.27 million RSD measurements that could be used to select vehicles for special

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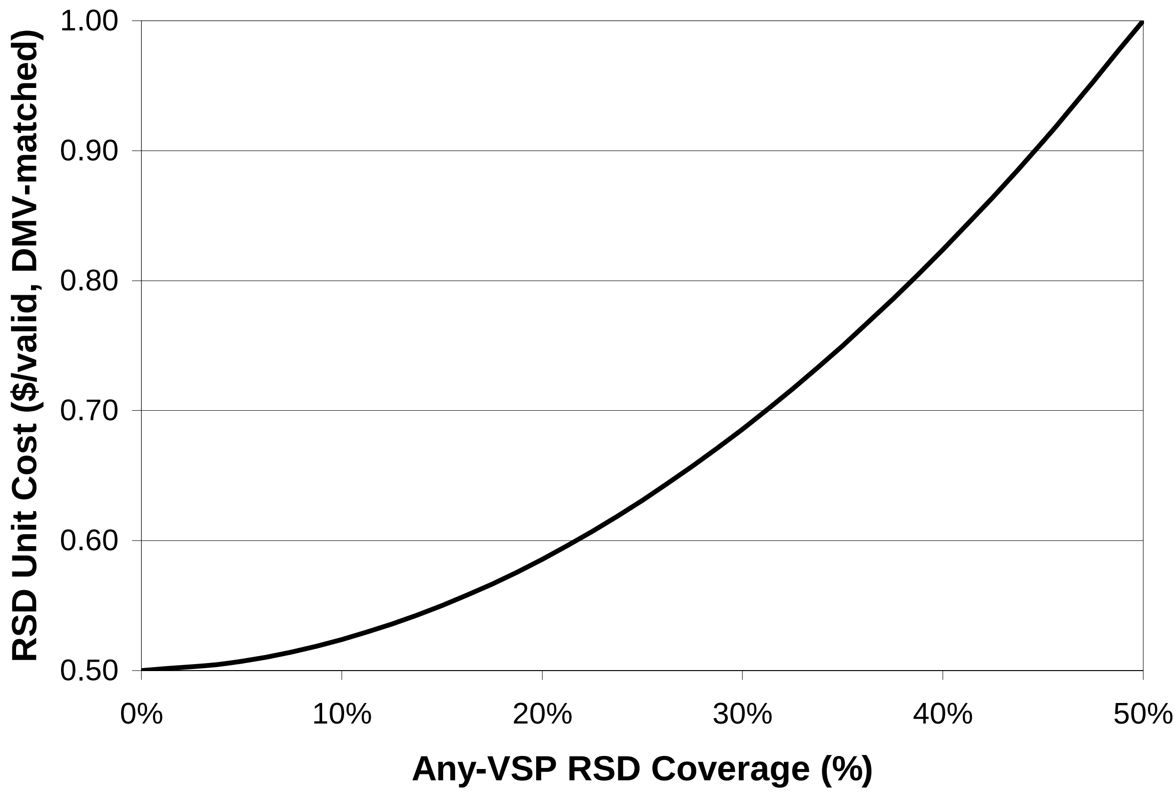
[7] VSP is an acronym for vehicle specific power, a measure of the load on the engine and which can be estimated from the vehicle's speed and acceleration and the road grade.

strategies. Thus, the average cost of RSD data collection for each usable RSD measurement is $13.92. Even at this price, as we shall see, this large RSD program provides a usable-VSP RSD coverage of only 17% of the statewide I/M fleet. The data collection for the smaller size RSD programs is less expensive overall and less expensive per I/M vehicle with a usable RSD reading; however, even smaller portions of the I/M fleet are covered.

Figure 6-2. Estimated RSD Unit Cost for Contracted, Manned Measurements



C:/MyDocuments/CA RSD Pilot Decision report/Implementation Report/RSD unit price function.xls

Table 6-5. Comparison of RSD Programs of Different Size

A	B	C	D	E	F	G	H	I	J
	Desired		**Required**			**Achieved**			
	Any-VSP RSD Coverage[8]	**Number of Unique I/M and non-I/M Vehicles with Valid, DMV-Matched RSD Readings**[9]	**Number of Valid, DMV-Matched RSD Readings**[10]	**RSD Unit Cost (approx.)**	**Annual RSD Data Collection Cost**	**Number of Unique I/M vehicles Driving in the 5 Largest AQMDs that have at least one In-Range-VSP, Valid, DMV-Matched RSD Reading**[11]	**Usable-VSP RSD Coverage**[12] **of I/M Vehicles Driving in the 5 Largest AQMDs**	**Usable-VSP RSD Coverage of I/M Vehicles Driving in the Entire State**	**Effective RSD Cost**
RSD Program Size	**(% of California I/M and non-I/M vehicles driving in the 5 largest AQMDs)**	**(based on 18,982,879 California I/M and non-I/M vehicles driving in the 5 largest AQMDs**[13]**)**		**($/ valid, DMV-matched RSD reading)**	**($)**		**(% of the 11,358,066 California I/M vehicles driving in the 5 largest AQMDs)**	**(% of the 13,388,069 California I/M vehicles driving in the State)**	**($/ IM vehicle with a usable RSD reading)**
Large	50%	9,491,440	31,638,132	$1.00	$31,638,132	2,271,613	20%	16.97%	$13.92
Medium	30%	5,694,864	16,749,599	$0.69	$11,485,402	1,362,968	12%	10.18%	$8.43
Small	10%	1,898,288	4,995,495	$0.52	$2,616,680	454,323	4%	3.39%	$5.76

C:/MyDocuments/CA RSD Pilot Decision Report/Implementation Report/Usable RSD Data Costs.xls

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[8] Fraction of fleet vehicles with at least one RSD measurement obtained under any vehicle operating condition. See Section 9.4.
[9] From Table 3-1b of Reference 4 and based on the EMFAC run results shown in Table N-1 of Appendix N of Reference 3.
[10] From Table 3-1b of Reference 4 and based on the EMFAC run results shown in Table N-1 of Appendix N of Reference 3.
[11] From Table 3-1b of Reference 4 and based on the EMFAC run results shown in Table N-1 of Appendix N of Reference 3.
[12] Fraction of fleet vehicles with at least one RSD measurement obtained under moderate engine load (VSP = 5 to 20 kW/Mg). See Section 9.4.
[13] From Table 3-1a of Reference 4 and based on the EMFAC run results shown in Table N-1 of Appendix N of Reference 3.

Central office costs –We developed functions to estimate central office costs that smoothly modify the cost according to the characteristics of the special strategy program. The resulting functions can calculate costs for a small central office serving a small piece of the state all the way up to a full size office that would cover the entire state. To calculate the central office costs, we made a few assumptions. First, the central office was assumed to be at a single location and housed at an existing state agency. The central office would be at one location regardless of the geographical scope of the fleet of vehicles that is covered by the central office. We did not assume the presence of any branch offices for separate AQMDs.

The job of the central office is to receive weekly data updates, including DMV registrations, VID records, valid DMV-matched RSD data (if RSD data is used), and records of past notices sent to owners, and in the cases of Calling-In and Scrapping, records of subsequent action by the owner. If RSD data collection were used for special strategies, the central office would hire an RSD contractor to provide RSD data and its associated information. However, the cost of the RSD data collection is estimated separately.

The main job of the central office is to create weekly lists of targeted vehicles for the special strategies. The central office would make the list of targeted vehicles by selecting them from the list of all vehicles ranked by the expected benefits of selecting each eligible vehicle. Directing and Exempting would apply only to vehicles that are soon due for an I/M inspection. Calling-In and Scrapping targeted vehicles would be eligible as long as the individual vehicle had not been targeted recently. Ranking of vehicles for targeting would be accomplished by running computer programs like those developed in this project to forecast the benefits of selecting individual vehicles for specific strategies. This is true even when RSD data alone is used because the ranking programs that we have built for this study perform better, that is, they provide greater emission reductions than those provided by using simple RSD cutpoints.

Table 6-6 shows the capital costs for the central office, which are split into three categories. The first item pays for programming changes and form changes for the Department of Motor Vehicles information. This is a one-time expense and would occur only if a Calling-In program were used. A one-time expense would also be incurred if a small central office or a statewide central office would be set up. The second capital expense is for the central office computer equipment. We have estimated this cost at $20,000 for a server plus $2,000 for each employee at the central office. The third capital cost is for the central office supplies and equipment and is directly proportional to the number of employees at the central office.

Table 6-6. Central Office Costs for the Statewide Program for Calling-In, Directing, Exempting, and Scrapping

Full-Fleet Ranking Method Description				VID/RSD + VID History
Strategies?				D X S C
Size of Program (Statewide=1)				1
% Sample Fleet Penetration for Calling-In				5%
With RSD [Yes(1) or No(0)]				1
Percent of Statewide I/M Vehicles Selectable by the Selection Method (%)				100%
Capital Costs				
DMV for Programming, form changes, etc. (One-time Fee for Calling-In Program)				$500,000
Central Office Computer Equipment ($20K for server + $2K per person)				$97,000
Other Capital Costs - central office supplies and equipment				$103,777
Annual O&M Costs				
Amortized capital costs for DMV for Programming, etc. (10yrs @10%)				**$81,373**
Amortized capital costs for computer equipment (5yrs @10%)				**$25,588**
Amortized capital costs for office supplies/equipment (10yrs @10%)				**$16,889**
Labor for Central Office				
Position	Annual Salary @ 40hrs/wk			
Program Administrator	$90,970		1.00	$90,970
Program Manager	$70,754		3.00	$212,262
Engineer /Data Analyst/Programmer	$70,754		5.00	$353,770
Attorney	$63,000		3.00	$189,000
Public Information/Communication	$30,323		20.00	$606,460
Administrative Assistant	$48,000		1.00	$48,000
Receptionist	$30,323		1.00	$30,323
Clerical and Secretarial Staff	$30,323		4.50	$136,454
Salary * Person-Years			38.5	$1,667,239
Overhead and Fringe (100%)				$1,667,239
Equipment maintenance (@20%)				$20,755
Supplies (@10% of Maintenance)				$2,076
Total Labor for Central Office, fully burdened				**$3,357,308**
Misc. Recurring Costs, Central Office				
Operating supplies ($250/person-yr)				$9,625
Travel ($250/person-yr)				$9,625
Hiring and training costs				$18,434
Total for misc. recurring costs at central office				**$37,684**
Other Contract Support (2% of program expenses)				**$70,377**
Total Annual CENTRAL OFFICE O&M Costs (including capital recovery)				**$3,589,219**

D = Directing, X = Exempting, C = Calling-In, S = Scrapping
/proj1/DecisionModel/Report/IM_Strategy_Evaluator_070323.xls

The annual operating and maintenance costs have several categories. The first three shown in Table 6-6 are the amortized capital costs. The largest expenses for operating the central office are the labor costs. The table uses eight different groups of positions with annual salaries. The table shows the sum of the salaries and benefits for personnel, and the costs for equipment maintenance, and supplies. This produces a total labor cost for the central office that is fully burdened. The table also shows miscellaneous recurring costs for central office for operating supplies, travel, and hiring and training costs.

The size of the staff for central office is determined by four variables: the number of I/M vehicles served by the central office, the fraction of the I/M fleet that is targeted for Calling-In, whether RSD data is being used to help select targeted vehicles, and the percent of statewide I/M vehicles eligible for the selection method. In Table 6-6, we show one example that estimates the central office cost for the four-strategy package which includes Directing, Exempting, Scrapping, and Calling-In when VID history and RSD are used together to select vehicles for targeting. The size of the program is statewide. The Calling-In strategy uses a 5% sample fleet penetration, RSD data is available and is being used to help select vehicles, and because VID history information is being used to select vehicles, essentially 100% of the statewide I/M vehicles are eligible for selection.

Scrappage vehicle purchase cost – For the Scrapping strategy, the state buys vehicles and destroys them as a means of eliminating the emissions of those vehicles from the inventory. Of the four special strategies evaluated in this study, Scrapping is the only strategy in which vehicles are purchased. Therefore, the purchase cost of these vehicles is a cost only for Scrapping, and not for Directing, Exempting, or Calling-In. In recent years, California has allocated a set amount of money to spend for the purchase of vehicles for Scrapping. The size of this fund determines the penetration that will be needed to target vehicles for scrappage each year. Once the penetration is determined, we can calculate the benefits and the other non-vehicle purchase costs incurred.

In the process of developing the I/M simulator, we found that being able to estimate the value of a scrappage vehicle candidate was critical to efficiently ranking the vehicle for scrappage. The best scrappage vehicle ranking methods used the estimated mass emissions of the vehicle over its remaining lifetime[14] divided by the value of the vehicle. This produced rankings that would maximize the reduction in vehicle emissions from Scrapping for a fixed vehicle purchase budget. Therefore, to estimate the purchase cost of vehicles that are targeted

[14] In this analysis the remaining lifetime of a vehicle was assumed to be 24 months.

for Scrapping, we need to be able to estimate the purchase cost for each individual vehicle. During the development of the I/M simulator, we created vehicle value estimating functions, which are based on vehicle make, vehicle type, and vehicle age.

A simple example will demonstrate why vehicle value is important for ranking vehicles for Scrapping. Suppose two vehicles have the same forecasted mass emissions over their remaining lifetime. One vehicle is a newer vehicle with a high value. The other vehicle is an older vehicle with a low value. If we base the selection of the vehicle solely on the mass of emissions remaining in the lifetime of the vehicle or even on the failure probability of the vehicle at the next I/M inspection, both vehicles will end up near each other in the ranking. However, the state would prefer to buy the lower valued vehicle for Scrapping. It makes more sense to repair the newer vehicle. The analysis indicates that using vehicle value in the ranking increases the emissions reduction for Scrapping by about a factor of three.

To estimate the size of the state's scrappage vehicle expenditure, we need to consider more than the value of each vehicle. In a Scrapping program, the state will not purchase every vehicle that is called in for a scrappage ASM. It will purchase only those vehicles that fail the scrappage ASM. Therefore, we need to consider the probability of ASM failure for each of the individual vehicles in the dataset at the time of the scrappage ASM. The I/M simulator provides these scrappage ASM failure probabilities. When we multiply the scrappage ASM failure probability by the estimated vehicle value, we get the probable purchase expense of each vehicle that is being targeted. The targeted vehicles for Scrapping are simply those from the top of the list whose sum of the vehicle probable purchase expense equals the state's purchase budget. We found that if the state's annual vehicle purchase budget were $8 million to purchase vehicles at their market value, depending on the method used to rank vehicles for Scrapping, between 0.24 and 0.62% of the I/M fleet would be targeted for a scrappage ASM in each biennium. Clearly, only a portion of the targeted vehicles would fail the scrappage ASM and therefore would be eligible for Scrapping purchase offers.

Vehicle repair costs – When special strategies are applied to the existing California I/M program, changes to the repair costs of individual vehicles that had been in the normal I/M process will occur. In the I/M simulator, we developed a method to quantify the size of these incremental repair cost changes by considering the size of the repair costs for the two paths under consideration for an individual vehicle: the normal I/M process path and a special strategy path. The time-dependent failure probabilities and the probability of completing the I/M program requirements in any given month, which were estimated by the I/M simulator, were used to forecast probable repair costs for individual vehicles for the different special strategies.

As an example, we configured a vehicle with different VID history and RSD measurement characteristics so that the calculations of vehicle repair costs would be estimated for a simulated low emitter and high emitter. The low emitter was simulated by setting the previous-cycle ASM results to all passes and the recent RSD measurements to the lowest possible concentration values. The high emitter was simulated by setting the previous-cycle ASM results to fail for ASM2525 NO and other ASM results to pass and the recent RSD measurements to low values for HC and CO but the RSD NO measurement to 7,800 ppm. The low emitter configuration was used to estimate the repair cost for Exempting in comparison with the normal I/M process. The high emitter configuration was used to examine the repair costs for Directing, Calling-In, and Scrapping in comparison with the normal I/M process. Table 6-7 shows a summary of the probable repair cost results from those calculations. The probable repair costs were calculated for the 48 months following the Decision Point, which is the date on which the decision is made to assign the vehicle to a special strategy or to let it remain in the normal I/M process.

Table 6-7. Probable Repair Costs Over 48 Months After the Decision Point for the Example Vehicle Description

Vehicle Emissions Characteristic	Intervention Strategy				
	Normal I/M Process	Exempting	Directing	Calling-In No-Sticker	Scrapping
Low Emitter	$7.78	$10.54	-	-	-
High Emitter	$98.32	-	$117.98	$140.80	$32.85

The table shows that the repair cost incurred by Exempting the low emitter is higher than if the low emitter is left in the normal I/M process. The increased repair cost is caused by the increase in probability of a repair being needed because the inspection is delayed two years. During this delay, the failure probability increases. In the case of Directing, which like Exempting occurs at the regularly scheduled biennial date, probable repair costs are higher than the corresponding repair cost for leaving the vehicle in the normal I/M process. This increase is due to the increased likelihood that a directed vehicle will fail the ASM test at a high-performing station compared to an average-performing station. The table shows that in the case of Calling-In, the probable repair costs are also higher than the repair costs for leaving the vehicle in the normal I/M process. A portion of the increased repair cost is due to the call-in ASM test which is an “extra” ASM test that the vehicle would not undergo if it remained in the normal I/M process. In the case of Scrapping, the probable repair cost for the high emitter was lower than the repair cost if the vehicle remained in the normal I/M process – but the repair cost was not zero. Of course, the future repair costs for vehicles that failed the scrappage ASM test would be zero – because those vehicles would be scrapped. However, there is always the probability that the high emitter would pass the scrappage ASM test and therefore, continue in the I/M program. It would thereby incur future repair costs. Our calculations also took into account that the vehicles that passed the scrappage ASM test would be less likely to need repairs in the future and therefore the repair costs for the scrappage ASM-passing vehicles would be lower than for all vehicles of the same age.

To estimate the probable repair costs of the California I/M fleet we needed to generalize the results so that they would be representative of the incremental repair costs as a whole when portions of the fleet would take the Exempting, Directing, Calling-In, or Scrapping path instead of the normal I/M process path. We selected repair cost adjustment factors for each of the different special strategies that generalized the effect of the strategy on the change in repair cost of the strategy with respect to the repair cost for the normal I/M process. Those relative costs were taken from the values in Table 6-7 to produce the repair cost adjustment factors shown in Table 6-8.

Table 6-8. Repair Cost Adjustment Factors

Repair Cost Adjustment Factor	**Intervention Strategy**			
	Exempting	**Directing**	**Calling-In No-Sticker**	**Scrapping**
	+45%	+20%	+70%	-75%

For each of the different strategies, the change in repair cost is based on the number of vehicles that would have failed in the normal I/M process. To get the change in repair cost, the unit repair cost of $194[15] is multiplied by the repair cost adjustment factor from Table 6-8 for the corresponding strategy and multiplied by the number of targeted vehicles that would have failed if they had remained in the normal I/M process.

Notices – In the base case I/M program scenario, notices are sent to all owners to remind them that their inspection date is approaching. Since owners can be directed and exempted by making changes to the wording of the reminder letter, there are no incremental costs for Directing and Exempting. On the other hand, Calling-In and Scrapping are off-cycle activities for this analysis. Therefore, special notices, which cause incremental notice costs, need to be sent out. The cost for notices is the same whether RSD is used or not. The unit cost for each notice is $3.00.

[15] Unit repair cost provided by the Bureau of Automotive Repair.

Certificates – The incremental cost for certificates varies for the different special strategies. In the case of Directing, directed vehicles are tested at high-performing stations rather than average-performing stations. However, in both cases the same number of certificates would be issued. In the case of Exempting, exempted vehicles would still be required to get new certificates even though they did not receive an inspection. In the case of Calling-In, vehicles that are called-in would not receive a new certification, which represents no change beyond the base case I/M program scenario. In the case of Scrapping, vehicles that pass the scrappage ASM test would not be given a new certification, but would be required to continue following the requirements of their existing certification. Vehicles that fail the scrappage ASM test would not be required to get a new certification since those vehicles would be scrapped. Since they are removed from the fleet, the absence of future certifications is a credit. The unit cost of certificates is $8.25.

Inspections – For incremental inspections beyond the base case scenario, the situation is different for the different special strategies. For Directing, the same number of inspections would be performed whether the vehicles were tested at high-performing stations or at average-performing stations. Accordingly, there is no incremental cost for inspections for Directing. In the cases of Calling-In and Scrapping, the call-in and scrappage ASM tests are in addition to the base case I/M program scenario. Accordingly, incremental costs for call-in and scrappage inspections are incurred. In the case of Exempting, no exempted vehicles would receive an ASM test. The large cost credit associated with this large decrease in the number of inspections performed is the major incentive for Exempting vehicles. The unit cost for inspections is $50[16].

Model update and maintenance – Vehicle ranking software similar to that developed for this study would be used weekly to rank the vehicles for the special strategies. As the fleet ages and turns over, and as more data is added to the VID, the registration database, and the historical RSD dataset, updates to the ranking software will be required. We estimate that updates and maintenance of this software would cost $200,000 annually.

[16] Unit inspection cost provided by the Bureau of Automotive Repair.

6.6 Evaluating the Benefits and Costs of Adding RSD to the IM Program

Our approach to evaluate the benefits and costs of supplementing the I/M program with an RSD component is to use different combinations of information sets to rank the vehicles for the four different special strategies. We used the I/M simulator to calculate the fleet benefits as described in Section 6.4 and costs as described in Section 6.5 for the set of 69,629 vehicles in the pilot study for which we had RSD measurements, VID records, and an initial-cycle ASM result after the RSD. We ranked these vehicles for targeting for each of the four strategies using the three individual vehicle ranking methods described in Section 6.3:

1) Individual vehicle VID records alone (VID-alone),

2) Individual vehicle RSD measurements alone (RSD-alone),

3) Individual vehicle VID records supplemented by individual vehicle RSD measurements (VID+RSD).

The results from these three methods were used to evaluate adding RSD to the existing I/M program over a wide range of penetrations for each of the four strategies. Specifically, comparing 2) with 1) reveals whether VID-alone or RSD-alone provides superior operating effectiveness, lower costs, and better cost-effectiveness for a given strategy. And comparing 3) with 1) reveals whether adding RSD measurement information to historical VID information will improve strategy performance. Performing these two comparisons is the source for the answers to five of the pilot study questions dealing with selection of vehicles for special strategies.

7.0 Evaluation of RSD's Ability to Select Individual Vehicles for Special Strategies: Cost-Benefit Analysis Results

In this section we present the benefits and costs for each of the four special strategies. Details of all of these results are presented in References 3 and 4. In the sub-sections below we present each strategy as implemented by itself:

- Calling-In vehicles between I/M cycles,
- Directing vehicles to high-performing stations,
- Exempting vehicles from I/M requirements, and
- Scrapping vehicles,

and then present the results for two packages of strategies:

- Four strategies (Calling-In, Directing, Exempting, and Scrapping)
- Three strategies (Directing, Exempting, and Scrapping).

The effectiveness of each of the three vehicle ranking methods (VID-alone, RSD-alone, VID+RSD) was calculated by projecting (for each of the future 24 months) which of the vehicles selected by each method would fail a Smog Check inspection in a regular I/M station (i.e., not a Referee or a roadside inspection) and how much benefit would be realized by their repair. The first benefit is the fleet's Δ Failed Miles Driven over the two years after the decision to select or not select each individual vehicle. The second benefit is the fleet's ΔFTP HC+NOx over the same two-year period. The calculations also determine the number of vehicles targeted and the number of vehicles that would fail an ASM test at the decision point.

We estimated costs for setting up and running the RSD program, administration costs, and costs associated with inspections and repair of additional vehicles specific to each strategy. All cost and benefit numbers assume that all targeted vehicles participate in the strategy. Details of the costs for each activity are described in Reference 4.

We estimated the costs and benefits for using other methods to select vehicles for special I/M program strategies including selection by model year, by vehicle description, which is similar to the current HEP, and by RSD measurement with ASM cutpoints [4]. Some methods used RSD data and some did not. The non-RSD information does not require field data collection, so it can be routinely obtained at low cost.

7.1 Calling-In Vehicles Between I/M Cycles

In this section we describe the benefits and costs for calling-in without the implementation of any other strategy. The current Smog Check program does not call-in vehicles between regular inspection cycles (referred to as "off-cycle" inspections), so the baseline program we compared costs and benefits to also did not call-in vehicles "off-cycle." Table 7-1 shows the strategy evaluation quantities for a comparison of the three key vehicle selection methods for identifying the top 5% high-risk vehicles and calling them in for inspection and potential repair between their regular I/M inspections.

The first row shows the number of vehicles targeted for calling-in. Note that the number targeted for RSD-alone is 17% of the numbers targeted for the other two selection methods. The reason for this is that even with the largest RSD measurement program, which obtains valid, DMV-matched RSD readings on 50% of the vehicles driving in the five largest AQMDs, usable RSD measurements can be obtained on only 17% of the vehicles in the statewide I/M fleet. The second row shows the number of vehicles expected to fail at the decision point. The third row shows the percent of the targeted vehicles that are expected to fail the call-in ASM test at the decision point. While RSD-alone targets failing vehicles more efficiently (43.5% vs. 33.2% and 34.3%) than the other two selection methods do, the observed fail rate is not up to the high fail rates (such as 90% or more) that are desired when vehicles are called-in off-cycle.

The fourth and fifth rows show the calculated benefits of the calling-in strategy at 5% fleet penetration. All three methods provide some benefits for the California fleet. The VID + RSD method provides the largest benefits for this strategy; however, the VID-alone method is not far behind. At 5% targeting, the VID + RSD method reduces FTP HC + NOx by about 129 more tons per 2 years than the VID-alone method does. Hence, RSD does help VID-alone in providing some additional emissions benefit. The RSD-alone method produces the smallest reduction in emissions – even though the ASM Fail Rate at Decision Point was the highest. The two main reasons for the poorer performance of RSD-alone are that only 17% of the statewide I/M fleet will have usable RSD measurements and the RSD-alone method can rank vehicles only by their expected ASM Fail Rate at Decision Point rather than by expected Δ Failed Miles Driven.

Table 7-1. Cost-Benefit Summary for Calling-In[a,b]

		Vehicle Selection Method			
		VID alone	**RSD alone**	**VID+RSD together**	**Adding RSD to VID-alone causes:**
Targeted Vehicles [c] at 5% Targeting (N)		669,403	113,581	669,403	
Targeted Vehicles that Fail ASM at Decision Point (N)		222,039	49,450	229,754	7,715 more vehicles to fail
ASM Fail Rate at Decision Point (%)		33.2%	43.5%	34.3%	
Benefits	**Δ Failed Miles Driven (miles/2years) [d]**	A decrease of **972,447,180** failed miles driven	A decrease of **72,776,491** failed miles driven	A decrease of **995,126,275** failed miles driven	A further decrease of **22,679,095** failed miles driven
Benefits	**Total ΔFTP HC+NOx (tons/2years) [f]**	A decrease of **4,595** tons	A decrease of **557** tons	A decrease of **4,724** tons	A further decrease of **129** tons
Total Costs ($/2years)		**$ 72,915,946** spent	**$ 80,692,952** spent	**$ 137,533,806** spent	A further increase of **$ 64,617,862** spent
Cost Effectiveness ($/ton HC+NOx) [h]		**$ 15,870** spent for each ton of emissions reduced	**$144,822** spent for each ton of emissions reduced	**$ 29,117** spent for each ton of emissions reduced	An additional **$ 500,867** spent for each additional ton of emissions reduced

[a] The costs and benefits presented in this table are for a large RSD measurement program that obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[b] The costs and benefits presented in this table are for a high-emitter Calling-In strategy that targets 5% of the I/M fleet.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

The cost effectiveness of each method is listed on the bottom row of Table 7-1. For example, for the VID-alone method, the total costs of the program would be about $73 million every two years. That cost is associated with reducing FTP HC+NOx emissions by about 4,600 tons every two years over (incremental to) the baseline program. The resulting cost effectiveness is calculated from those two numbers at about $16,000 per ton of HC+NOx. As shown, using RSD-alone produces smaller emissions reductions at substantially higher cost. The result is that RSD-alone is quite cost-ineffective at $145,000 per ton.

The last column of Table 7-1 shows that adding RSD information to VID information for calling-in is very cost-ineffective. Adding RSD helps in that VID+RSD performs better than either RSD-alone or VID-alone. However, 97% (=4595/4724) of the benefit of VID+RSD and only 53% (=$72,915,946/$137,533,806) of the cost of VID+RSD is provided by VID-alone .

The benefits, costs, and cost-effectiveness results for Calling-In at 2%, 5%, 7%, and 10% penetrations are shown in Appendix A Tables A-1, A-2, A-3, and A-4. Those results show a weak trend toward better cost-effectiveness as penetration for Calling-In increases.

7.2 Directing Vehicles to High-Performing Stations

High-performing stations are those stations that can more reliably measure the ASM pass/fail status of a vehicle than the average I/M station can. High-performing stations tend to have higher fail rates than average-performing stations because vehicles inspected at high-performing stations are more likely to get needed repairs than if they had been inspected at average-performing stations. Therefore, Directing vehicles to high-performing stations results in higher fleet-average emissions reductions. Ideally, we would want to direct the fleet’s highest risk vehicles to high-performing stations. The highest risk vehicles are those that are expected to drive a large number of ASM-failed miles and produce a large mass of emissions over the next two years.

Currently, the State uses a High Emitter Profile (HEP) model to direct some vehicles to high-performing stations. An improved HEP could have inputs from either the Vehicle Information Database (VID), which is maintained by the Smog Check program, or from RSD data collected in the five largest AQMDs, or from both sources. To provide the information for the three basic ranking methods (VID-alone, RSD-alone, VID+RSD), we used three of the eleven improved HEPs developed in this study.

Table 7-2 shows the results of the cost-benefit analysis for Directing using a 40% fleet targeting level (40% was selected solely for demonstration purposes). This means that, after the vehicles are ranked by a vehicle selection method, the top 40% of the vehicles were chosen to participate in the Directing calculations. The first row in the table shows the number of vehicles targeted for Directing. The number targeted by RSD-alone is 17% of the numbers targeted by the other two methods since the RSD program can provide usable RSD readings on only 17% of the statewide I/M fleet. The second row of the table shows the increase in the number of vehicles that would fail the ASM at Decision Point as a result of being tested at a high-performing station versus the number that would have failed at an average-performing station. The third row shows this number expressed as a percentage of the number of targeted vehicles for each vehicle selection method. These increased counts and ASM Fail Rates at Decision Point are based on the assumption that average stations fail 80% of the vehicles that would have failed at high-performing stations.[4]

The fourth and fifth rows show the size of the benefits in terms of Δ Failed Miles Driven and Δ FTP HC + NOx. The largest benefits are seen for the VID + RSD vehicle selection method. However, just as for Calling-In, we see that the VID-alone method is almost as good. Again, the RSD-alone method shows the smallest benefit for the three vehicle selection methods. This is the result of RSD being able to obtain usable measurements on only 17% of the vehicles in the statewide I/M fleet and of the ranking of vehicles by the expected ASM Fail Rate at Decision Point rather than by Δ Failed Miles Driven.

The sixth row shows the total costs for the three vehicle selection methods. The costs for the second and third methods, which include RSD measurements, are substantially higher than the cost for the VID-alone method, which does not require on-going RSD measurements. The last row shows the cost-effectiveness values in $/ton and indicates that the VID-alone method is cost-effective and the methods that use RSD are not.

In summary, the RSD-alone method captures about one-sixth of the Δ Failed Miles Driven and the Δ FTP HC + NOx at about three times the cost of VID-alone. This makes Directing using RSD-alone unattractive at $97,000/ton. The VID + RSD method actually captures slightly more Δ Failed Miles Driven and Δ FTP HC + NOx emissions than VID-alone but it is also not cost-effective because the cost of performing the RSD measurements is high.

Table 7-2. Cost-Benefit Summary for Directing[a,b]

		Vehicle Selection Method: VID alone	Vehicle Selection Method: RSD alone	Vehicle Selection Method: VID+RSD together	Adding RSD to VID-alone causes:
Targeted Vehicles [c] **at 40% Targeting (N)**		5,355,228	908,645	5,355,228	
Δ[i] **Targeted Vehicles that Fail ASM at Decision Point (N)**		115,080	23,107	118,245	3,165 more vehicles to fail
Δ[i] **ASM Fail Rate at Decision Point (%)**		2.1%	2.5%	2.2%	
Benefits	**Δ Failed Miles Driven (miles/2years)** [d]	A decrease of **594,758,300** failed miles driven	A decrease of **96,525,257** failed miles driven	A decrease of **606,709,974** failed miles driven	A further decrease of **11,951,674** failed miles driven
Benefits	**Total ΔFTP HC+NOx (tons/2years)** [f]	A decrease of **4,339** tons	A decrease of **730** tons	A decrease of **4,423** tons	A further decrease of **84** tons
Total Costs ($/2years)		**$ 25,785,903** spent	**$ 71,192,233** spent	**$ 89,969,958** spent	A further increase of **$ 64,184,057** spent
Cost Effectiveness ($/ton HC+NOx) [h]		**$ 5,943** spent for each ton of emissions reduced	**$ 97,488** spent for each ton of emissions reduced	**$ 20,342** spent for each ton of emissions reduced	An additional **$ 765,450** spent for each additional ton of emissions reduced

[a] The costs and benefits presented in this table are for a large RSD measurement program that annually obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[b] The costs and benefits presented in this table are for a high-emitter Directing strategy that targets 40% of the I/M fleet.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

[i] Inspecting targeted vehicles at high-performing stations rather than at average-performing stations causes these increases in the number of targeted vehicles that fail and corresponding increases in ASM fail rates.

The last column in the table shows the incremental numbers for adding RSD information to VID information. Doing this does increase the benefits of Directing by 84 tons over 2 years; however, the increase in cost is $64 million since the entire large RSD program must be instituted to get the RSD measurements needed to gain the 84 tons.

The benefits, costs, and cost-effectiveness of Directing for 20%, 30%, 40%, and 50% penetrations are shown in Appendix A Tables A-5, A-6, A-7, and A-8. In general, the trends with increasing penetrations are increasing benefits, slight improvement in RSD-alone cost-effectiveness, and slight degradation in incremental RSD cost-effectiveness over VID-alone. We have also investigated the effect of the size of the RSD measurement program on cost-effectiveness and found that even for smaller RSD measurement efforts the cost-effectiveness of Directing using RSD information continues to be not cost-effective.

7.3 Exempting Vehicles from I/M Requirements

We explored several methods for using RSD to exempt (also called "clean screen") vehicles from Smog Check and compared them to methods that do not rely upon RSD. We only investigated options that are incremental to a baseline program similar to the current Smog Check program, which already exempts the most recent six model years from I/M. Our baseline program and the current Smog Check program are identical with respect to "clean screen." So, the costs and benefits we present are incremental to the current Smog Check program. The cost and benefit results for the three key vehicle selection methods are summarized in Table 7-3. In this example we present an aggressive "clean screen" that exempts 20% of the vehicles beyond those currently exempted due to their age.

The disadvantage of exempting vehicles from I/M is that a small fraction of them would have failed the inspection and presumably would have gotten needed repairs. By erroneously exempting these few vehicles, a small amount of failed-miles-driven and emissions-reduction benefits are lost. Since those reductions are not realized, exempting a meaningful number of vehicles will always increase fleet failed miles driven and emissions to some extent. The goal is to intelligently select the vehicles so that the small loss in benefits is minimized. Table 7-3 shows that for 20% fleet targeting, the lowest increase of the three methods is provided by RSD-alone with about 529 tons increase over 2 years. However, since RSD measurements would be available on only about 17% of the statewide I/M fleet, 83% of the fleet is not covered by RSD-

Table 7-3. Cost-Benefit Summary for Exempting[a,b]

		Vehicle Selection Method: VID alone	Vehicle Selection Method: RSD alone	Vehicle Selection Method: VID+RSD together	Adding RSD to VID-alone causes:
Targeted Vehicles [c] at 20% Targeting (N)		2,677,614	454,323	2,677,614	
Targeted Vehicles that Fail ASM at Decision Point (N)		58,371	3,963	54,125	4,247 fewer failing vehicles to be exempted
ASM Fail Rate at Decision Point (%)		2.2%	0.9%	2.0%	
Benefits	**Δ Failed Miles Driven (miles/2years) [d]**	An increase of **143,777,037** failed miles driven	An increase of **26,921,267** failed miles driven	An increase of **122,609,996** failed miles driven	The reduction of an additional **21,167,040** failed miles driven are preserved
Benefits	**Total ΔFTP HC+NOx (tons/2years) [f]**	An increase of **2,358** tons	An increase of **529** tons	An increase of **2,212** tons	An additional **146** tons of emissions reductions are preserved
Total Costs ($/2years)		A savings of **$ 74,449,922**	**$ 52,971,366** spent	A savings of **$ 11,250,529**	A further increase of **$ 63,199,395** spent
Cost Effectiveness ($/ton HC+NOx) [h]		A savings of **$ 31,573** for each ton of emissions increased	**$ 100,179** spent for each ton of emissions increased	A savings of **$ 5,086** for each ton of emissions increased	An additional **$ 433,376** spent for each additional ton of emission reductions not lost through exemption

[a] The costs and benefits presented in this table are for a large RSD measurement program that annually obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[b] The costs and benefits presented in this table are for a low-emitter Exempting strategy that targets 20% of the I/M fleet.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

alone and does not get a chance to be exempted. Accordingly, the primary reason that the 529 ton number is so low is that it applies to only 17% of the statewide I/M fleet. Of the methods in Table 7-3 that cover the entire fleet, the one resulting in the lowest FTP HC+NOx emissions increase with 2,212 tons over two years is VID + RSD together.

From the perspective of costs, the strategy of exempting vehicles is different than the other strategies because it can actually lead to a net savings. When a vehicle is exempted, the owner no longer must pay for an inspection or a repair, which usually would not have been necessary anyway for these vehicles. Exempting also improves the convenience of the I/M program to the public. Vehicle owners avoid traveling to the inspection station and waiting for the inspection. If enough vehicles are exempted, and if the other costs that go into exempting vehicles are low enough, a savings to vehicle owners is realized in the form of more money remaining in their pockets for other uses.

An example of such a savings is shown in Table 7-3 under the column for the VID-alone vehicle selection method. The savings of more than $74 million comes from exempting 20% of the vehicles that are not already exempted because of their age. Unfortunately for the agencies implementing the program, the program savings do not increase funds to spend administering the program. But perhaps the savings to the public would justify a request of more funds to improve other aspects of the State's efforts at reducing on-road pollution. One can also see in Table 7-3 that for the methods that use RSD readings, the savings are much less; the RSD-alone method actually costs money, which defeats the purpose of Exempting. The reason for this is that the large cost of RSD data collection offsets the savings from the large reduction in the number of inspections that Exempting produces.

The previously mentioned cost savings and improved convenience of exemptions somewhat mitigate the emissions increases. So we compare the methods for Exempting by noting which methods have the smallest emissions increase and result in the highest net savings to the public. A scenario that saves money has promise for inclusion into a suite of strategies, as long as the other strategies reduce pollution enough to offset the increases from the exemptions. The RSD-alone method is not attractive because this vehicle selection method costs millions of dollars to increase fleet failed miles driven and mass emissions. On the other hand, the VID-alone method is quite attractive. While it does allow failed miles driven and emissions to increase, the increases are not substantially larger than those for the VID + RSD vehicle selection method, which costs $63 million more than the VID-alone method.

Comparison of the cost-effectiveness value for the VID-alone method for Exempting with the Carl Moyer criterion suggests an attractive opportunity. Usually we think of the Carl Moyer criterion in this way: If the cost of "buying" emissions is less than $14,300 per ton, the purchase is attractive. That use of the criterion applies to Calling-In, Directing, and Scrapping. But we can turn the Carl Moyer criterion around in this way: If the income from "selling" emissions is more than $14,300 per ton, the sale is attractive. This statement applies to Exempting by the VID-alone method where more than $31,000 is saved for each ton of HC and NOx emitted. Thus, the cost-benefit analyses reveal that with the VID-alone method we can "sell" emissions for $31,573 per ton using Exempting and then use the money to "buy" emissions at $8,943 per ton using Directing (see Table 7-2) and at $5,385 per ton using Scrapping (see Table 7-4).

As shown in Table 7-3, when RSD is compared to other, similarly effective methods, the additional cost of using RSD to identify vehicles only for Exempting is not justified for California.

Tables A-9, A-10, A-11, A-12, and A-13 show the results of the cost-effective analysis for Exempting penetrations of 5%, 10%, 20%, 30%, and 40%. In general, the benefits lost increase rapidly as Exempting penetration increases.

7.4 Scrapping Vehicles

A vehicle retirement (Scrapping) program that operates like the one currently run by BAR would solicit the purchase of vehicles "off cycle" between their regular inspections. We simulated a program that would ask vehicle owners to come for a voluntary, "off-cycle" inspection, which we call a scrappage ASM. For the purposes of evaluating the benefits and costs of the simulated Scrapping program, we assumed that if a vehicle failed the scrappage ASM test, the vehicle would be purchased by the State for the market value of the vehicle. This approach allows us to estimate the average value of vehicles that would be targeted for Scrapping. Program administrators need to have estimates of vehicle values of scrappage candidates so that they can determine the size of vehicle purchase offers. Clearly, in the real application of a Scrapping strategy, the owner's perception of the value of his vehicle will be important in determining whether he will accept an offer. Vehicle owners will not likely accept an offer that does not include at least some above-market-value incentive.

The three vehicle selection methods evaluated in Table 7-4 use combinations of two data sources to target the vehicles: the Vehicle Information Database maintained by the Smog Check program, and RSD data collected on roadways in California. All three options targeted purchasing a group of vehicles with the largest mass emissions with a total fair market (Blue Book) value of approximately $16 million.

Table 7-4 shows the summary of the cost-benefit analysis for Scrapping. Targeting vehicles for Scrapping is based on the size of the budget allocated to purchasing vehicles for scrappage. The I/M simulator indicates that for a biennial scrappage budget of $16 million, approximately 0.24% to 0.62% of the I/M fleet would be targeted depending on the vehicle selection method. The second row in Table 7-4 shows the number of targeted vehicles that would fail the scrappage ASM test. The third row shows that vehicles targeted by RSD-alone would have a higher fail rate then either of the other two vehicle selection methods. The fourth and fifth rows of the table show the benefits for Δ Failed Miles Driven and total Δ FTP HC + NOx for the three vehicle selection methods. The largest benefits are seen for VID + RSD together. However, as we have seen for the other three strategies, the VID-alone method has benefits that are almost as good. The RSD-alone method, even though it demonstrates a higher ASM Fail Rate at Decision Point, has poorer performance because only 17% of the statewide I/M fleet is accessible by this large RSD measurement program. This RSD coverage limitation causes the selection of the scrappage candidate vehicles to cut deeper into the ranking than for the other two methods in order to spend the $16 million purchase budget. Thus, the RSD-alone method selects fewer vehicles for scrappage, and these vehicles on average are lower emitting and are higher valued than the vehicles selected by the other two methods.

The last row of Table 7-4 shows the average market value of the vehicles selected by each method. To have a hope of purchasing vehicles that fail the scrappage ASM test, the state will probably need to offer owners somewhat more than the market value of each vehicle. Thus, the State would need to offer more, on the average, for vehicles selected by RSD-alone than for vehicles selected by VID-alone or VID + RSD together. This consideration puts the RSD-alone method at a disadvantage in comparison with the other two methods.

The sixth row shows the total cost for the three methods. The costs for the VID-alone method are significantly lower than the cost for the other two methods, which include on-going RSD measurements of the on-road fleet. The cost-effectiveness in terms of $/ton are shown in the seventh row of Table 7-4. These values indicate that vehicle selection by VID-alone is cost-effective, but both methods that use RSD measurements are not cost-effective.

Tables A-14, A-15, A-16, and A-17 in Appendix A show the cost-effectiveness analysis results for biennial purchase budgets of $8, $16, $32, and $64 million.

Table 7-4. Cost-Benefit Summary for Scrapping[a,b]

		Vehicle Selection Method			
		VID alone	**RSD alone**	**VID+RSD together**	**Adding RSD to VID alone causes:**
Targeted Vehicles [c] (N)		58,908	31,803	56,230	
Targeted Vehicles that Fail ASM at Decision Point (N)		22,936	14,384	22,820	116 fewer vehicles to fail
ASM Fail Rate at Decision Point (%)		38.9%	45.2%	40.6%	
Benefits	**Δ Failed Miles Driven (miles/2years) [d]**	A decrease of **190,210,114** failed miles driven	A decrease of **133,180,660** failed miles driven	A decrease of **194,587,521** failed miles driven	A further decrease of **4,377,407** failed miles driven
Benefits	**Total ΔFTP HC+NOx (tons/2years) [f]**	A decrease of **3,478** tons	A decrease of **2,034** tons	A decrease of **3,527** tons	A further decrease of **49** tons
Total Costs ($/2years)		**$ 18,728,744** spent	**$ 81,325,746** spent	**$ 82,276,673** spent	A further increase of **$ 63,547,930** spent
Cost Effectiveness ($/ton HC+NOx) [h]		**$ 5,385** spent for each ton of emissions reduced	**$ 39,978** spent for each ton of emissions reduced	**$ 23,326** spent for each ton of emissions reduced	An additional **$ 1,286,021** spent for each additional ton of emissions reduced
Average Market Value of Targeted Vehicles ($)		$ 683	$ 1,053	$ 691	

[a] The costs and benefits presented in this table are for a large RSD measurement program that annually obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[b] The costs and benefits presented in this table are for a high-emitter Scrapping strategy that spends approximately $16,000,000 over two years to purchase vehicles for scrappage.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

7.5 Four Strategies in Combination

In the previous four sub-sections, we presented cost-benefit results for each strategy when each strategy is used by itself as a supplement to the existing I/M program. However, some types of costs – primarily the RSD measurement costs – can be shared by strategies if several strategies were used simultaneously. Accordingly, in this sub-section we report an additional cost-benefit analysis for the combined use of all four strategies. The effects of Calling-In, Directing, Exempting, and Scrapping were calculated at respective fleet targeting percentages of 5%, 40%, 20% and biennially spending $16 million for scrappage vehicle purchase.

The total benefits from the four strategies are shown in Table 7-5 and are based on the three vehicle ranking methods. The various values for number of targeted vehicles, number of targeted vehicles that would fail an ASM test at the decision point, and the ASM fail rate at the decision point are the same values that were presented in tables 7-1, 7-2, 7-3, and 7-4 for the corresponding strategies. The total emissions benefit of 10,461 tons/2years is largest for the VID + RSD method, while the best non-RSD ranking method (VID-alone) results in emissions benefits of 10,053 tons/2years – almost as large. Thus, the incremental benefits of the best RSD model over the best non-RSD model are about 408 tons/2years, which is about 0.07% of the I/M fleet biennial emissions inventory, but these incremental emissions reductions come at a significantly higher cost – $64,838,889 higher.

The costs for each aspect of the activity and the expected benefits are presented in Table 7-6. Note that for the VID-alone method, the total costs are dominated by the savings associated with the exemption of 20% of the fleet. By Exempting 20% of the fleet, we estimate that there is a savings of $83 million because a large part of the fleet does not get inspected. For the RSD models, the costs are dominated by the $63 million spent collecting RSD measurements in the five major AQMDs in the state, as well as by the $83 million savings from Exempting.

According to Table 7-5, the cost-effectiveness of the VID-alone method is attractive at only about $3,200 per ton. On the other hand, the cost-effectiveness of the VID + RSD method is $9,314/ton of HC and NOx emissions. While this is nearly three times higher than the cost-effectiveness of the VID-alone method, it is a substantial improvement over the VID + RSD method values when strategies were considered singly in the previous four sub-sections and is a

Table 7-5. Cost-Benefit Summary for Calling-In, Directing, Exempting, Scrapping[a,b]

		Vehicle Selection Method			
		VID alone	**RSD alone**	**VID+RSD together**	**Adding RSD to VID-alone causes:**
Targeted Vehicles [c] (N)		Various See Table B-3	Various See Table B-3	Various See Table B-3	
Targeted Vehicles that Fail ASM at Decision Point (N)		Various See Table B-3	Various See Table B-3	Various See Table B-3	
ASM Fail Rate at Decision Point (%)		Various See Table B-3	Various See Table B-3	Various See Table B-3	
Benefits	**Δ Failed Miles Driven (miles/2years) [d]**	A decrease of **1,613,638,558** failed miles driven	A decrease of **275,561,141** failed miles driven	A decrease of **1,673,813,774** failed miles driven	A further decrease of **60,175,216** failed miles driven
Benefits	**Total ΔFTP HC+NOx (tons/2years) [f]**	A decrease of **10,053** tons	A decrease of **2,793** tons	A decrease of **10,461** tons	A further decrease of **408** tons
Total Costs ($/2years)		**$ 32,599,772** spent	**$ 86,054,087** spent	**$ 97,438,659** spent	A further increase of **$ 64,838,889** spent
Cost Effectiveness ($/ton HC+NOx) [h]		**$ 3,243** spent for each ton of emissions reduced	**$ 30,811** spent for each ton of emissions reduced	**$ 9,314** spent for each ton of emissions reduced	An additional **$ 158,877** spent for each additional ton of emissions reduced

[a] The costs and benefits presented in this table are for a large RSD measurement program that annually obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[b] The costs and benefits presented in this table are for a high-emitter Calling-In strategy that targets 5% of the I/M fleet, a high-emitter Directing strategy that targets 40% of the I/M fleet, a low-emitter Exempting strategy that targets 20% of the I/M fleet, and a Scrapping strategy that spends approximately $16,000,000 over two years to purchase vehicles for scrappage.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

Table 7-6. Cost Details for the Four Strategy Combination

Cost Items ($/2years)		Vehicle Selection Method			Incremental RSD Cost (VID+RSD over VID)
Penetration	Strategy	VID alone	RSD alone	VID+RSD together	
Central Office					
5%	Calling-In No-Sticker	$6,884,584	$4,281,405	$7,178,438	$293,854
40%	Directing				
20%	Exempting				
16M$	Scrapping				
RSD Measurements					
5%	Calling-In No-Sticker	$0	$63,276,265	$63,276,265	$63,276,265
40%	Directing				
20%	Exempting				
16M$	Scrapping				
Notice					
5%	Calling-In No-Sticker	$2,008,210	$340,742	$2,008,210	$0
40%	Directing	$0	$0	$0	$0
20%	Exempting	$0	$0	$0	$0
16M$	Scrapping	$176,723	$95,408	$168,690	($8,033)
Certificate					
5%	Calling-In No-Sticker	$0	$0	$0	$0
40%	Directing	$0	$0	$0	$0
20%	Exempting	$0	$0	$0	$0
16M$	Scrapping	($189,220)	($118,670)	($188,261)	$959
Inspection					
5%	Calling-In No-Sticker	$33,470,173	$5,679,033	$33,470,173	$0
40%	Directing	$0	$0	$0	$0
20%	Exempting	($83,006,028)	($14,084,001)	($83,006,028)	$0
16M$	Scrapping	$2,945,375	$1,590,129	$2,811,494	($133,881)
Repair					
5%	Calling-In No-Sticker	$30,152,846	$6,715,313	$31,200,589	$1,047,744
40%	Directing	$22,325,603	$4,482,830	$22,939,542	$613,939
20%	Exempting	$5,095,806	$345,963	$4,725,082	($370,724)
16M$	Scrapping	($3,337,149)	($2,092,905)	($3,320,241)	$16,908
Vehicle Purchases					
5%	Calling-In No-Sticker	$0	$0	$0	$0
40%	Directing	$0	$0	$0	$0
20%	Exempting	$0	$0	$0	$0
16M$	Scrapping	$15,672,716	$15,142,381	$15,774,574	$101,858
Model Update & Maintenance					
5%	Calling-In No-Sticker	$400,000	$400,000	$400,000	$0
40%	Directing				
20%	Exempting				
16M$	Scrapping				

consequence of sharing the RSD measurement cost among the four strategies. While the cost-effectiveness of VID + RSD meets the Carl Moyer criterion, almost all of its cost-effectiveness is a result of VID information: 96% (=10,053/10,461) of the emissions benefits and only 33% (=$32,599,772/$97,438,659) of the costs are derived from the VID information. Adding the RSD information buys only slightly more tons of emissions at great cost. And the cost-effectiveness of RSD-alone at $30,800/ton does not come close to the Carl Moyer criterion of $14,300/ton.

Table 7-5 provides the cost-benefit analysis results for the large RSD program coverage of the fleet, that is, at 50% any-VSP RSD coverage. Appendix B provides the same results for smaller RSD programs that have 10% and 30% any-VSD RSD coverage.

7.6 Three Strategies in Combination

The previous sub-section presented the cost-benefit analysis results for a combination of all four strategies. The cost-benefit results for the situations when each strategy was used by itself indicated attractive results for the VID-alone method for Directing, Exempting, and Scrapping. On the other hand, the cost-benefit results for Calling-In were not attractive for any of the three vehicle selection methods. The most cost-effective implementation for Calling-In was nearly $16 thousand per ton of HC + NOx. This suggests that the use of a package of the three attractive strategies might be even more cost beneficial than the combination of all four strategies. Accordingly, in this sub-section, we present the cost-benefit results for a combination of strategies made up of Directing, Exempting, and Scrapping.

Table 7-7 shows the benefits, costs, and cost-effectiveness numbers for this combination using the same vehicle targeting percentages as have been used previously. The only difference is that the cost and benefits for Calling-In have not been included. The table shows that the benefits of Δ Failed Miles Driven and Δ FTP HC + NOx are the largest for the VID + RSD method, but the benefits for the VID-alone method are almost as large. The RSD-alone method does not perform as well, just as we have seen for all other cost-benefit analyses in this study. The individual costs for this combination of three strategies are summarized in Table 7-8. Except for central office costs and the costs specific to Calling-In, these values are the same values as were shown in Table 7-6 for the four strategy combination. The resulting total costs shown in Table 7-7 indicate a large cost <u>savings</u> for the VID-alone vehicle selection method. For the RSD-alone and VID + RSD methods, the total costs are large since they are dominated by the cost of the RSD measurement program.

Table 7-7. Cost-Benefit Summary for Directing, Exempting, Scrapping[a, b]

		Vehicle Selection Method: VID alone	Vehicle Selection Method: RSD alone	Vehicle Selection Method: VID+RSD together	Adding RSD to VID-alone causes:
Targeted Vehicles [c] (N)		various	various	various	
Targeted Vehicles that Fail ASM at Decision Point (N)		various	various	various	
ASM Fail Rate at Decision Point (%)		various	various	various	
Benefits	**Δ Failed Miles Driven (miles/2years) [d]**	A decrease of **641,191,378** failed miles driven	A decrease of **202,784,650** failed miles driven	A decrease of **678,687,499** failed miles driven	A further decrease of **37,496,121** failed miles driven
Benefits	**Total ΔFTP HC+NOx (tons/2years) [f]**	A decrease of **5,459** tons	A decrease of **2,236** tons	A decrease of **5,738** tons	A further decrease of **279** tons
Total Costs ($/2years)		A savings of **$ 36,855,875**	**$ 72,070,538** spent	**$ 26,935,269** spent	A further increase of **$ 63,791,145** spent
Cost Effectiveness ($/ton HC+NOx) [h]		A savings of **$ 6,752** for each ton of emissions reduced	**$ 32,235** spent for each ton of emissions reduced	**$ 4,694** spent for each ton of emissions reduced	An additional **$ 228,563** spent for each additional ton of emissions reduced

[a] The costs and benefits presented in this table are for a large RSD measurement program that annually obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[b] The costs and benefits presented in this table are for a high-emitter Directing strategy that targets 40% of the I/M fleet, a low-emitter Exempting strategy that targets 20% of the I/M fleet, and a Scrapping strategy that spends approximately $16,000,000 over two years to purchase vehicles for scrappage.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

Table 7-8. Cost Details for the Three Strategy Combination

Cost Items ($/2years)		Vehicle Selection Method			Incremental RSD Cost (VID+RSD over VID)
Penetration	Strategy	VID alone	RSD alone	VID+RSD together	
Central Office					
0%	Calling-In No-Sticker	$3,060,165	$3,032,944	$3,354,019	$293,854
40%	Directing				
20%	Exempting				
16M$	Scrapping				
RSD Measurements					
0%	Calling-In No-Sticker	$0	$63,276,265	$63,276,265	$63,276,265
40%	Directing				
20%	Exempting				
16M$	Scrapping				
Notice					
0%	Calling-In No-Sticker	$0	$0	$0	$0
40%	Directing	$0	$0	$0	$0
20%	Exempting	$0	$0	$0	$0
16M$	Scrapping	$176,723	$95,408	$168,690	($8,033)
Certificate					
0%	Calling-In No-Sticker	$0	$0	$0	$0
40%	Directing	$0	$0	$0	$0
20%	Exempting	$0	$0	$0	$0
16M$	Scrapping	($189,220)	($118,670)	($188,261)	$959
Inspection					
0%	Calling-In No-Sticker	$0	$0	$0	$0
40%	Directing	$0	$0	$0	$0
20%	Exempting	($83,006,028)	($14,084,001)	($83,006,028)	$0
16M$	Scrapping	$2,945,375	$1,590,129	$2,811,494	($133,881)
Repair					
0%	Calling-In No-Sticker	$0	$0	$0	$0
40%	Directing	$22,325,603	$4,482,830	$22,939,542	$613,939
20%	Exempting	$5,095,806	$345,963	$4,725,082	($370,724)
16M$	Scrapping	($3,337,149)	($2,092,905)	($3,320,241)	$16,908
Vehicle Purchases					
0%	Calling-In No-Sticker	$0	$0	$0	$0
40%	Directing	$0	$0	$0	$0
20%	Exempting	$0	$0	$0	$0
16M$	Scrapping	$15,672,716	$15,142,381	$15,774,574	$101,858
Model Update & Maintenance					
0%	Calling-In No-Sticker	$400,000	$400,000	$400,000	$0
40%	Directing				
20%	Exempting				
16M$	Scrapping				

In terms of cost-effectiveness, the VID-alone combination of three strategies is particularly attractive since the benefits of Δ Failed Miles Driven and Δ FTP HC + NOx are almost as large as the best vehicle ranking method, which is VID + RSD, yet the VID-alone method saves almost $37 million every two years.

Table 7-7 shows that attempting to improve the VID-alone method by supplementing the VID information with RSD information is not cost-effective. The calculations in the last column indicate that for each additional ton of emissions reduced with supplemental RSD information, the cost increases by a quarter of a million dollars. We have found this cost-effectiveness value to be independent of the size of the RSD program. Therefore, using a small RSD program to identify a few vehicles for these strategies is still not cost-effective.

8.0 Evaluation of RSD's Ability to Characterize Fleet Emissions

Two of the pilot study questions involve investigating RSD's ability to measure the on-road exhaust emissions of the fleet and subsets of the fleet. These questions are specifically targeted at uses of RSD measurements that are not related to targeting individual vehicles for individual treatment such as in special strategies. This section discusses RSD's ability to characterize the emissions of the on-road fleet in general, to evaluate the I/M program, and to verify the benefits of emission-reduction strategies. This includes evaluation of vehicles that are not participating in the I/M program such as out of area and out of state vehicles.

For an on-road test to be effective at characterizing the tailpipe emissions of the fleet and subsets of the fleet, it must have certain attributes. RSD developers and analysts have been working for several years to ensure that RSD measurements are taken in such a way that they meet these attributes:

1) The test needs to provide an unbiased measure of on-road tailpipe emissions across the full range of emission levels. For characterizing the emissions of a fleet, it doesn't matter greatly if the test provides measurements that are randomly scattered around the characteristic emissions values of vehicles. The reason for this is that averaging large numbers of measurements will produce average emissions levels with low uncertainty.

2) The test needs to cover a representative sample of the fleet. This includes all vehicle types, emission control system technologies, and ages. It is alright if the sample obtained randomly is somewhat unrepresentative of the fleet as long as the bias in the sample can be estimated and then corrected. An example of this is the bias in the model year distribution that occurs in RSD samples which is caused by the well-known tendency of new vehicles to have higher annual vehicle miles traveled.

3) The test must be performed either at the operating modes that the vehicles use or at a subset of operating modes that produce emissions characteristic of emissions at the operating modes that the vehicles use. This attribute is also one of sample representativeness.

4) The test must be conducted without vehicle owners knowing in advance that their vehicles will be tested. This attribute is required so that vehicle owners do not perform pretest repairs and, therefore, bias the results of the measurements.

5) The test must be conducted without the possibility that the test operator can influence the outcome of the test.

6) The test must be performed so that vehicles are sampled at random times with respect to their I/M cycles.

If the on-road test results are to be used to estimate emissions inventory, there is an additional requirement:

7) The test result must be convertible to a mass emissions basis so that the mass emissions of individual vehicles can be summed to get the inventory. This means that the relative usage of different vehicles needs to be available for the calculation. Two commonly used measures of vehicle usage are vehicle miles traveled and fuel consumed.

As discussed in the remainder of this section and in Section 9, we believe that RSD meets the above requirements reasonably well. However, RSD is not the only test that can be used to characterize fleet emissions. California has considerable experience with random roadside pullover ASM emissions testing. While RSD and roadside ASMs can both be used to characterize fleet emissions, they each have their individual mix of attributes where they excel. In particular, RSD obtains a large number of one half second emissions snapshots of vehicles in a variety of operating modes at a relatively low cost per test. On the other hand, roadside ASM testing acquires 90-second snapshots of emissions on a smaller number of vehicles at a higher cost per test but under controlled operating modes. We have not performed comparative cost-benefit analyses of these two competing methods for this study.

In the subsections below, we examine a few different ways that RSD can be used to evaluate the I/M program and to characterize emissions of the fleet in general.

8.1 Using RSD to Evaluate the I/M Program

For RSD data to be used to evaluate the IM program, it must characterize the emissions of the fleet. RSD takes a snapshot measurement (less than one-second) of a vehicle's exhaust. Much like a photographic portrait taken while the subject is blinking, an RSD measurement may not be a fair representation of the vehicle's normal condition unless it is carefully taken and analyzed.

One question from the objectives of this project is whether remote sensing data can be used to independently verify the emission reductions achieved by Smog Check. Indicating a federal acceptance of this concept is the fact that USEPA has published guidance [5] summarizing three methods to estimate I/M benefits using RSD. The Step Method compares on-road emissions before and after a change in an I/M program. The Comprehensive Method compares on-road emissions as a function of time before and after I/M testing. The Reference Method compares on-road emissions of vehicles in an I/M area with those of vehicles in a non-I/M area.

South Coast I/M change example – As an example of how RSD can be used to help quantify the exhaust emissions reductions of Smog Check we have used the South Coast basin as a test subject. Although it is not representative of the entire state, an ample RSD data set was collected in the South Coast region during the pilot project, so it provides enough data for these types of analyses. About 236,000 readings in the SCAQMD were from vehicles in the appropriate driving mode for this analysis.

We compared fleet-average RSD concentrations from vehicles that have been through the Enhanced Smog Check program to emissions from vehicles that have never been through the Enhanced program such as newly registered vehicles or those registered in Basic I/M areas but driving in the SCAQMD. Figure 8-1 indicates that in the South Coast basin, vehicles that had not yet received an Enhanced Smog Check have higher HC and NOx (especially for light trucks), but the same or lower CO, than vehicles that were measured on-road after an Enhanced Smog Check. By this measure both the cars and trucks seem to have CO emissions relatively unchanged by Enhanced I/M, but the HC and NOx emissions seem to be significantly reduced by the program, especially for the trucks. Since cars and trucks are represented about equally in the fleet, the average of these results is a good approximation of what would be calculated by combining the data of the two vehicle types. The reductions indicated for HC (about an 11% average) and NOx (about a 13% average) are comparable with those presented in the most recent Smog Check Evaluation [6] and we found them to be statistically significant. However, the CO results are quite different. The last Smog Check evaluation by ARB and BAR estimated a statewide, fleet-average reduction of about 14%, while these RSD results indicate no such reduction.

Use of RSD to quality assure analysis methods – Another way RSD can be used to help evaluate the Smog Check program is as an independent means of quality assuring other analysis methods. Results from the pilot study indicate that older vehicles driving past surface street sites are different from older vehicles driving on the freeway. Since a great deal of the benefits of Smog Check come from older vehicles, it is important that this possible difference be investigated.

Figure 8-1. Comparison of SCAQMD cars and trucks not in Smog Check to those having been through Smog Check (up to one-year ago)

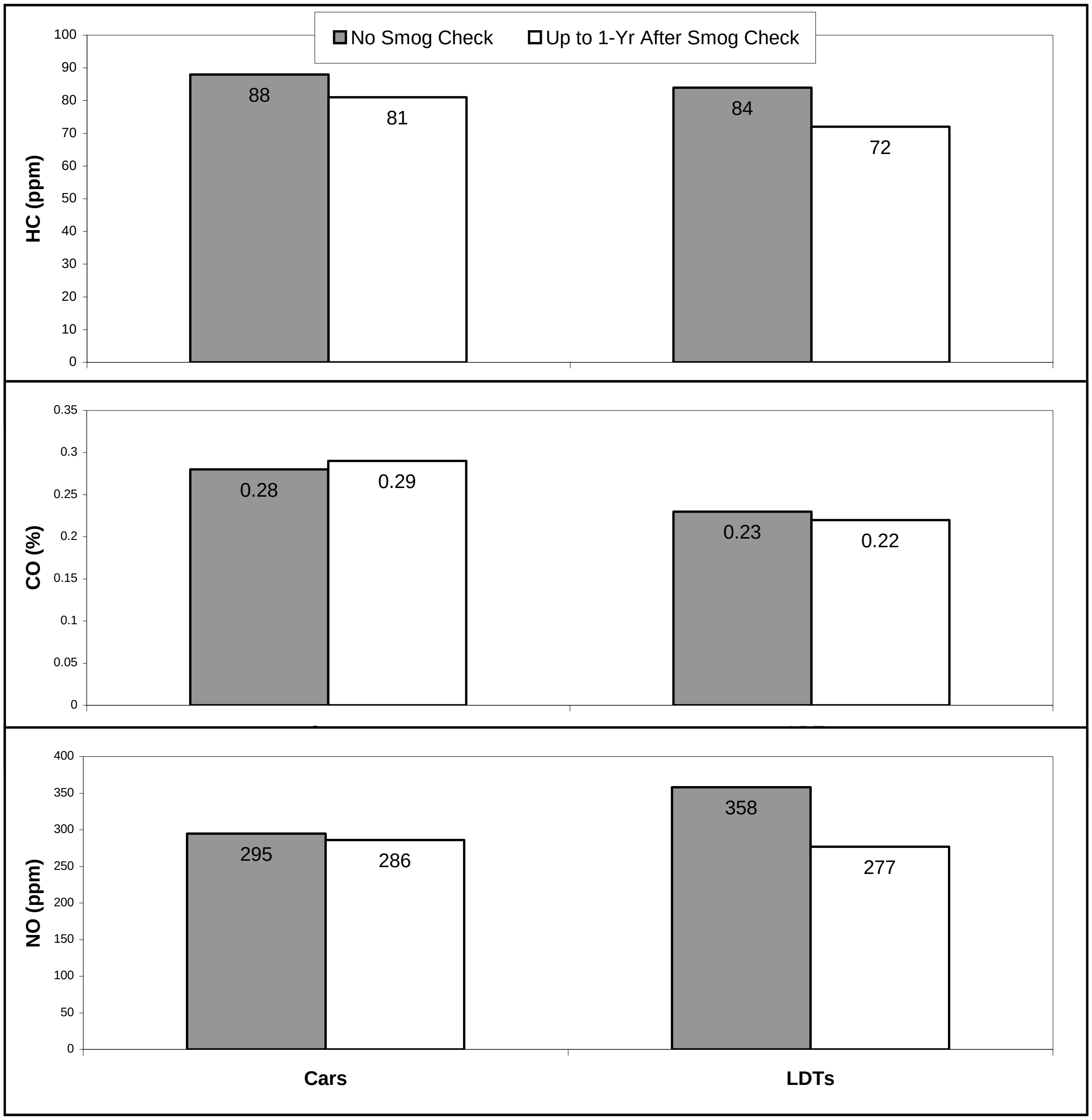
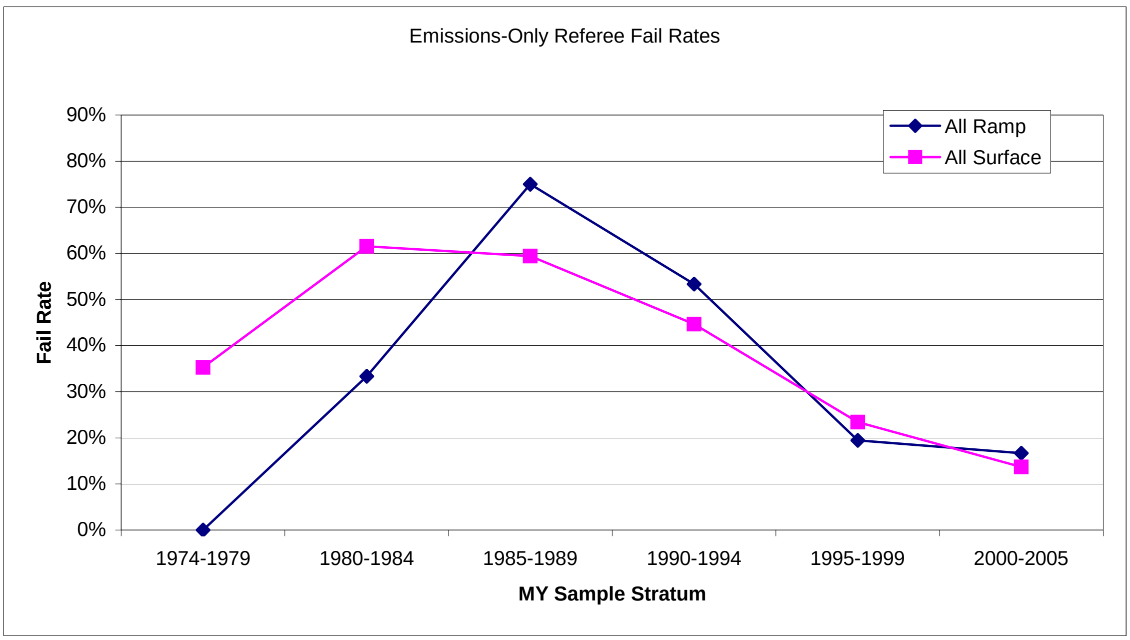


Figure 8-2 shows the average ASM emissions fail rates of vehicles that were observed by RSD at freeway ramp sites and at surface street sites. These fail rates are based on voluntary follow-up I/M tests conducted at referee facilities. In the older model years, the vehicles traveling on freeway ramps have significantly lower average fail rates than vehicles traveling on surface streets. These trends are supported by the RSD data for these vehicles, as the ramp RSD measurements were significantly lower than the surface street measurements. They are also supported by the visual and tampering inspection results in that the older surface street vehicles had much higher overall fail rates than the ramp vehicles, whose overall fail rates were about the same as their emissions-only fail rates. We conclude that, on a model year basis, the average surface street fleet is significantly different than the average freeway ramp fleet.

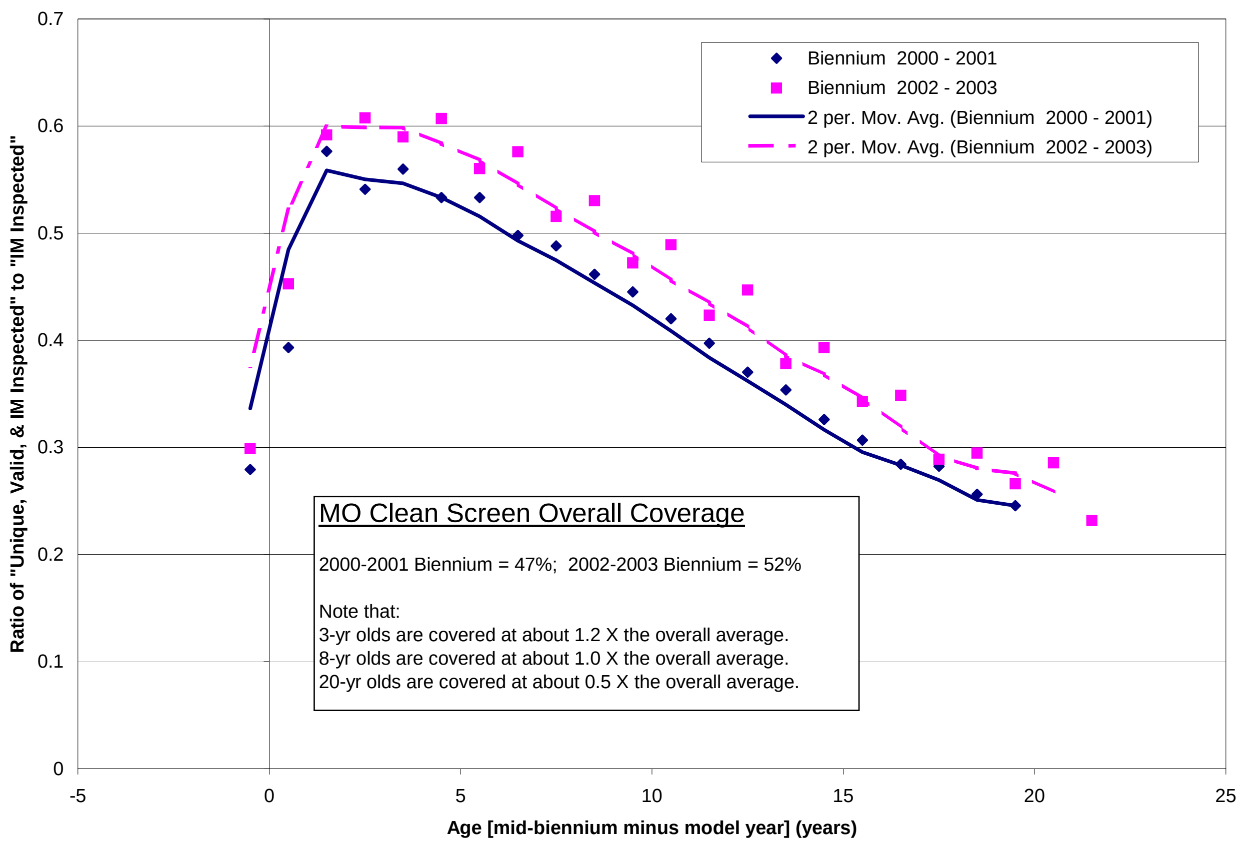
Figure 8-2. Emissions-Only Fail Rates, by Model Year Group, of Freeway Ramp and Surface Street Vehicles



8.2 Using RSD to Characterize Fleet Emissions

Determination of age characteristics of the on-road fleet – One benefit of the way RSD is collected (from an analyst's point of view) is that vehicles that are driven the most are also measured the most. Figure 8-3 contains data from the Missouri RSD clean screen program. The data show the ratio of unique RSDed vehicles that are identified in the I/M data for a particular age to all the vehicles in the I/M data for that age. This is shown for the 2000-2001 and 2002-2003 bienniums. They obtain valid measurements on about half of the fleet that is subject to I/M. But as the curves show, more than half of the new model year vehicles (where the bulk of the fleet and the miles traveled are located) are measured, while less than a third of the oldest vehicles are measured. Unfortunately, the oldest vehicles also pollute the most for every mile they travel, so it is important to collect data on a sufficiently large sample of these vehicles.

Figure 8-3. Variation in RSD Coverage with Vehicle Model Year (from the Missouri Clean Screen Program)
(Data source: Applied Analysis)



Estimation of fleet inventory – As an example of how RSD can be used to characterize the fleet, we estimated the light-duty and medium-duty vehicle exhaust emissions inventory for the South Coast air basin using on-road exhaust emission factors from RSD (i.e., not including cold-start emissions). We used all remote sensing measurements of vehicles registered in the South Coast basin, and two independent sources of vehicle activity: the number of vehicles, average annual miles driven, and average fuel economy, by vehicle type and model year, from the EMFAC model; and estimated total gasoline use in the South Coast (obtained from fuel tax receipts reported by the California Board of Equalization). Both estimates use the same set of emission factors, from the remote sensing measurements; however, the EMFAC-based estimate is disaggregated by vehicle type and model year, and then summed to obtain the emission inventory, while the fuel-based estimate uses the weighted average gram per gallon emission factors for the on-road fleet, calculated from the RSD data. The fuel-based estimate multiplies the fleet-average gram-per-gallon emission factors by the estimated South Coast fuel consumption (we attributed 41% of statewide fuel consumption to vehicles in the South Coast, based on the South Coast portion of the statewide vehicle miles traveled for light-duty and medium-duty cars and trucks).

Table 8-1 shows the estimated exhaust emission inventory for light-duty and medium-duty vehicles using these two methods. For THC and CO, the fuel-based inventory is almost identical to that estimated using the EMFAC vehicle activity numbers; however, the fuel-based inventory estimates 16% more NOx emissions. Note that the EMFAC-based estimate only accounts for 1972 through 2004 vehicles; including vehicles older or newer than these model years would slightly increase the estimated emissions inventory. The fuel-based emissions inventory does not account for the small fraction of non-gasoline fuel consumption; previous estimates excluded the roughly 3% of fuel sales attributable to non-gasoline fuels. Excluding non-gasoline fuel use would slightly reduce the fuel-based emission inventory.

Table 8-1. Estimated 2004 Inventory for the South Coast Basin, using RSD and Two Sources of Vehicle Activity

	Tons per day		Difference between fuel-based and EMFAC-based estimates
Pollutant	Number of vehicles, vehicle use, and vehicle fuel economy from EMFAC model	Vehicle use from South Coast portion of statewide fuel sales	
THC	143	144	1%
CO	1,478	1,480	0%
NOx	152	177	16%

Table 8-2 compares the fuel consumption based inventory estimated in Table 8-1 with the official 2004 inventory for "hot-stabilized" light-duty and medium-duty vehicles in the South Coast basin. We use hot-stabilized emissions to compare against because in this study RSD was only used to measure exhaust from warmed-up vehicles. Other emissions not measured by RSD (such as cold-start and evaporative emissions) can be a substantial portion of the official inventory, but they are usually not measured by RSD so we do not include them here. For THC the official inventory estimates substantially lower emissions than our estimate (by about 45%), but for CO and NOx, the official inventory estimate is higher by about 20%. According to research by the University of Denver, fuel consumption based emission inventories from RSD data have an uncertainty in the area of +/-18% for THC, +/-15% for CO and +/-11% for NOx [7].

This indicates that the differences between these predictions are likely to be real and not a result of variability in the data.

Table 8-2. Comparison of RSD Based and Official Inventory for 2004 South Coast Basin

Estimate	Vehicle type	Tons per day		
		THC	**CO**	**NOx**
Estimate using remote sensing and South Coast Fuel Sales	Light & Med Cars & Trucks	144 +/- 26	1480 +/- 20	177 +/- 19
Official EMFAC “hot stabilized” emission inventory	Light & Med Cars & Trucks	99.9	1930	213
Difference (EMFAC to RSD/Fuel Based)	Light & Med Cars & Trucks	44%	-23%	-17%

To determine whether the differences originate from assumptions in the RSD based inventory or in EMFAC, or in both, would require some research. Sensitivity analyses of assumptions would help pinpoint important questions for further research. Tracking these differences over a period of years would also help build experience with the RSD based method and help determine whether the method could be improved with changes in assumptions and/or the way the data are analyzed.

Determination of weekday/weekend vehicle emissions distributions – As an example of how RSD can be used to monitor traffic emissions during weekday and weekend travel we again use the South Coast basin as our test case. Figures 8-4 through 8-6 show the average RSD exhaust emissions of on-road vehicles registered in the South Coast basin, by model year, but separated into measurements taken during weekdays (dotted line) and those taken on weekends (solid line). Vehicles measured on weekends have marginally lower or about the same HC and CO emissions as vehicles measured on weekdays. However, vehicles measured on weekends have consistently and significantly lower NOx emissions than vehicles measured on weekdays.

Figure 8-4. Average On-Road ppm HC Exhaust Concentrations Of Vehicles Measured On Weekdays And Weekends, By Model Year

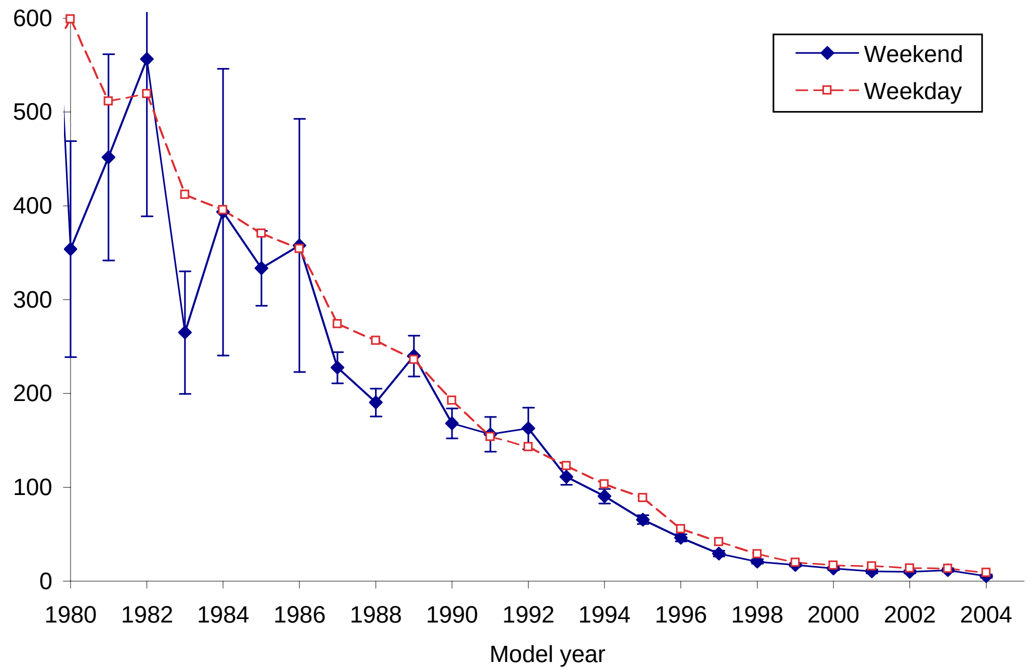


Figure 8-5. Average On-Road % CO Exhaust Concentrations Of Vehicles Measured On Weekdays And Weekends, By Model Year

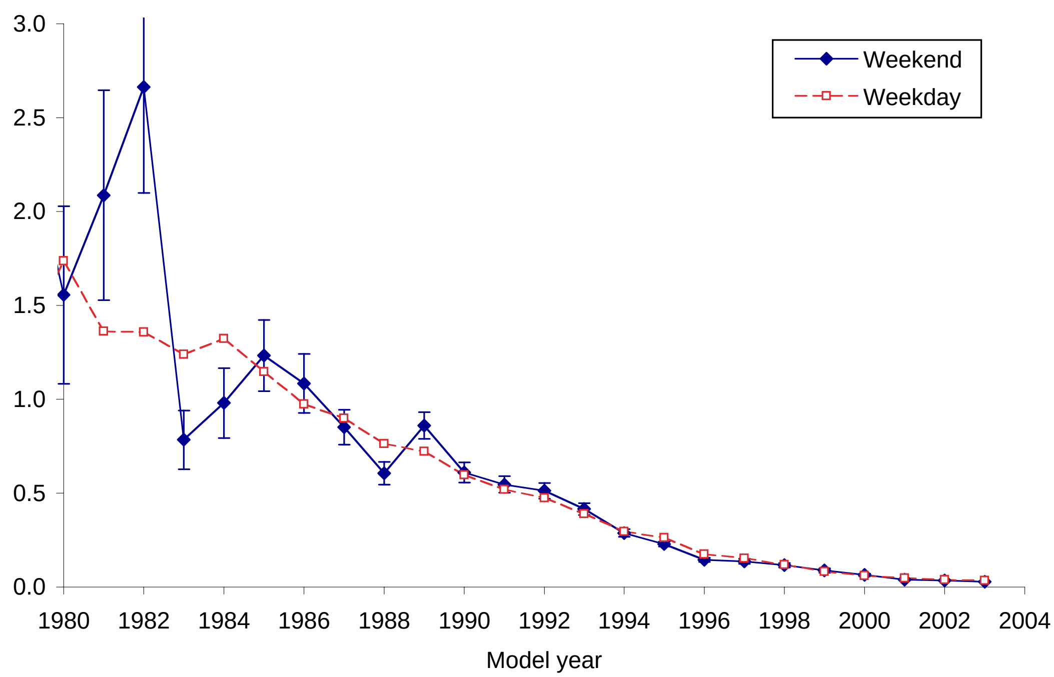
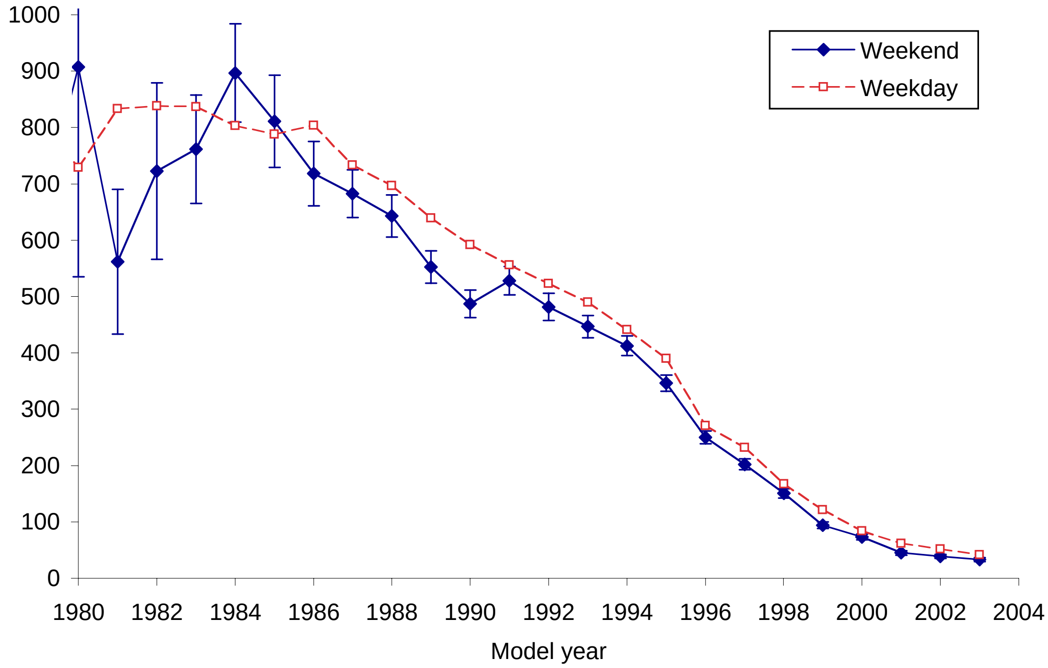


Figure 8-6. Average On-Road ppm NOx Exhaust Concentrations Of Vehicles Measured On Weekdays And Weekends, By Model Year



Although it is by no means conclusive, this result seems to validate current thinking on the mechanism behind elevated ozone levels during the weekend. It has been postulated that lower NOx during the weekends leads to higher ozone because of the chemical reaction kinetics of how ozone is formed [8]. Ambient HC/NOx ratio differences can produce conditions that either promote or inhibit the formation of ozone. Lower weekend NOx emissions are speculated to be due to less commercial (i.e., diesel) traffic and less congestion (i.e., stop and go driving) on the weekends.

9.0 Discussion

Our analysis presented in Section 7 indicates that adding an RSD measurement component to the existing California I/M program would not cost-effectively improve strategies that target individual vehicles such as Calling-In, Directing, Exempting, and Scrapping. On the other hand, in Section 8 we found that RSD measurements can be an important source of information to measure the on-road tailpipe emissions of large groups of vehicles in the fleet and subsets of the fleet. On the surface, these conclusions seem to be inconsistent and cause an important question to arise:

Why is RSD not cost-effective for selecting individual vehicles for supplemental I/M strategies, while RSD is effective for measuring the average exhaust emissions of large groups of fleet vehicles?

Based on our experience performing the analyses in this study, it is apparent that the answer to this question centers primarily around four factors:

1) The inherent temporal emissions variability of each individual vehicle.

2) Use of the I/M station emissions test as a validation of vehicle selection.

3) Low usable-RSD coverage of the statewide I/M fleet.

4) High RSD data collection cost.

Each of the above four factors hurt RSD's ability to effectively and cost-effectively select individual vehicles for special strategies that supplement the existing I/M program. On the other hand, none of the factors harms RSD's ability to measure the average exhaust emissions of large vehicle groups in the fleet.

First, for selecting individual vehicles for special strategies, the inherent time-varying emissions of individual vehicles – present even when vehicle operation and environmental factors are constant – cause a poor agreement between the on-road RSD emissions measurement and the result of a validation ASM test that is performed at an I/M station. Other sources of variability also contribute to the poor correlation. Second, even the largest practical RSD program designed to cover vehicles in the five largest AQMDs would provide only about 17% of the vehicles in the statewide I/M fleet with at least one RSD measurement. The loss of usable-RSD information because of the poor correlation between RSD and the I/M station validation test and because of low I/M fleet coverage makes the RSD data collection cost to cover the five largest AQMDs high relative to the emissions reduction benefits that can be obtained.

On the other hand, using RSD to characterize fleet emissions is not hampered by any of the four items listed above. Because RSD can sample the emissions of a large group of vehicles at different times, the average of the measurements is close to the average of the inherent emissions of the group of vehicles even though individual vehicles have time-varying emissions. When RSD is used to measure fleet emissions, a validation of emissions measurements by a second test is not required as long as the RSD measurements are unbiased, which can be monitored through regular audits of the RSD instruments. For fleet characterization, it is not necessary to cover the majority of the vehicles in the fleet; only a representative sample of vehicles in the fleet needs to be measured. Finally, the cost of an RSD data collection program of the size needed to adequately characterize the emissions of the fleet does not need to be tremendously high because only a representative sample of the fleet is required.

In this section, we discuss the inherent variability of emissions and issues related to the comparison of two variable measurements (RSD and ASM), and the attributes of RSD that make it good for characterizing fleet emissions and those that make it less effective for incrementally identifying individual vehicles for special strategies.

Section 9.1 discusses and contrasts the sources of variability in emissions measurements when using RSD for individual vehicle selection and when using RSD for fleet characterization. Then, Section 9.2 describes the variability of individual ASM measurements and individual RSD measurements taking into account the time-varying nature of individual vehicle emissions as well as the errors inherent in ASM and RSD instruments. Section 9.3 examines the scattered relationship between RSD measurements and near-simultaneous roadside ASM measurements taken on individual vehicles in this study. The section goes on to compare roadside ASM measurements with subsequent I/M station ASM measurements both at referee I/M stations and regular I/M stations. Section 9.4 discusses fleet coverage by RSD. Section 9.5 goes into more detail in discussing the reasons that RSD was not successful at cost-effectively identifying individual vehicles for special strategies. Finally, Section 9.6 discusses the reasons that RSD is effective at measuring fleet exhaust emissions and evaluating I/M programs.

9.1 Sources of Variability in Emissions Measurements

RSD for individual vehicle selection – In each special strategy, RSD is expected to identify vehicles that are likely to fail an I/M station ASM test and to estimate the mass emissions rate of vehicles at the inspection. When used as a source of information to select individual vehicles for special strategies, RSD is hampered by at least nine sources of variability:

Source 1) The time-varying nature of vehicle emissions, Source 2) RSD instrumental error,

Source 3) Vehicle operation variability during an RSD emissions test,

Source 4) ASM instrumental error,

Source 5) Vehicle operation variability during an ASM emissions test,

Source 6) Differences in ASM test accuracy among I/M stations,

Source 7) Vehicle pre-inspection repairs between the RSD test and the I/M station ASM test,

Source 8) Differences in the emissions response of a vehicle to RSD and ASM tests,

Source 9) The elapsed time between the RSD test and the ASM test.

We believe that because of the above sources of variability, the RSD measurement loses a large part of its ability to predict individual vehicle ASM results obtained at I/M stations. As a consequence, when used for that purpose, a vehicle's elevated RSD measurement becomes more of an ASM "risk factor" than a guarantor of ASM failure. When used for this purpose, RSD is not much better than any other method, such as VID History, but RSD is more expensive.

We believe that RSD's difficulty in forecasting I/M station ASM failures is not a fault of the RSD test or technique but is a consequence of the sources of variability listed above. Accordingly, we expect that probably no test – not ASM, not IM240, and not even FTP – could forecast I/M station ASM failures of individual vehicles with the accuracy needed to significantly improve upon predictions made by the VID-alone.

RSD for fleet characterization – However, when RSD measurements are used to characterize the fleet or evaluate the I/M program, the situation is entirely different. The RSD technique was originally designed to measure the on-road emissions of vehicles – not to forecast the I/M station emissions results of individual vehicles. For fleet characterization, RSD is used to determine, through averaging, the average on-road emissions of large groups of vehicles, and in this situation only the first three sources of variability apply:

Source 1) The time-varying nature of vehicle emissions,

Source 2) RSD instrumental error, and

Source 3) Vehicle operation variability during an RSD emissions test.

The other five sources of variability (Sources 4 through 8) go away because they relate to ASM measurements. When RSD is used to characterize the on-road emissions of the fleet, the ASM results that might be obtained are not relevant.

When large numbers of RSD measurements are taken, the averages of the measurements have relatively small errors. With proper RSD data collection and analysis, California can obtain valuable information for characterizing the on-road emissions of sub-fleets. This information can be used to independently evaluate the I/M program or can be used for a variety of other uses, for example, to evaluate I/M station performance.

9.2 Variability of Individual ASM and RSD Measurements

While the measurement error of emissions instrumentation and variations in the emissions test procedure contribute to the variability in the measured emissions value, a main cause of the variability in measured emissions is the inherent variability of the "true" emissions of the vehicle (Source 1). The true emissions of an individual vehicle vary widely with time as a result of changes in vehicle driving mode, fuel and environmental factors, and the internal operation of the engine and emission control systems. Because of this underlying variability in the true emissions of the vehicle, subsequent measurements of the emissions of the same vehicle, even by the same type of test, will vary considerably. In this subsection, we provide evidence to quantify instrumental and procedural variability of ASM and RSD emissions and vehicle emissions variability.

Measurement Variability of ASM and RSD Instruments – ASM instrumental variability (Source 4) and RSD instrumental variability (Source 2) affect the ability of RSD to predict I/M station ASM results. ASM and RSD instrument manufacturers publish specifications that define the variability of measurements produced by their instruments in a dry gas audit situation. These specifications are intended to quantify the inaccuracies and uncertainties associated with just the instrumental measurement process itself. That is, the specs do not include any sources of variability that arise from the vehicle or vehicle exhaust.

Table 9-1 gives the acceptance test criteria for the measurement of ASM emissions in the BAR-97 Instrument Emissions Inspection System Specifications. These values provide an idea of the uncertainty when dry cylinder gas is measured with the instrument.

Table 9-1. Acceptance Criteria for ASM Concentration Measurements

C_6H_{14} ± 5ppm or ± 3.40% of reading, whichever is greater CO ± 0.03% or ± 3.32% of reading, whichever is greater NO ± 27ppm or ± 4.25% of reading, whichever is greater

Table 9-2 gives the relative accuracy specification given by the manufacturer for ESP's Accuscan RSD4000 instrument, which was used in this pilot study. These RSD specifications apply to dry gas audit conditions, that is, when the RSD instrument is measuring a simulated dry gas stream, which is created by cylinder gases emitted from the simulated tailpipe of a moving audit gas truck.

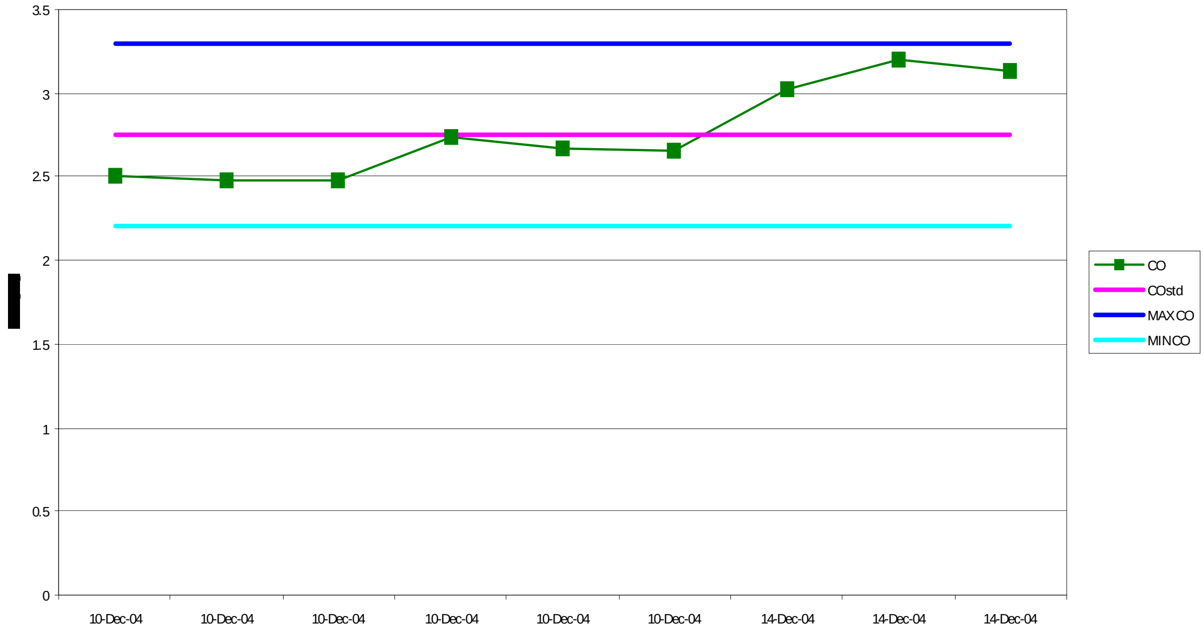
Table 9-2. Relative Accuracy for the Accuscan RSD4000 Instrument

The performance of the RSD4000 product will meet or exceed the following absolute and relative accuracy specifications:
C_3H_8 ± 100ppm or ± 10% of reading, whichever is greater CO ± 0.1% or ± 10% of reading, whichever is greater NO ± 150ppm or ± 10% of reading, whichever is greater
Static background conditions and mean value of CO_2 plume < 20 %-cm:
C_3H_8 ± 150ppm or ± 15% of reading, whichever is greater CO ± 0.15% or ± 15% of reading, whichever is greater NO ± 225ppm or ± 15% of reading, whichever is greater

A comparison of the values in Table 9-1 and 9-2 shows that the RSD instrument has a variability about three times as large as the ASM instrument at high values and from three to ten times as large as the ASM instrument at concentrations near zero. This difference in relative accuracy between the ASM and RSD instruments is not too surprising given that RSD measures a gas plume remotely with a beam of light while ASM measures by aspirating a sample of exhaust gas into the instrument.

During the field collection of RSD data, a dry gas audit truck was used to periodically check the RSD instruments. Examination of these audit results indicated that the variability of the RSD instruments was within the instrument specification. Figure 9-1 shows an example for a mixture containing 2.8% CO. For this concentration, BAR's requirement for RSD equipment is ±20% of the reading, as indicated by the upper and lower limits on the plot. All readings were within these limits and are also within the manufacturers specifications of ±15%.

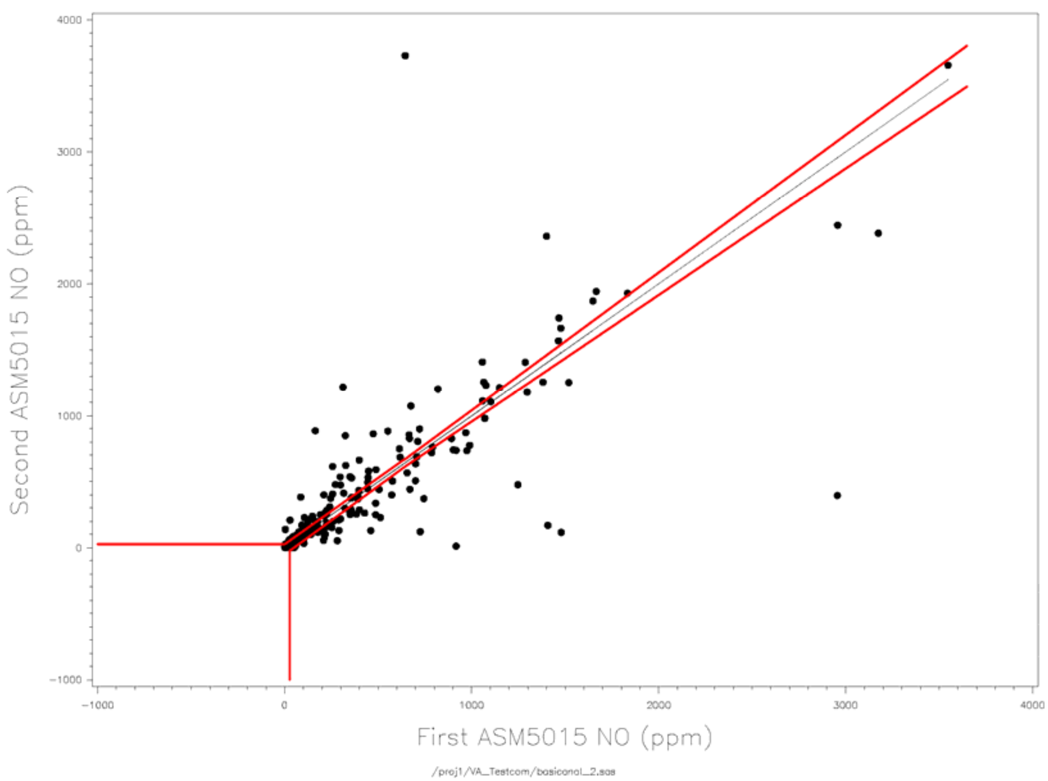
Figure 9-1. Actual Vs. Measured CO Concentration for RSD Unit # 4503 and Cylinder "E"



Variability of Vehicle Emissions– Another source of variability of the measured emissions concentration values is the time variability of the vehicle emissions themselves (Source 1). If we could measure the true instantaneous emissions concentration of a vehicle, even at constant operating conditions, we would see that the emissions are constantly changing with time. RSD measurements have an added source of variability (Source 3) because a range of operating conditions (5 < VSP < 20 kW/Mg) is acceptable. Even though ASM tests are performed at a nominally constant operating condition, small procedural variations in speed always occur (Source 5). As a result, an RSD measurement is a 0.5s snapshot and an ASM is a 90s snapshot of the vehicle's time-varying emissions. Even for the same vehicle, two or more ASM snapshots will not be exactly the same, nor will two or more RSD snapshots. Nevertheless, those tests do provide a general "idea" of the emissions of the vehicle.

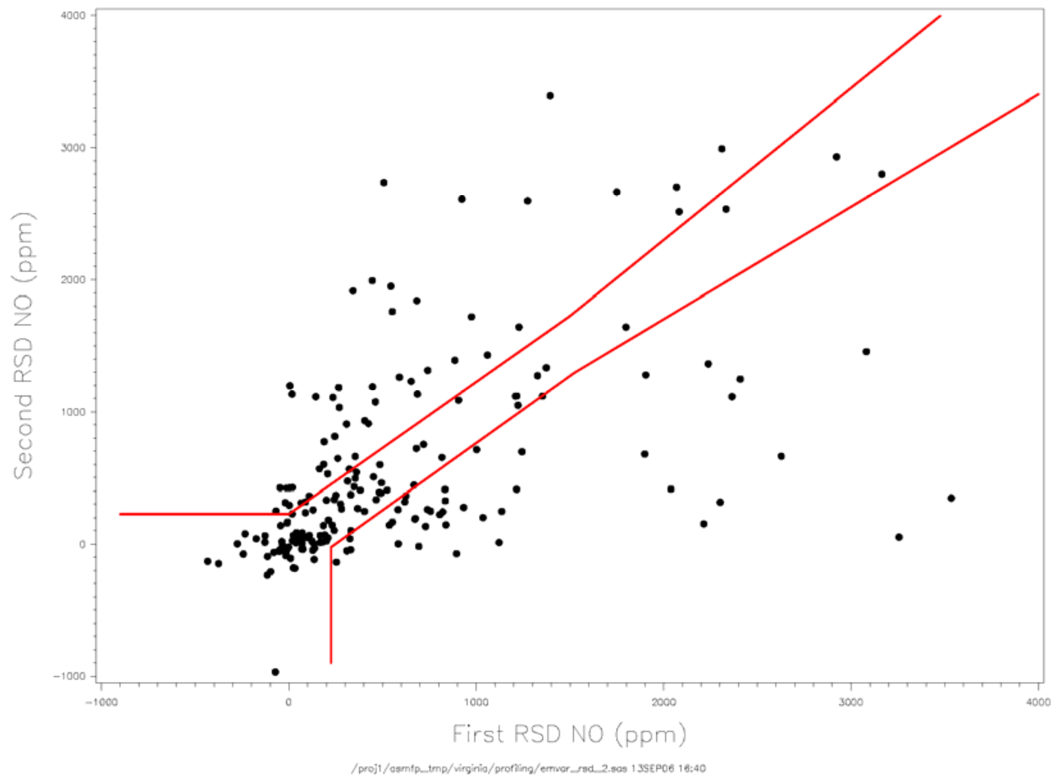
To get an idea of the size of vehicle emissions variability (Source 1), we can examine repeat tests on vehicles. As an example, Figure 9-2 shows repeat ASM5015 NO values from a study that ERG performed for the Virginia Department of Environmental Quality in 2002 [9]. Each point shows the measurements from two separate emissions tests. In that study, TESTCOM made duplicate ASM measurements of 197 New York state light-duty vehicles using a stratified random sampling design by model year group and vehicle type. Ideally, the duplicate measurements would fall exactly on the 1:1 line on the plot. However, the points do not fall on the 1:1 line because of three sources of variability: the inherent time variability of vehicle emissions (Source 1), the variability of vehicle operation during the ASM test (Source 5), such as small deviations in vehicle speed, and variability in the measurements from the ASM instruments (Source 4). The area inside the red lines defines the acceptance criteria for the ASM instrument, which are taken from Table 9-1. These limits determine the estimated variability of ASM instruments (Source 4). Most of the data points are outside of this area; we attribute this to the inherent time variability of vehicle emissions (Source 1) and the ASM procedural variability (Source 5).

Figure 9-2. Replicate Measurements of ASM5015 NO on 197 New York Vehicles



Virginia also performed an RSD pilot study. As part of the California pilot study, ERG obtained RSD values from the Virginia pilot study's dataset and found about 20,000 pairs of in-VSP-range RSD measurements taken less than two days apart on the same vehicle by the same RSD instrument. We randomly selected 197 observations of this dataset so that the model year distribution was the same as that of the New York State vehicles shown in Figure 9-2. Figure 9-3 shows the repeat RSD NO (ppm) values of these vehicles with the estimated variability of the RSD instrument, which was taken from Table 9-2, shown by the red lines. Many of the data points are outside of the red lines. Again, points will fall outside of the red lines because of the inherent time variability of vehicle emissions (Source 1) and because of RSD vehicle operation variability (Source 2), which arises from the variation of vehicle specific power (VSP) within the acceptable range of 5 to 20 kW/Mg.

Figure 9-3. Replicate Measurements of RSD NO on 197 Virginia Vehicles



We can examine the figures to determine the fraction of observations that fall within the instrumental variability specifications. If vehicles had no emissions variability, about 95% of the data points would fall within the red-line limits. Analysis of the data near zero emissions indicates that many of the data points fall within instrumental variability. This tends to confirm the instrumental variability specs near zero emissions for the RSD and ASM instruments since the emissions of very clean vehicles generally do not vary by large amounts. Therefore, the only significant source of variability of the measurements for very clean vehicles is the instrumental variability itself since there are no emissions to vary. The plots show that for emissions greater than zero, most data points fall outside of the instrumental variability specs for both types of instruments. This indicates that vehicle emissions variability is larger than instrumental variability.

We believe the main reason that most of the points in Figures 9-2 and 9-3 are outside of the red-lined areas is vehicle emissions variability. However, there can be additional reasons. This is hinted at by the figures showing that the RSD values are substantially farther away from the 1:1 line than the ASM values are. This could be caused by differences in the time between the replicate tests. ASM tests were done sequentially; RSD tests were done no more than two days apart. Alternatively, the ASM data points may be closer to the 1:1 line in comparison to the RSD data points because of the longer duration of the ASM test vs. the RSD test (90s vs. 0.5s). Longer duration tests could produce results with lower variability.

In any case, the duplicate values in Figures 9-2 and 9-3 show that, for both ASM and RSD, vehicles routinely produce emission values that vary substantially. A comparison of the figures indicates that the RSD measurements are less able to repeat themselves than the ASM measurements are. Through a comparison of this repeat measurement variability with the instrumental variability specifications, we conclude that the sum of the time variability of vehicle emissions (Source 1) and the test procedural variability (Sources 3 and 5) is substantially larger than the instrumental variability (Sources 2 and 4).

9.3 Variability of RSD Values with ASM Values for Individual Vehicles

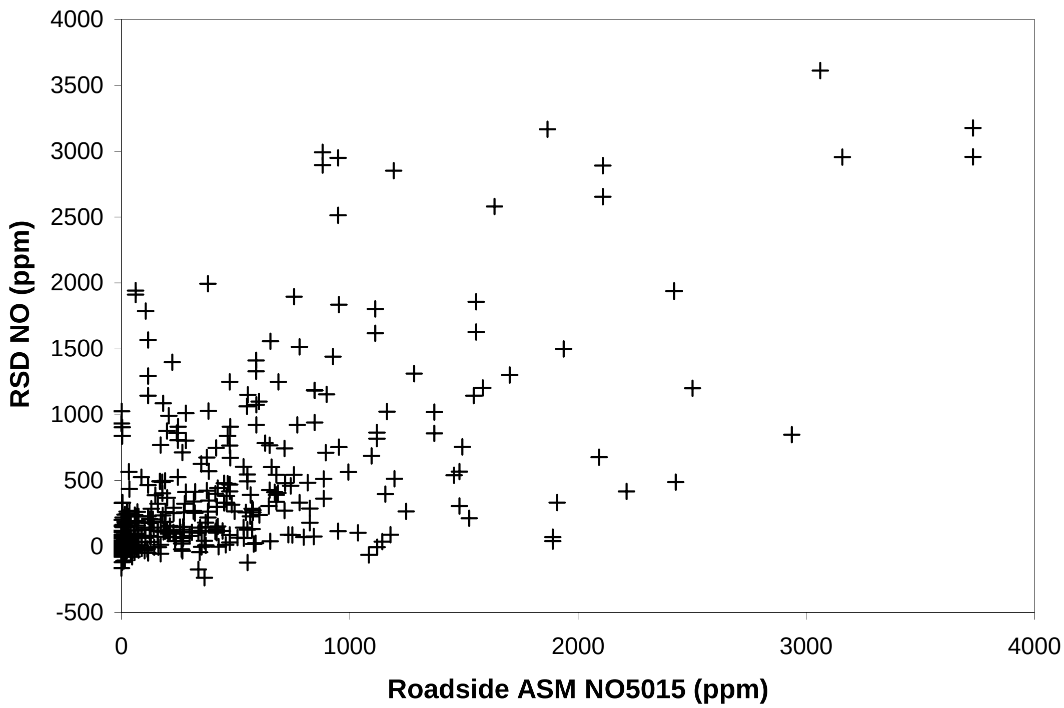
In this study we want to use RSD measurements to predict I/M station ASM results since passing or failing the I/M station ASM emissions test is one of the important factors in evaluating the different special strategies. The I/M station ASM emissions test is the reference test for validating individual vehicle selection for a special strategy. Specifically, for Calling-In, Directing, and Scrapping, if the selected vehicle does not fail the I/M station ASM test that follows the RSD, the vehicle's selection will be viewed as inappropriate. Therefore, we need to investigate the I/M station ASM-prediction ability of RSD. We can do this by looking at RSD/ASM pairs. In the discussion below, we first compare emissions measurements of RSD and Roadside ASMs that were taken nearly simultaneously. Then, we examine the effects of the pre-inspection repair and I/M station performance by comparing Roadside ASMs and Referee ASM results and by comparing Roadside ASMs and regular I/M station ASM results.

Comparison of RSD and Roadside ASM Measurement Pairs – The ability of RSD to predict ASM can be evaluated using the paired RSD and Roadside ASM data collected in this study. Vehicles were randomly given a Roadside ASM within minutes of receiving a standard RSD measurement. Vehicles were selected with a stratified random sampling plan based on model year group and vehicle type and not the RSD measurements. After filtering for in-range vehicle specific power during the RSD measurements, 416 vehicles remained in the dataset.

Figure 9-4 shows a plot of the RSD NO vs. the ASM5015 NO for the 416 vehicles. The plot shows an unmistakable, though highly scattered, relationship between the RSD and the Roadside ASM5015 NO measured values. The scatter is caused by the RSD instrumental error

(Source 2), VSP variability during the RSD test (Source 3), ASM instrumental error (Source 4), vehicle operation variability during the ASM test (Source 5), time variability of the vehicle emissions (Source 1) plus the difference in responses of individual vehicles to ASM and RSD tests (Source 8). Clearly, the plot demonstrates that RSD will have some ability to predict Roadside ASM results. However, the wide scatter of the points is troublesome if we want to use an individual vehicle's RSD measurements to predict its I/M station ASM results. For example, if the RSD NO measurement were 1000 ppm, the Roadside ASM5015 NO could be anywhere between 0 and 3000 ppm. The I/M station ASM5015 NO could be anywhere over an even wider range because of additional variability from Sources 6 and 7.

Figure 9-4. Comparison of NO Concentrations Measured by RSD then Immediate Roadside ASM



/proj1/DecisionModel/Report/RSD-RASM-DataForTHD_1_VSPinRange_1.xls

The ASM5015 NO inspections for the data plotted in Figure 9-4 had ASM cutpoints ranging from 360 to 1600 ppm. Because a wide range in technologies could explain part of the scatter in Figure 9-4, we separated the data into groups with similar ASM5015 NO cutpoints. When we examined the large set of recent ASM inspections in the VID, we found that the ASM5015 NO cutpoints, which were all in Phase 4.3, fell into four distinct bands defined by the groupings of the emissions standards categories (ESC) shown in Table 9-3. The table gives the range of cutpoints and the median cutpoint of each group. Splitting the data in Figure 9-4 into the four groups of ESCs produces Figures 9-5, 9-6, 9-7, and 9-8. The plots all have the same scales. The vertical line on each plot, which designates the median cutpoint, is different for each plot. Points to the right of the cutpoint line represent Roadside ASM5015 NO fails. All four figures show scatter that is somewhat less than the scatter in Figure 9-4, but each still has substantial scatter. The consequence of the scatter is that it prevents RSD from being able to effectively predict the Roadside ASM5015 pass/fail result.

Table 9-3. Groups of ASM5015 NO Cutpoints

Phase 4.3 Emission Standards Category	Model Year / Vehicle Type		ASM5015 NO Cutpoint (ppm)	
			Range	Median
2, 10, 11, 18, 19	75-80 PC	75-83 LDT	1220 - 1600	1440
3, 4, 12, 13, 20, 21	81-86 PC	84-92 LDT	940 - 1220	1000
5, 6	87-95 PC		640 - 940	760
7, 8, 9, 14, 15, 16, 17, 22, 23, 24, 25	96-04 PC	93-04 LDT	360 - 640	480

For example, consider Figure 9-6, which shows the results for 103 vehicles. If we apply the median ASM5015 NO cutpoint of 1000 ppm, the plot shows that 15 of the vehicles would fail and 88 would pass the ASM5015 NO test. (That is, 15 are to the right and 88 are to the left of the vertical cutpoint line.) We would like RSD to be able to distinguish these 15 ASM failers from the 88 ASM passers. The plot shows that this is not going to be possible. We can imagine a horizontal RSD NO cutpoint line running across the scatter plot. It divides the plot into four quadrants. For example, if we apply an RSD NO cutpoint of 1000 ppm, the plot shows that 15 of the vehicles would have RSD NOs above 1000 ppm and would be designated failers, and 88 of the vehicles would have RSD NOs below 10000 ppm and would be designated passers.

For the 103 vehicles, the fail rates for RSD NO and ASM5015 NO using 1000 ppm cutpoints are both 14%. However, a simple comparison of fail rates is misleading because it gives the impression that RSD can accurately predict ASM. To properly evaluate the ability of RSD (or any test) to properly predict the ASM pass/fail result, we always need to examine all four quadrants. Table 9-4 gives the four quadrant performance for this situation. RSD NO correctly designates 80 ASM5015 NO passers and 7 ASM5015 NO failers; however, RSD incorrectly designates the 16 other vehicles in the other two quadrants. Thus, we see that while RSD gets the fail rate correct, it makes errors in classifying individual vehicles.

Figure 9-5. NO Concentrations Measured by RSD and ASM for 75-80 PCs + 75-83 LDTs

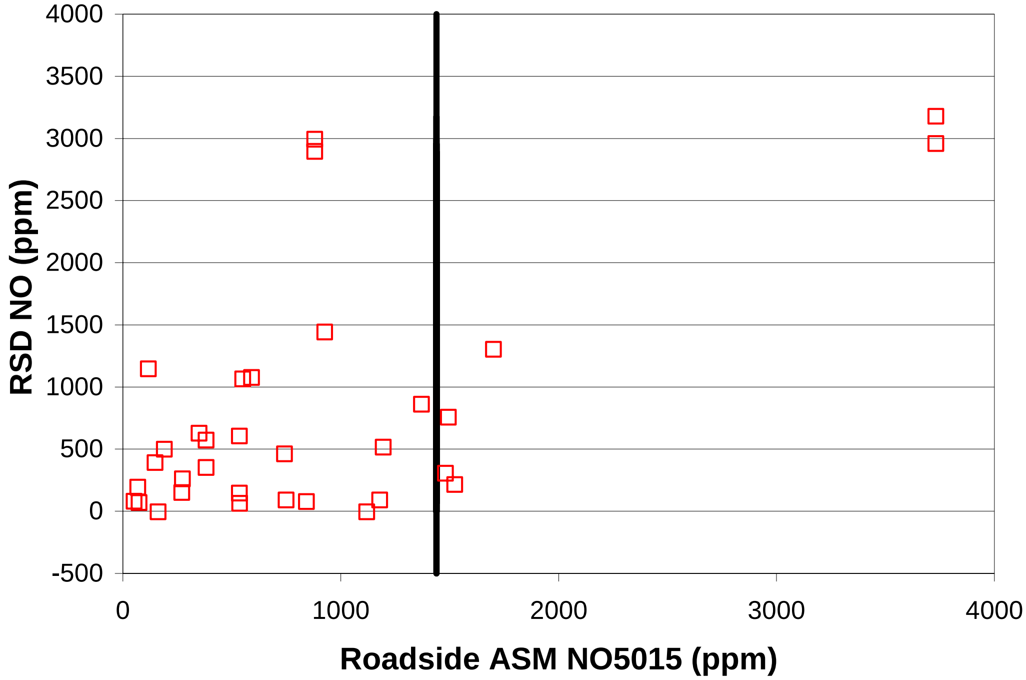


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Figure 9-6. NO Concentrations Measured by RSD and ASM for 81-86 PCs + 84-92 LDTs

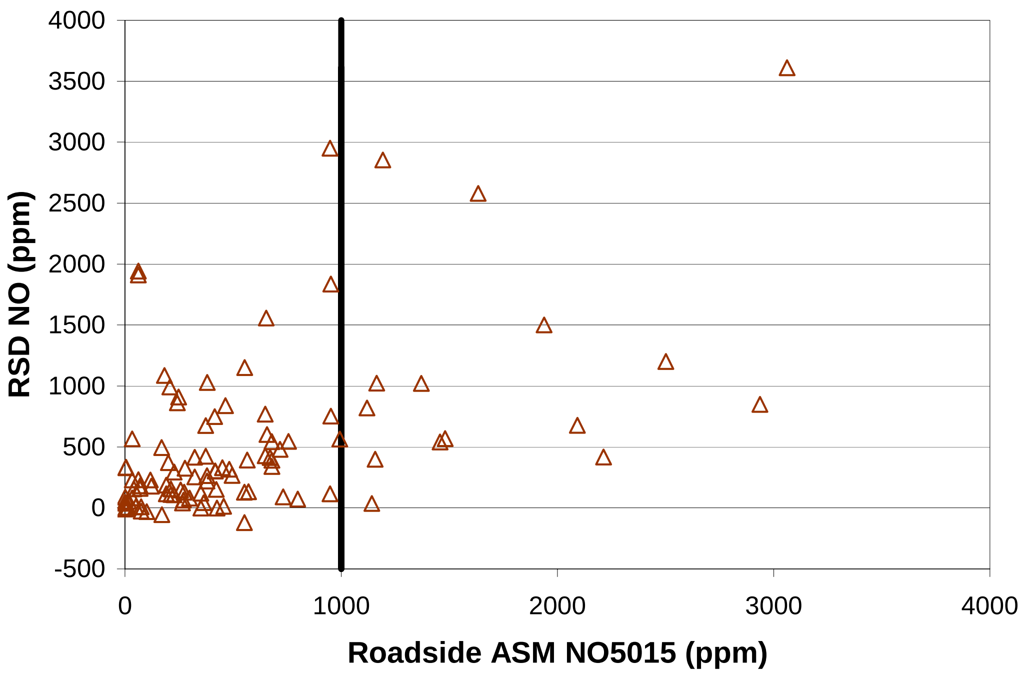

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Figure 9-7. NO Concentrations Measured by RSD and ASM for 87-95 PCs

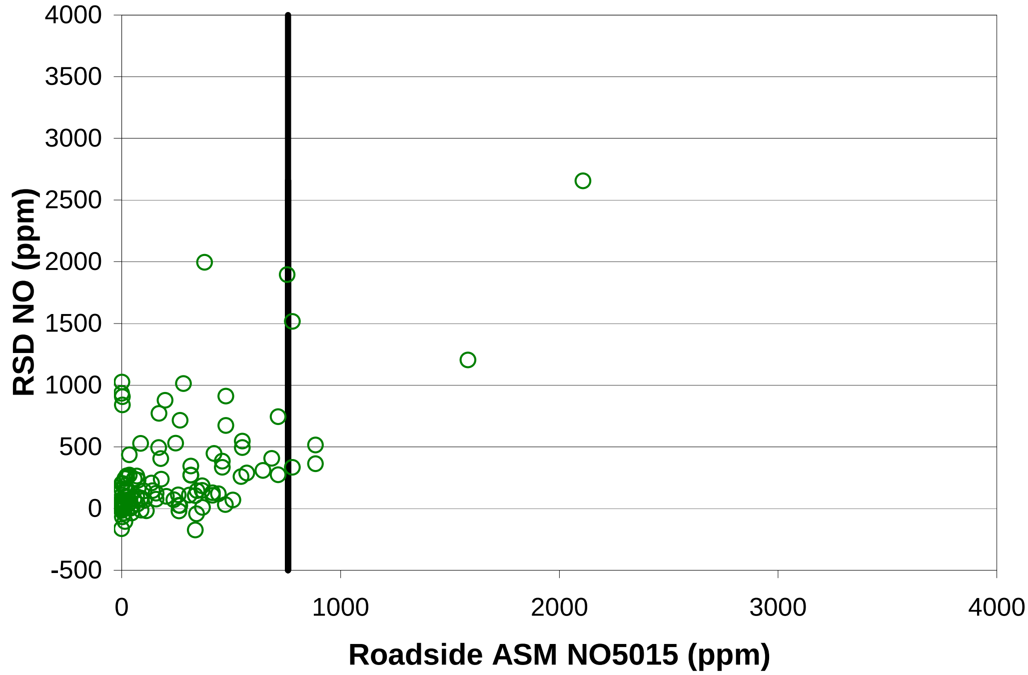

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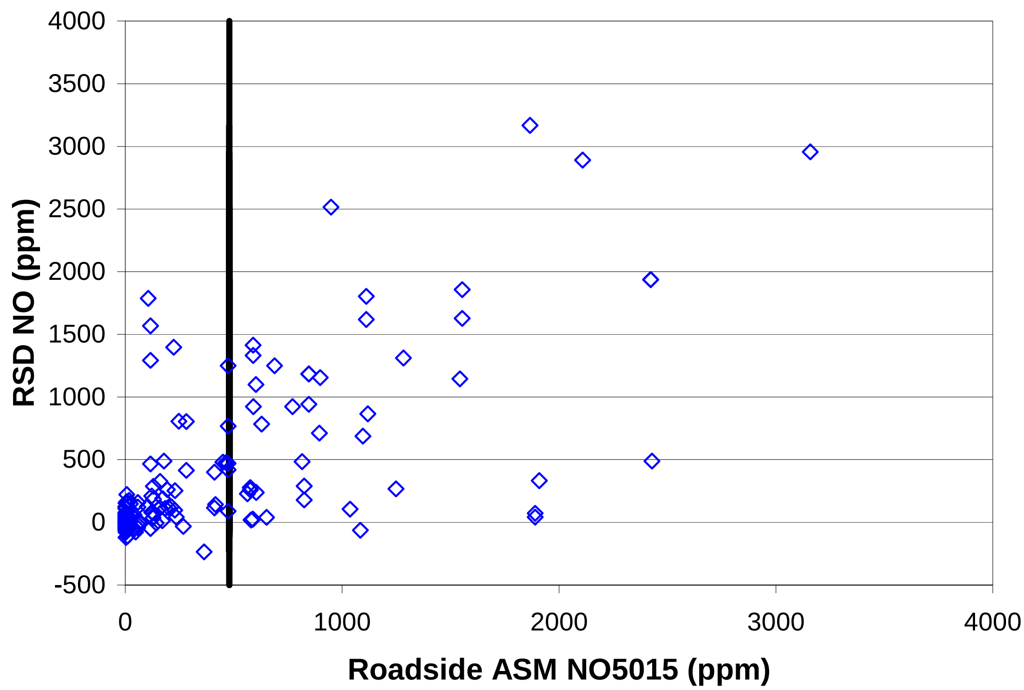
Figure 9-8. NO Concentrations Measured by RSD and ASM for 96-04 PCs + 93-04 LDTs



/proj1/DecisionModel/Report/RSD-RASM-DataForTHD_1_VSPinRange_1.xls

Table 9-4. ASM-Prediction Performance for an RSD Cutpoint at 1000 ppm for 81-86 PCs and 84-92 LDTs Data

		ASM5015 NO Result (1000 ppm cutpoint)			
		Pass	**Fail**	**Total for RSD NO**	
RSD NO Result (1000 ppm cutpoint)	**Fail**	8	7	15	14%
	Pass	80	8	88	
	Total for Roadside ASM5015 NO	88	15	103	
			14%		

By looking at Figure 9-6, as well as Figures 9-5, 9-7, and 9-8, we can see that no matter where the RSD cutpoint line is located, RSD will always either miss some ASM-failing vehicles in the lower right quadrant or will improperly designate passing vehicles in the upper left quadrant. Setting the RSD cutpoint at a high value such as 3000 ppm to assure that all of the selected vehicles would fail the ASM test is not an effective approach since the other 14 (non-selected) vehicles (in the lower right quadrant) that also fail the ASM would still be left on the road to excessively emit.

It is the scatter in the RSD vs. ASM measured values that causes the poor ability of RSD to predict Roadside ASM results. Why is there such large scatter? Earlier we discussed some of the sources of variability in RSD and ASM individually; however, when we compare RSD results with Roadside ASM results, as we do in Figures 9-4, 9-5, 9-6, 9-7, and 9-8, a new source of variability enters the problem: A vehicle responds differently to different tests (Source 8). If the predictor test (RSD, in this case) is different from the I/M inspection test (ASM), the two emissions results for a given vehicle will not have the same value – even though both measure tailpipe concentrations – because the two tests measure the vehicle at two different operating conditions using different procedures. In addition, the difference in response to ASM and RSD is different for different individual vehicles. Overall, the scatter in Figures 9-4, 9-5, 9-6, 9-7, and 9-8 is produced by four contributions: the relatively small contributions of RSD measurement variability and ASM measurement variability, the large inherent emissions variability of the vehicle, and the difference in responses of the vehicle to the RSD and the ASM tests.

Comparison of Roadside ASM Measurements and I/M Station ASM Measurements – The discussion above compared RSD measurements with Roadside ASM measurements. However, RSD must be able to predict the ASM result taken at an I/M station if it is to be used for a special strategy. We believe it is common for vehicle owners to get vehicles repaired in the few days before they get an I/M station ASM inspection because failing the ASM test has consequences. If these so-called pre-inspection repairs occur, they are beneficial to the I/M program, but they further hinder the ability of RSD measurements to predict I/M station ASM results for individual vehicles. As discussed below, whether the I/M station ASM test has consequences or not affects the connection between Roadside ASM result and I/M station ASM result.

In the study, after drivers received the Roadside ASM, they were offered $50 worth of gasoline if they would go to a Referee station to get a follow-up ASM test. They were told that there would be no consequences to the Referee station test. That is, if they failed the test they would not be required to get repairs. Of the 1,113 vehicles that we made the offer to, 60 ultimately had a Referee ASM performed. The four-quadrant comparison of the Roadside ASM and Referee results is given in Table 9-5. The table shows that while 33% of the 60 vehicles failed the Roadside ASM, 45% failed the Referee ASM. We believe that the quality of Roadside ASMs and Referee ASMs are comparable; therefore, the significant difference[17] between the fail rates may be a consequence of the fact that all Referee ASMs occurred a period of time after the Roadside ASMs.

Table 9-5. Comparison of Roadside ASM and Referee I/M Station ASM Results

		Referee Station Result			
		Pass	**Fail**	**Total for Roadside ASM**	
Roadside ASM Result	**Fail**	3	17	20	33%
	Pass	32	8	40	
	Total for Referee Stations	35	25	60	
			45%		

The other important feature of Table 9-5 is that 18% (= (3+8)/60) of the vehicles received different ASM pass/fail results for the roadside and referee tests. We believe that this is largely due to vehicle emissions variability and is consistent with the ASM repeatability results shown in Figure 9-2. Too often we think of an ASM test result as <u>the</u> answer for a vehicle, and we forget that emissions variability can cause a vehicle to pass one ASM and shortly thereafter fail the next.

Also in the study, many of the 1,113 vehicles that received a Roadside ASM later received an ASM test as part of their normal participation in the I/M program. At the time of this

[17] Both fail rates for this dataset of 60 observations have 95% confidence limits of ±12%. Therefore, the 95% confidence intervals are 21% to 45% for the Roadside ASM fail rate and 32% to 57% for the Referee ASM fail rate.

analysis we found VID records for 174 of these vehicles. The four-quadrant comparison of the Roadside ASM and regular I/M Station results that followed are shown in Table 9-6. The table shows that while 53% of these vehicles failed the Roadside ASM, only 27% failed the regular I/M station ASM. We have seen this factor of two difference between Roadside ASM and I/M station fail rates in previous studies. In this situation, it can be caused by several factors including: 1) pre-inspection repairs before regular I/M inspections, or 2) inaccuracy at regular I/M stations. Whatever the reasons for the difference in fail rates, they cause a further decoupling of on-road emissions characteristics (as measured by Roadside ASM and RSD) from I/M station ASM measurements.

The four-quadrant analysis of Table 9-6 also shows that 35% (= (53+8)/174) of the vehicles received different results for the Roadside ASM and regular I/M station tests.

Table 9-6. Comparison of Roadside ASM and Regular I/M Station ASM Results

		Regular I/M Station Result			
		Pass	**Fail**	**Total for Roadside ASM**	
Roadside ASM Result	**Fail**	53	39	92	53%
	Pass	74	8	82	
	Total for Regular Stations	127	47	174	
			27%		

Summary – The fact that individual vehicle emissions vary with time, that a vehicle responds differently to RSD and ASM tests, and that vehicles may receive pre-inspection repairs between the RSD and the “official” I/M station ASM test means that the connection between RSD concentration values and the ASM concentration values will be loose. Thus, an RSD measurement[18] of a vehicle’s emissions will be an imperfect predictor of the vehicle’s ASM emissions and ASM emissions pass/fail result at I/M inspection. Nevertheless, by convention, the “correctness” of the selection of the vehicle is judged by a single I/M-station inspection ASM test result. Any lack of correctness is blamed entirely on the predictor test, in this case the RSD test, even though the sources of incorrectness[19] come from the ASM test and vehicle emissions variability in addition to the RSD test.

[18] We need to keep in mind that this conclusion is not dependent on the fact that the predictor test is an RSD measurement. It is not that RSD measurements have bad qualities. All types of predictor tests – a roadside ASM, a roadside IM240, an I/M station pre-test ASM, or even the venerable FTP – will be imperfect predictors of the official I/M inspection ASM result.

[19] The sources of incorrectness are the variability of the “true” emissions of the vehicle, the RSD instrumental measurement error, the RSD procedural errors, the ASM instrumental measurement error, the ASM procedural

Because RSD is a measurement, the casual observer thinks, “With RSD I can find the high-emitting vehicles and fix them.” However, in an existing I/M program it is not as simple as that. The selected vehicle must fail the I/M station ASM test before repairs are required. Because of all of the sources of variability that are involved in using RSD measurements to predict I/M station ASM pass/fail results, when the individual vehicles that are identified by RSD get to the I/M station for their “official” test, they are not as likely to fail as their RSD measurements would seem to indicate. In this situation, an elevated RSD is just another “risk factor” for vehicles that are likely to need repairs rather than a guarantee that the vehicle will fail the ASM. Overall, for individual vehicles, even though RSD is a measurement, its ASM-predicting ability is probabilistic when it comes to forecasting the result of the I/M station emissions test.

9.4 Fleet Coverage by RSD

RSD can see only those vehicles that pass by an RSD instrument. As explained theoretically and empirically below, even a very large California RSD program can provide valid, DMV-matched RSD measurements on only about half of the fleet. Further, only 40% of those measurements are usable for selecting individual vehicles for special strategies or characterizing fleet emissions since vehicle operation during the RSD must be in the 5 to 20 kW/Mg vehicle-specific-power range. Finally, the largest practical RSD program that we costed would have RSD measurement activities in only the five largest AQMDs in which an estimated 85% of the I/M fleet drive. Thus, a very large RSD program can provide no more than 17% (=50% * 40% * 85%) of the I/M fleet with usable RSD readings. This means that the emissions of the other 83% of the fleet vehicles are not available for selection by a special strategy that uses an RSD measurement. The discussion below first addresses fleet coverage of RSD measurements of any VSP and second discusses fleet coverage of usable (in-range VSP) RSD measurements.

Any-VSP RSD Coverage – From the practical experience of other RSD programs in other states, we know that it is not very practical to get non-VSP-qualified RSD measurements on much more than half of the fleet. Existing RSD programs that wish to maximize fleet coverage have found that once the best RSD sites have been used, the other sites tend to provide a diminishing number of unmeasured vehicles. It takes more and more sites to find fewer and fewer unmeasured vehicles. This concept is shown in Figure 9-9 taken from the final report on Virginia’s most recent pilot RSD project. We use data from Virginia instead of the California Pilot RSD project because of the site permit restrictions our RSD data collection teams had to comply with.

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errors, differences between the driving modes of the RSD test and the ASM test, and the difference in response of the vehicle to the RSD test and to the ASM test.

Figure 9-9 indicates that it should be possible to cover 75% or even 80% of a fleet with RSD measurements if RSD readings were to be collected at enough sites for enough time. The theoretical result (green dots and green line) was projected from actual data (blue dots and black line) using a theory commonly accepted in traffic studies. According to Figure 9-9, if an RSD program wanted to cover 60% of the fleet in an area (60% on the vertical axis), then the required number of RSD measurements would be about 1.5 times the number of vehicles registered in the area (150% on the horizontal axis). In practice, this result has not yet been achieved and Table 9-7 gives an indication of this. In addition, it turns out that this relationship is very similar to the one derived for Sacramento, CA, in the Radian I/M Pilot study in March 1995 (14). In that study about 100% of the vehicle measurements to registration ratio provided 47% coverage for unique registrations in Sacramento, CA.

Figure 9-9. Fleet Coverage Graphic from Virginia's 2002 Pilot RSD Project (Source: Virginia Remote Sensing Device Study – Final Report, February 2003)

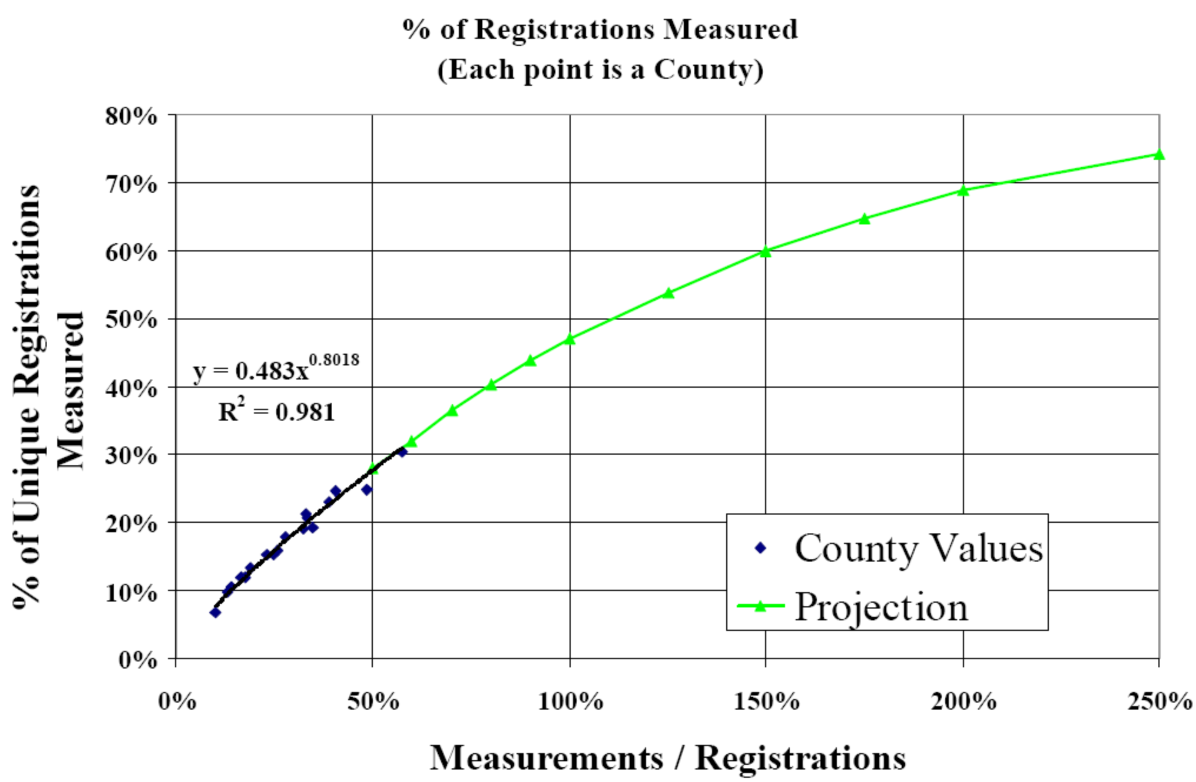


Table 9-7 gives annual fleet coverage results from Missouri's clean screen program. In that program, RSD sites are chosen to be convenient to as much of the fleet as possible, and are advertised to the public, so that vehicle owners may conveniently opt into the program if they choose. We expect this would be a good example of the realistic coverage possible in an RSD program, especially for newer vehicles, the majority of which would qualify for the clean screen program. Comparing data from Table 9-7 to Figure 9-9 shows that the actual coverages from Missouri are lower than the projected coverages from Virginia. For example, in the Missouri program when a number of RSD measurements equal to between 1.33-times (in 2000) and 1.66-times (in 2002) the number of registered vehicles are gathered between 44% and 51% of the fleet is covered. This is significantly lower than the 55% to 65% projected from the Virginia data in Figure 9-9. Other analyses have shown that even for the newest vehicles and even if the coverages are calculated for two-year periods instead of one-year periods, the actual coverage data from Missouri fall below the projected data from Virginia.

Table 9-7. Annual Coverage Results from the Missouri Clean Screen Program.

(Source: Peter McClintock, Applied Analysis)

Test Year	Annual Ratio of RSDed Vehicles to Registered Vehicles (Measurements/Registrations)	Annual Fleet Coverage (% of Unique Registrations Measured)
2000	133%	44%
2001	145%	46%
2003	144%	48%
2002	166%	51%

We conclude from the theoretical and empirical arguments that it is not practical to cover much more than about 50% of the fleet in an RSD program. This would especially be true in a program where vehicle owners had an incentive to avoid RSD sites, such as a gross emitter identification program where "off-cycle" test and repair were mandatory.

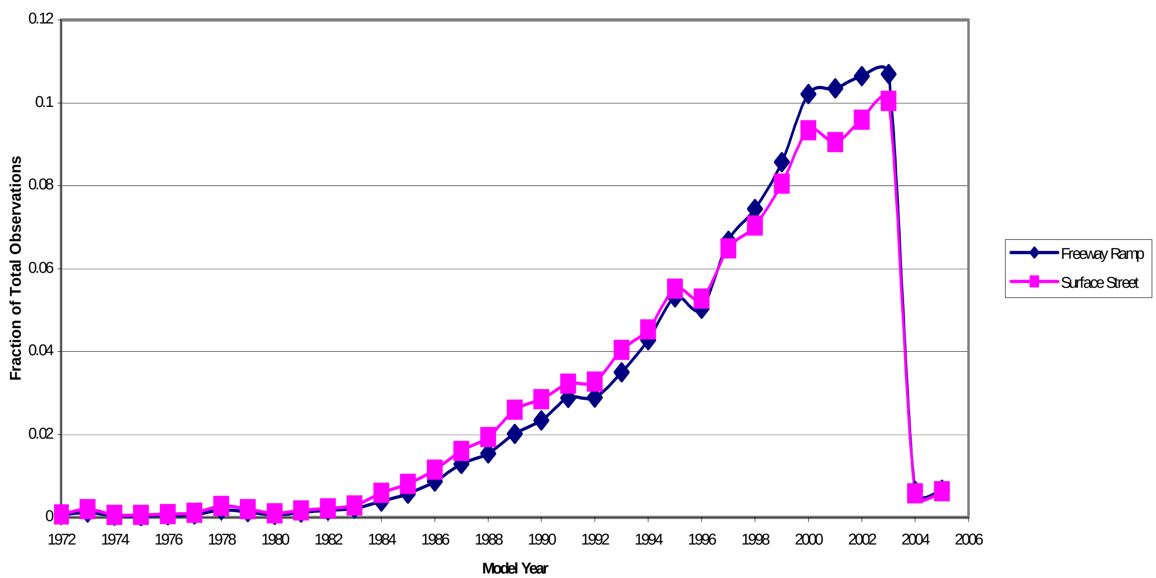
Usable-VSP RSD Coverage – The previous discussion provides evidence that a very large RSD program could provide 50% of the vehicles driving in a geographical area with at least one RSD measurement. However, those RSD measurements are counted for vehicles operating in any mode including decelerations and heavy accelerations. Only RSD readings taken while vehicles are under moderate load (VSPs between 5 and 20 kW/Mg) are representative of the average emissions of the vehicle. In this study, we found that about 40% of the any-VSP RSD readings were taken when VSPs were in the moderate load range of 5 to 20 kW/Mg. Therefore, only these usable-VSP RSD readings are usable for selecting individual vehicles for special strategies.

Further, since we expected that obtaining RSD measurements in rural areas would not be cost-effective since traffic flows are low, we costed the large RSD program only for coverage in the five largest AQMDs. When we assumed that about 10% of vehicles not registered in the five largest AQMDs sometimes drive in the five largest AQMDs, we estimated that 85% of the I/M fleet would be available for viewing by RSD instruments in the large RSD program.

When we put together the 50% of vehicles that a very large RSD program can obtain any-VSP RSD readings on, the 40% of those that will have usable-VSPs, and the 85% of the I/M fleet that drives in the five largest AQMDs, we see that only 17% of the I/M fleet will have produced usable RSDs.

Local and highway roadway fleet coverage – Figure 9-10 shows the model year distributions for vehicles seen by RSD on Freeways and Local roadways. As expected more newer model year vehicles are seen on the Freeways and more older vehicles are seen on the surface streets. Such issues need to be kept in the forefront when site decisions are made for any RSD program.

Figure 9-10. Model Year Distribution by Roadway Type



9.5 RSD for Identifying Individual Vehicles for Special Strategies

The results of this study indicated that using RSD to supplement special strategies for the existing California I/M program would not be cost-effective. First, we believe that the inherent time-varying emissions of individual vehicles and other sources of variability cause a relatively poor correlation between the RSD measurements obtained on the road and the ASM validation test that would be performed at an I/M station before a vehicle would be allowed to participate in a special strategy. Second, even in the largest practical RSD program, coverage of the vehicles in the I/M fleet with usable RSD measurements would not exceed 17%. The loss in benefits because of poor correlation between the RSD measurements and the I/M station test and from the low I/M fleet coverage results in an application of RSD measurements that would not be cost-effective.

In Section 9.2 we demonstrated using duplicate RSD data and duplicate ASM data that vehicle emissions are inherently time-varying. This vehicle emissions variability produces poor correlations between RSD readings on the same vehicle on consecutive days, poor correlations between ASM readings on the same vehicle in separate tests, poor correlations between RSD and roadside ASMs that immediately follow the RSD, and it helps to produce the poor correlation between RSD measurements and I/M station ASM tests performed weeks later. Although we have not performed a formal analysis of variance to quantify the size of the different contributions toward the variability of emissions measurements it seems apparent that the inherent variability of vehicle emissions is a large contributor.

It is a common and perhaps reasonable notion that whenever a vehicle is identified by an RSD measurement as a candidate for a special strategy, the emissions of the vehicle should be validated by an ASM test at an I/M station. While validation seems to be a requirement of selection by RSD, doing it opens up the vehicle emissions variability "can of worms." Besides emissions variability, there are several other reasons that a validation ASM test would not be able to validate the RSD reading. These include Sources of Variability 2 through 9 in Section 9.1.

It would seem that requiring multiple RSDs for selection of a vehicle and multiple ASMs for validation could help reduce the variability. However, if that were done, the cost of the program would increase, the number of vehicles that could participate in special strategies would decrease, and Sources of Variability 6, 7, 8, and 9 would still remain. Even if the validation test were changed to be validation by RSD, the fraction of validated failures would probably still not be near the desired value of 100% because of Sources of Variability 1, 2, 3, 7, and 9.

Even in the largest practical RSD program that we can conceive of (50% any-VSP RSD coverage in the five largest AQMDs), only about 17% of the vehicles in the statewide I/M fleet would receive at least one usable RSD measurement. This means that only 17% of the statewide vehicles would even be available for selection using RSD measurements. Furthermore, the cost of that large RSD data collection program would be high. Our analysis indicates that medium and small RSD programs would have disproportionately lower costs and would, therefore, be more cost-effective than the large program. Nevertheless, even the smaller programs would still not be cost-effective and would cover even smaller portions of the I/M fleet.

9.6 RSD for Fleet Emissions Characterization and I/M Program Evaluation

One of the valuable uses of RSD information is to "characterize fleet emissions." When we characterize fleet emissions, we are not interested in the emissions of any individual vehicles. We are not trying to identify ASM passes or failers. We are not trying to predict I/M station ASM test results for individual vehicles. Instead, we are interested in the emissions characteristics of different types of large subsets of the fleet. For example, we might want to know average emissions for different model years, different I/M program calendar years, different AQMDs, test-only station clients vs. test-and-repair station clients, 90 days before I/M inspection vs. 90 days after I/M inspection, different vehicle operating modes, in-state plates vs. out-of-state plates, or I/M program participants vs. I/M program non-participants.

The need is to measure emissions and not to predict an I/M ASM result – To select individual vehicles for a special strategy, RSD must forecast the result of an I/M station ASM emission test. As discussed in the previous subsections, that is a challenging job for any emissions test. Even though RSD is a measurement, because of the many sources of variability, forecasting ASM pass/fails from RSD is highly probabilistic in nature. On the other hand, to characterize fleet emissions we do not need to examine the emissions of individual vehicles or to forecast what their I/M station ASM results will be. RSD just needs to provide an unbiased measurement of tailpipe emissions. RSD can even be noisy – as long as it is unbiased. Averaging many individual vehicle observations can reduce noise, but it cannot reduce bias.

RSD measures actual tailpipe emissions concentrations – Dry gas audit tests show that RSD is able to measure known gas concentrations with relatively good accuracy and low uncertainty (although not quite as low as ASM audits). From this we conclude that RSD measurements on vehicles are a relatively good measure of the tailpipe emissions of the vehicle <u>at the exact time of the measurement</u>.

Sub-fleet averages of RSD values have low variability and (probably) low bias – While the RSD values are good measurements of instantaneous emissions concentrations, the emissions of an individual vehicle vary widely with time. Part of the time the instantaneous emissions are above and at other times the instantaneous emissions are below the characteristic, long-term average emissions of the vehicle. The individual RSD measurements of many individual vehicles can be averaged to reduce the variability produced by different sources of variability. If RSD measures a representative sample of the fleet under a representative set of vehicle operating conditions, the average of the emissions values will be representative of the fleet as a whole. We can apply the same approach to different sub-fleets to arrive at emissions characteristics for them.

All of this depends on RSD being unbiased, which means that the RSD values match the actual emissions concentration of the vehicle. It may be that under certain vehicle operating modes, for example, during decelerations with closed throttle when the tailpipe plume is small, RSD may have problems obtaining a reliable emissions measurement.

The value of averaging RSD measurements for the purpose of characterizing the fleet can be also demonstrated using the 416 pairs of RSD and ASM measurements that were collected in this study. These measurements were used in Section 9.3 to demonstrate the highly scattered connection between RSD values and ASM values for individual vehicles. However, in this case, the large amount of scatter is not a great concern because when a large number of individual readings of RSD concentrations are averaged the uncertainty in the average value can be much smaller than the uncertainty in the individual values for an individual vehicle.

Figures 9-9, 9-11, and 9-13 show scatter plots for the 416 pairs of observations for RSD versus Roadside ASM2525 HC, CO, and NO measured immediately after the RSDs. For each of the three plots, there are a handful of points that are off the plots, which we have made to focus on the vicinity near the origin. Each of these three plots again demonstrates the poor correlation between the RSD and ASM measured values for individual vehicles. The r^2 statistics for the three plots would be quite low. The plots do not show any clear evidence of a linear relationship between RSD and ASM values.

However, if we average the RSD values and the ASM values by model year and plot the model year averages for RSD against those for ASM2525, we arrive at the plots in Figures 9-10, 9-12, and 9-14. In these figures, the areas of the bubbles are proportional to the number of data points that were averaged for each model year. The number of observations for each model year ranges from 1 to 35. Examination of these three model year average plots shows the beginning of the appearance of a proportional relationship between the RSD and ASM2525 model year average values. This means that a group of vehicles that has a high average RSD value will have a high average ASM2525 value. Groups of vehicles that are observed on the road with a low average RSD value will have a low average roadside ASM2525 value on the road.

The averages shown in Figures 9-10, 9-12, and 9-14 were based on the small dataset with 416 observations. Collection of this dataset, which is made up of RSD measurements followed immediately by roadside ASM measurements on a randomly selected set of vehicles, is rather unusual because of the effort required to collect the roadside/RSD paired data. If additional data had been collected, we would expect that the plots of model year averages would become less and less scattered as more data points were added to the dataset. In spite of the relatively small size of the dataset that was collected, the Figures 9-9, 9-11, and 9-13 clearly show that RSD measurements on individual vehicles are highly scattered with ASM measurements. However, when averages are taken, the average RSD measurement of a group of vehicles is proportional to the average ASM measurement of the same group of vehicles.

RSD measurements are independent of the I/M program – One of the big strengths of RSD is that it can be used to evaluate an I/M program because the RSD measurements are independent of the measurements reported by the I/M program in the VID. Emission results in the VID are affected by the measurement inaccuracies of the I/M stations and instruments. Pre-inspection repairs by vehicle owners also prevent the I/M measurements from representing the characteristic emissions of the vehicle. I/M inspections also measure emissions at only one time per I/M cycle – when the vehicle comes in for inspection – but vehicles emit and degrade throughout the I/M cycle. Because the timing of RSD measurements is random with respect to I/M inspections, RSD is better able to measure the overall effect of I/M. Finally, unlike VID data, RSD measures non-I/M vehicles as well as I/M vehicles. This allows comparisons to be made between different segments of the on-road fleet that are impossible to make with VID data alone.

Figure 9-9. Comparison of Individual Vehicle RSD and Immediate Roadside ASM2525 for HC

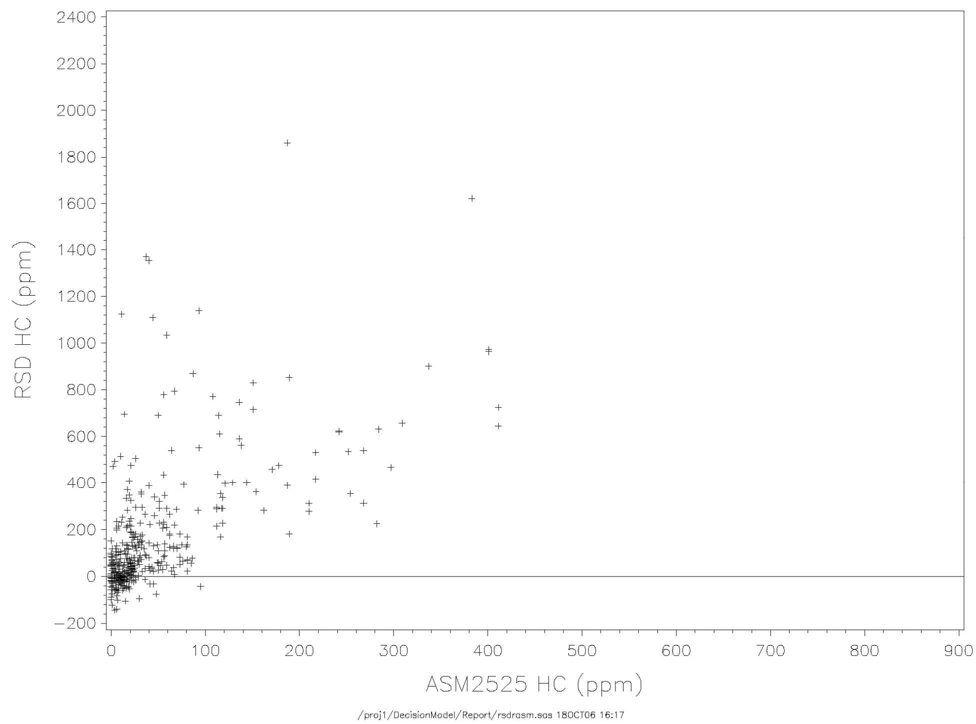


Figure 9-10. Comparison of Model Year Average RSD and Immediate Roadside ASM2525 for HC

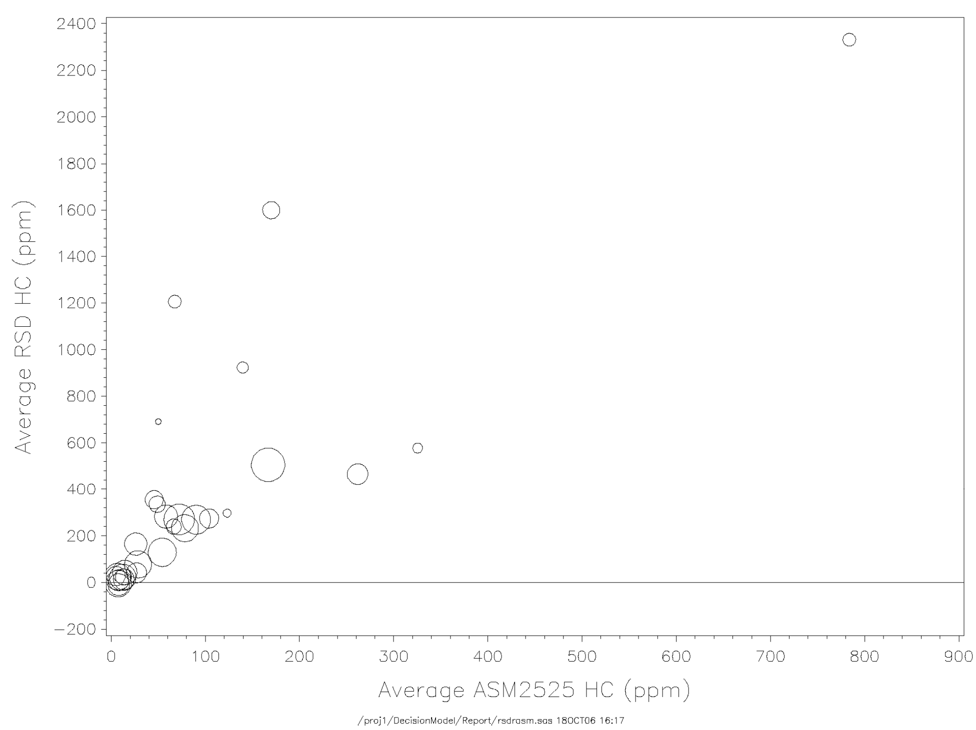


Figure 9-11. Comparison of Individual Vehicle RSD and Immediate Roadside ASM2525 for CO

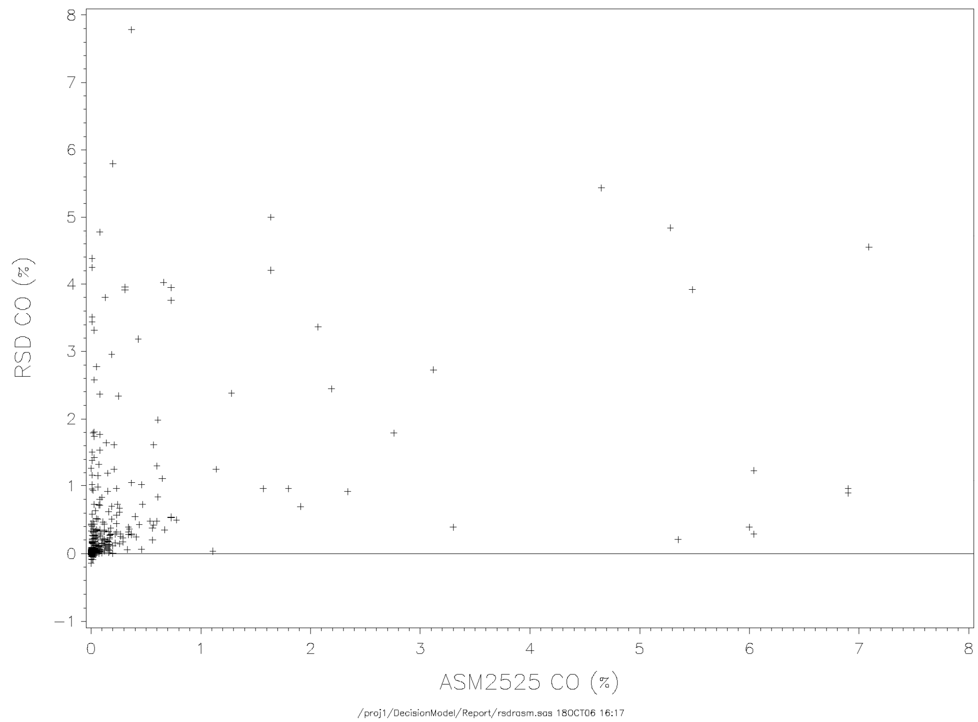


Figure 9-12. Comparison of Model Year Average RSD and Immediate Roadside ASM2525 for CO

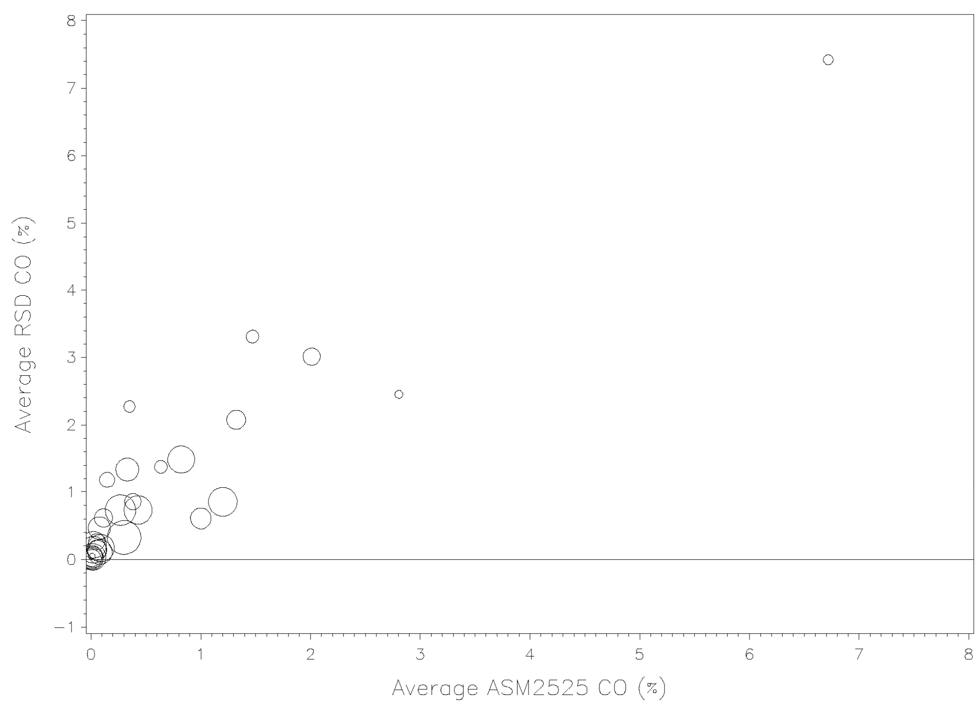


Figure 9-13. Comparison of Individual Vehicle RSD and Immediate Roadside ASM2525 for NO

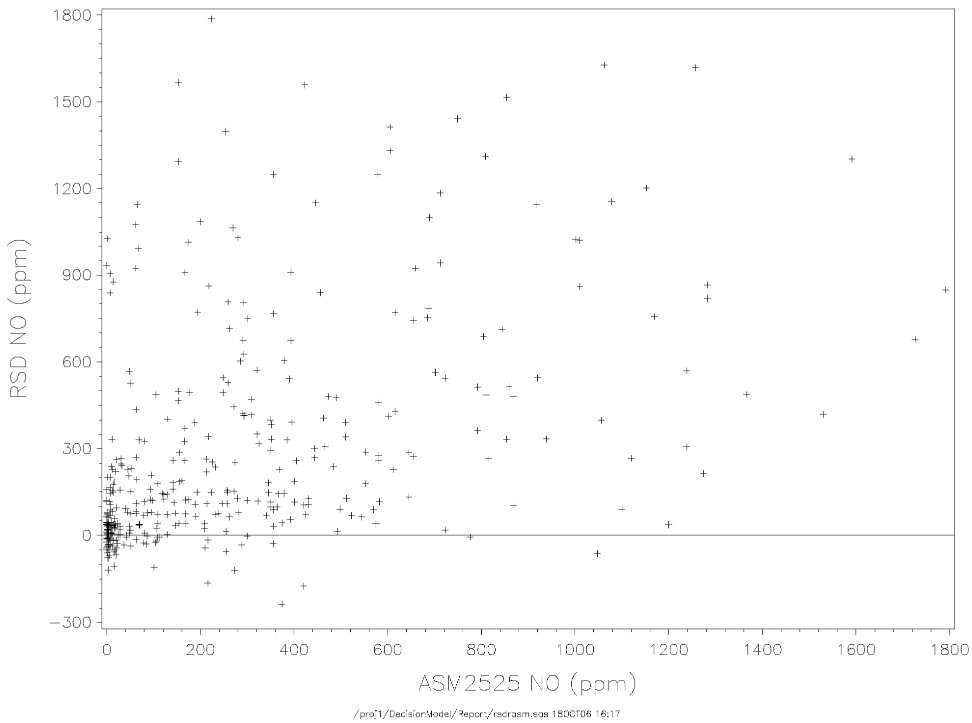
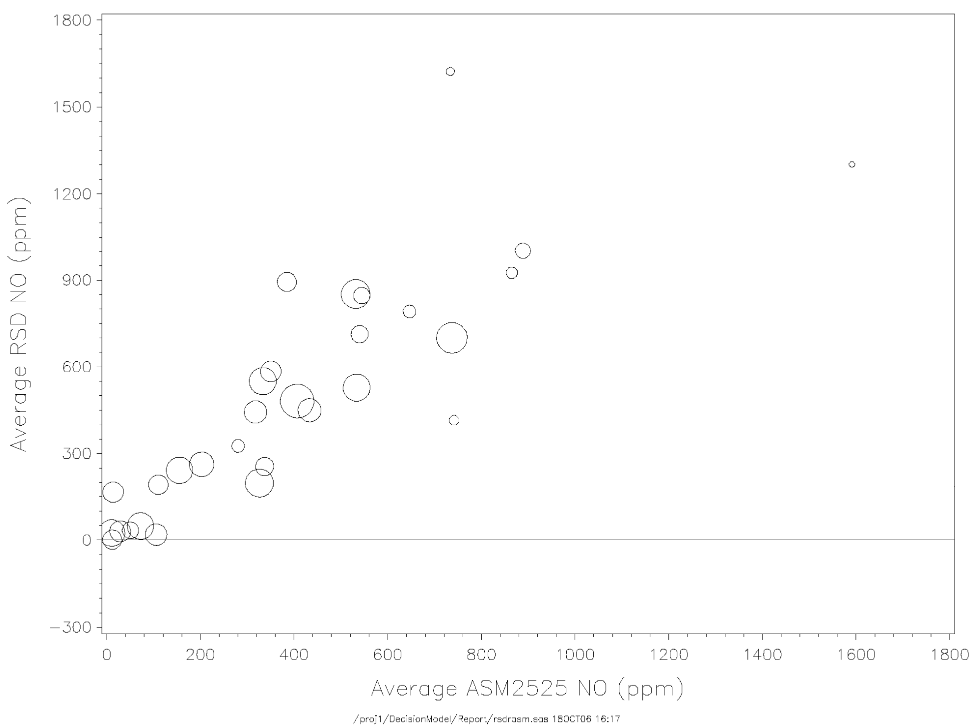


Figure 9-14. Comparison of Model Year Average RSD and Immediate Roadside ASM2525 for NO



Vehicle selection using VID history is a better first choice than using RSD – The historical VID data from California's I/M program can be used to build effective and cost-effective vehicle selection strategies. The reason these strategies can be built is because the program performs tailpipe emissions tests on all I/M-eligible model year vehicles[20] – even on OBD vehicles. These VID-history-based strategies are as good as RSD-based strategies at reducing the mass of emissions, cover virtually the entire I/M fleet, and are far less costly to implement than an RSD program. Therefore, in this competitive situation, it makes sense to choose the VID-history method over the RSD program for special strategies as the first level of improvement to the existing I/M program.

Then, the question becomes, "Does it make sense to add RSD as a second level improvement?" If RSD was not cost-effective when competing directly against the VID-history-based strategies, then it only makes sense that after the VID-history-based strategies have identified the most obvious vehicles, RSD will be even less cost-effective than before. RSD measurements, or any emissions test, will have a difficult time in further reducing the tons of emissions. The high cost of an RSD program makes getting those few "incremental" tons not cost-effective.[21]

[20] Jurisdictions that do not perform emissions inspections on 1996 and newer vehicles do not have VID data that can be used to build these models.

[21] Keep in mind that this study's conclusion of RSD cost-ineffectiveness applies only to using RSD as an incremental component to an existing I/M program that conducts an emissions inspection on all vehicles of all eligible model years. We have not studied the effectiveness and cost-effectiveness of an RSD program in jurisdictions that do not have an I/M program.

10.0 Conclusions

This study finds that in the California situation where an I/M program already exists:

- Supplementing the I/M program with an RSD measurement component can effectively reduce mass emissions through special strategies by selecting individual vehicles. However, even the largest practical RSD program would be able to obtain usable RSD measurements only on about 17% of the statewide I/M fleet. Whether the RSD program is large or small, the high cost of RSD relative to the mass of emissions reduced makes RSD not cost-effective for selecting individual vehicles for participation in special strategies.

- Supplementing the I/M program with a VID-History-based High Emitter Profiler can reduce mass emissions just as effectively as RSD. In contrast to RSD, the VID History method can cover essentially 100% of the fleet and, because the source of information is the VID rather than an on-going field data collection effort, the VID History method can be cost-effective.

- Adding an RSD measurement component to an I/M program that has already been improved with VID-History-based special strategies can make only minor further reductions in mass emissions. The high cost of RSD relative to the mass of emissions reduced makes adding an RSD component in this scenario quite cost-ineffective.

- Nevertheless, because of RSD's ability to measure the on-road emissions of groups of vehicles without bias and to measure them independently of the I/M program, we believe RSD can be an effective tool for characterizing the fleet and evaluating the I/M program. (We did not attempt to estimate its cost-effectiveness for this activity).

11.0 References

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Appendix A
Effects of Varying Fleet Targeting Percentage

Table A-1. Calling-In at 2% Targeting[a]

	Vehicle Selection Method: VID alone	Vehicle Selection Method: RSD alone	Vehicle Selection Method: VID+RSD together	Adding RSD to VID-alone causes:
Targeted Vehicles [c] at 2% Targeting (N)	267,761	45,432	267,761	
Targeted Vehicles that Fail ASM at Decision Point (N)	92,176	22,281	96,552	4,376 more vehicles to fail
ASM Fail Rate at Decision Point (%)	34.4%	49.0%	36.1%	
Benefits: Δ Failed Miles Driven (miles/2years) [d]	A decrease of **542,980,156** failed miles driven	A decrease of **29,360,544** failed miles driven	A decrease of **562,044,060** failed miles driven	A further decrease of **19,063,904** failed miles driven
Benefits: Total ΔFTP HC+NOx (tons/2years) [f]	A decrease of **2,312** tons	A decrease of **244** tons	A decrease of **2,409** tons	A further decrease of **97** tons
Total Costs ($/2years)	**$ 32,132,224** spent	**$ 73,075,712** spent	**$ 96,296,574** spent	A further increase of **$ 64,164,352** spent
Cost Effectiveness ($/ton HC+NOx) [h]	**$ 13,899** spent for each ton of emissions reduced	**$299,044** spent for each ton of emissions reduced	**$ 39,976** spent for each ton of emissions reduced	An additional **$ 661,930** spent for each additional ton of emissions reduced

[a] The costs and benefits presented in this table are for a large RSD measurement program that obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

Table A-2. Calling-In at 5% Targeting[a]

		Vehicle Selection Method			
		VID alone	RSD alone	VID+RSD together	Adding RSD to VID-alone causes:
Targeted Vehicles [c] at 5% Targeting (N)		669,403	113,581	669,403	
Targeted Vehicles that Fail ASM at Decision Point (N)		222,039	49,450	229,754	7,715 more vehicles to fail
ASM Fail Rate at Decision Point (%)		33.2%	43.5%	34.3%	
Benefits	**Δ Failed Miles Driven (miles/2years) [d]**	A decrease of **972,447,180** failed miles driven	A decrease of **72,776,491** failed miles driven	A decrease of **995,126,275** failed miles driven	A further decrease of **22,679,095** failed miles driven
Benefits	**Total ΔFTP HC+NOx (tons/2years) [f]**	A decrease of **4,595** tons	A decrease of **557** tons	A decrease of **4,724** tons	A further decrease of **129** tons
Total Costs ($/2years)		**$ 72,915,946** spent	**$ 80,692,952** spent	**$ 137,533,806** spent	A further increase of **$ 64,617,862** spent
Cost Effectiveness ($/ton HC+NOx) [h]		**$ 15,870** spent for each ton of emissions reduced	**$144,822** spent for each ton of emissions reduced	**$ 29,117** spent for each ton of emissions reduced	An additional **$ 500,867** spent for each additional ton of emissions reduced

[a] The costs and benefits presented in this table are for a large RSD measurement program that obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

Table A-3. Calling-In at 7% Targeting[a]

		Vehicle Selection Method: VID alone	Vehicle Selection Method: RSD alone	Vehicle Selection Method: VID+RSD together	Adding RSD to VID-alone causes:
Targeted Vehicles [c] at 7% Targeting (N)		937,165	159,013	937,165	
Targeted Vehicles that Fail ASM at Decision Point (N)		294,208	64,636	304,192	9,984 more vehicles to fail
ASM Fail Rate at Decision Point (%)		31.4%	40.6%	32.5%	
Benefits	**Δ Failed Miles Driven (miles/2years) [d]**	A decrease of **1,156,345,280** failed miles driven	A decrease of **99,073,364** failed miles driven	A decrease of **1,178,220,976** failed miles driven	A further decrease of **21,875,697** failed miles driven
Benefits	**Total ΔFTP HC+NOx (tons/2years) [f]**	A decrease of **5,673** tons	A decrease of **733** tons	A decrease of **5,812** tons	A further decrease of **139** tons
Total Costs ($/2years)		**$ 98,148,876** spent	**$ 85,373,675** spent	**$ 163,074,759** spent	A further increase of **$ 64,925,885** spent
Cost Effectiveness ($/ton HC+NOx) [h]		**$ 17,302** spent for each ton of emissions reduced	**$116,407** spent for each ton of emissions reduced	**$ 28,058** spent for each ton of emissions reduced	An additional **$ 466,172** spent for each additional ton of emissions reduced

[a] The costs and benefits presented in this table are for a large RSD measurement program that obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

Table A-4. Calling-In at 10% Targeting[a]

		Vehicle Selection Method			Adding RSD to VID-alone causes:
		VID alone	**RSD alone**	**VID+RSD together**	
Targeted Vehicles [c] at 10% Targeting (N)		1,338,807	227,161	1,338,807	
Targeted Vehicles that Fail ASM at Decision Point (N)		387,754	84,402	401,464	13,709 more vehicles to fail
ASM Fail Rate at Decision Point (%)		29.0%	37.2%	30.0%	
Benefits	**Δ Failed Miles Driven (miles/2years) [d]**	A decrease of **1,337,903,777** failed miles driven	A decrease of **135,826,787** failed miles driven	A decrease of **1,362,286,252** failed miles driven	A further decrease of **24,382,475** failed miles driven
Benefits	**Total ΔFTP HC+NOx (tons/2years) [f]**	A decrease of **6,824** tons	A decrease of **969** tons	A decrease of **7,007** tons	A further decrease of **184** tons
Total Costs ($/2years)		**$ 134,000,880** spent	**$ 91,985,532** spent	**$ 199,432,718** spent	A further increase of **$ 65,431,841** spent
Cost Effectiveness ($/ton HC+NOx) [h]		**$ 19,638** spent for each ton of emissions reduced	**$ 94,902** spent for each ton of emissions reduced	**$ 28,461** spent for each ton of emissions reduced	An additional **$ 356,168** spent for each additional ton of emissions reduced

[a] The costs and benefits presented in this table are for a large RSD measurement program that obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

Table A-5. Directing at 20% Targeting[a]

		Vehicle Selection Method: VID alone	Vehicle Selection Method: RSD alone	Vehicle Selection Method: VID+RSD together	Adding RSD to VID-alone causes:
Targeted Vehicles [c] **at 20% Targeting (N)**		2,677,614	454,323	2,677,614	
Δ[i] **Targeted Vehicles that Fail ASM at Decision Point (N)**		72,309	16,513	75,677	3,368 more vehicles to fail
Δ[i] **ASM Fail Rate at Decision Point (%)**		2.7%	3.6%	2.8%	
Benefits	**Δ Failed Miles Driven (miles/2years)** [d]	A decrease of **418,433,374** failed miles driven	A decrease of **62,339,941** failed miles driven	A decrease of **432,730,94**1 failed miles driven	A further decrease of **14,297,567** failed miles driven
Benefits	**Total ΔFTP HC+NOx (tons/2years)** [f]	A decrease of **2,703** tons	A decrease of **471** tons	A decrease of **2,803** tons	A further decrease of **100** tons
Total Costs ($/2years)		**$ 17,488,178** spent	**$ 69,912,981** spent	**$ 81,711,738** spent	A further increase of **$ 64,223,562** spent
Cost Effectiveness ($/ton HC+NOx) [h]		**$ 6,470** spent for each ton of emissions reduced	**$ 148,395** spent for each ton of emissions reduced	**$ 29,156** spent for each ton of emissions reduced	An additional **$ 644,532** spent for each additional ton of emissions reduced

[a] The costs and benefits presented in this table are for a large RSD measurement program that obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

[i] Inspecting targeted vehicles at high-performing stations rather than at average-performing stations causes these increases in the number of targeted vehicles that fail and corresponding increases in ASM fail rates.

Table A-6. Directing at 30% Targeting[a]

	Vehicle Selection Method: VID alone	Vehicle Selection Method: RSD alone	Vehicle Selection Method: VID+RSD together	Adding RSD to VID-alone causes:
Targeted Vehicles [c] at 30% Targeting (N)	4,016,421	681,484	4,016,421	
Δ[i] Targeted Vehicles that Fail ASM at Decision Point (N)	96,260	20,401	99,717	3,458 more vehicles to fail
Δ[i] ASM Fail Rate at Decision Point (%)	2.4%	3.0%	2.5%	
Benefits: Δ Failed Miles Driven (miles/2years) [d]	A decrease of **518,814,235** failed miles driven	A decrease of **81,860,355** failed miles driven	A decrease of **532,680,295** failed miles driven	A further decrease of **13,866,060** failed miles driven
Benefits: Total ΔFTP HC+NOx (tons/2years) [f]	A decrease of **3,591** tons	A decrease of **614** tons	A decrease of **3,686** tons	A further decrease of **95** tons
Total Costs ($/2years)	**$ 22,134,667** spent	**$ 70,667,180** spent	**$ 86,375,596** spent	A further increase of **$ 64,240,931** spent
Cost Effectiveness ($/ton HC+NOx) [h]	**$ 6,164** spent for each ton of emissions reduced	**$ 115,140** spent for each ton of emissions reduced	**$ 23,431** spent for each ton of emissions reduced	An additional **$ 675,437** spent for each additional ton of emissions reduced

[a] The costs and benefits presented in this table are for a large RSD measurement program that obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

[i] Inspecting targeted vehicles at high-performing stations rather than at average-performing stations causes these increases in the number of targeted vehicles that fail and corresponding increases in ASM fail rates.

Table A-7. Directing at 40% Targeting[a]

	Vehicle Selection Method: VID alone	Vehicle Selection Method: RSD alone	Vehicle Selection Method: VID+RSD together	Adding RSD to VID-alone causes:
Targeted Vehicles [c] at 40% Targeting (N)	5,355,228	908,645	5,355,228	
Δ[i] Targeted Vehicles that Fail ASM at Decision Point (N)	115,080	23,107	118,245	3,165 more vehicles to fail
Δ[i] ASM Fail Rate at Decision Point (%)	2.1%	2.5%	2.2%	
Benefits: Δ Failed Miles Driven (miles/2years) [d]	A decrease of **594,758,300** failed miles driven	A decrease of **96,525,257** failed miles driven	A decrease of **606,709,974** failed miles driven	A further decrease of **11,951,674** failed miles driven
Benefits: Total ΔFTP HC+NOx (tons/2years) [f]	A decrease of **4,339** tons	A decrease of **730** tons	A decrease of **4,423** tons	A further decrease of **84** tons
Total Costs ($/2years)	**$ 25,785,903** spent	**$ 71,192,233** spent	**$ 89,969,958** spent	A further increase of **$ 64,184,057** spent
Cost Effectiveness ($/ton HC+NOx) [h]	**$ 5,943** spent for each ton of emissions reduced	**$ 97,488** spent for each ton of emissions reduced	**$ 20,342** spent for each ton of emissions reduced	An additional **$ 765,450** spent for each additional ton of emissions reduced

[a] The costs and benefits presented in this table are for a large RSD measurement program that obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

[i] Inspecting targeted vehicles at high-performing stations rather than at average-performing stations causes these <u>increases</u> in the number of targeted vehicles that fail and corresponding increases in ASM fail rates.

Table A-8. Directing at 50% Targeting[a]

		Vehicle Selection Method			
		VID alone	**RSD alone**	**VID+RSD together**	**Adding RSD to VID-alone causes:**
Targeted Vehicles [c] at 50% Targeting (N)		6,694,035	1,135,807	6,694,035	
Δ[i] Targeted Vehicles that Fail ASM at Decision Point (N)		131,230	25,028	133,631	2,402 more vehicles to fail
Δ[i] ASM Fail Rate at Decision Point (%)		2.0%	2.2%	2.0%	
Benefits	**Δ Failed Miles Driven (miles/2years) [d]**	A decrease of **655,005,214** failed miles driven	A decrease of **107,288,221** failed miles driven	A decrease of **664,032,746** failed miles driven	A further decrease of **9,027,532** failed miles driven
Benefits	**Total ΔFTP HC+NOx (tons/2years) [f]**	A decrease of **5,007** tons	A decrease of **829** tons	A decrease of **5,071** tons	A further decrease of **64** tons
Total Costs ($/2years)		**$ 28,918,826** spent	**$ 71,564,900** spent	**$ 92,954,900** spent	A further increase of **$ 64,036,076** spent
Cost Effectiveness ($/ton HC+NOx) [h]		**$ 5,776** spent for each ton of emissions reduced	**$ 86,336** spent for each ton of emissions reduced	**$ 18,331** spent for each ton of emissions reduced	An additional **$ 998,730** spent for each additional ton of emissions reduced

[a] The costs and benefits presented in this table are for a large RSD measurement program that obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

[i] Inspecting targeted vehicles at high-performing stations rather than at average-performing stations causes these increases in the number of targeted vehicles that fail and corresponding increases in ASM fail rates.

Table A-9. Exempting at 5% Targeting[a]

		Vehicle Selection Method: VID alone	Vehicle Selection Method: RSD alone	Vehicle Selection Method: VID+RSD together	Adding RSD to VID-alone causes:
Targeted Vehicles [c] at 5% Targeting (N)		669,403	113,581	669,403	
Targeted Vehicles that Fail ASM at Decision Point (N)		26,877	746	24,745	2,132 fewer failing vehicles to be exempted
ASM Fail Rate at Decision Point (%)		4.0%	0.7%	3.7%	
Benefits	**Δ Failed Miles Driven (miles/2years) [d]**	An increase of **72,521,124** failed miles driven	An increase of **5,505,791** failed miles driven	An increase of **58,052,412** failed miles driven	The reduction of an additional **14,468,713** failed miles driven are preserved
Benefits	**Total ΔFTP HC+NOx (tons/2years) [f]**	An increase of **433** tons	An increase of **121** tons	An increase of **348** tons	An additional **85** tons of emissions reductions are preserved
Total Costs ($/2years)		A savings of **$ 14,944,866**	**$ 63,253,556** spent	**$ 48,439,167** spent	A further increase of **$ 63,384,034** spent
Cost Effectiveness ($/ton HC+NOx) [h]		A savings of **$ 34,542** for each ton of emissions increased	**$ 521,043** spent for each ton of emissions increased	**$ 139,168** spent for each ton of emissions increased	An additional **$ 749,286** spent for each additional ton of emission reductions not lost through exemption

[a] The costs and benefits presented in this table are for a large RSD measurement program that obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

Table A-10. Exempting at 10% Targeting[a]

		Vehicle Selection Method: VID alone	Vehicle Selection Method: RSD alone	Vehicle Selection Method: VID+RSD together	Adding RSD to VID-alone causes:
Targeted Vehicles [c] at 10% Targeting (N)		1,338,807	227,161	1,338,807	
Targeted Vehicles that Fail ASM at Decision Point (N)		37,467	1,645	34,504	2,963 fewer failing vehicles to be exempted
ASM Fail Rate at Decision Point (%)		2.8%	0.7%	2.6%	
Benefits	**Δ Failed Miles Driven (miles/2years) [d]**	An increase of **92,618,632** failed miles driven	An increase of **11,709,447** failed miles driven	An increase of **75,645,684** failed miles driven	The reduction of an additional **16,972,948** failed miles driven are preserved
Benefits	**Total ΔFTP HC+NOx (tons/2years) [f]**	An increase of **788** tons	An increase of **251** tons	An increase of **700** tons	An additional **88** tons of emissions reductions are preserved
Total Costs ($/2years)		A savings of **$ 34,771,829**	**$ 59,811,044** spent	**$ 28,539,606** spent	A further increase of **$ 63,311,437** spent
Cost Effectiveness ($/ton HC+NOx) [h]		A savings of **$ 44,134** for each ton of emissions increased	**$ 238,623** spent for each ton of emissions increased	**$ 40,751** spent for each ton of emissions increased	An additional **$ 723,356** spent for each additional ton of emission reductions not lost through exemption

[a] The costs and benefits presented in this table are for a large RSD measurement program that obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

Table A-11. Exempting at 20% Targeting[a]

		Vehicle Selection Method: VID alone	Vehicle Selection Method: RSD alone	Vehicle Selection Method: VID+RSD together	Adding RSD to VID-alone causes:
Targeted Vehicles [c] at 20% Targeting (N)		2,677,614	454,323	2,677,614	
Targeted Vehicles that Fail ASM at Decision Point (N)		58,371	3,963	54,125	4,247 fewer failing vehicles to be exempted
ASM Fail Rate at Decision Point (%)		2.2%	0.9%	2.0%	
Benefits	**Δ Failed Miles Driven (miles/2years) [d]**	An increase of **143,777,037** failed miles driven	An increase of **26,921,267** failed miles driven	An increase of **122,609,996** failed miles driven	The reduction of an additional **21,167,040** failed miles driven are preserved
Benefits	**Total ΔFTP HC+NOx (tons/2years) [f]**	An increase of **2,358** tons	An increase of **529** tons	An increase of **2,212** tons	An additional **146** tons of emissions reductions are preserved
Total Costs ($/2years)		A savings of **$ 74,449,922**	**$ 52,971,366** spent	A savings of **$ 11,250,529**	A further increase of **$ 63,199,395** spent
Cost Effectiveness ($/ton HC+NOx) [h]		A savings of **$ 31,573** for each ton of emissions increased	**$ 100,179** spent for each ton of emissions increased	A savings of **$ 5,086** for each ton of emissions increased	An additional **$ 433,376** spent for each additional ton of emission reductions not lost through exemption

[a] The costs and benefits presented in this table are for a large RSD measurement program that obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

Table A-12. Exempting at 30% Targeting[a]

		Vehicle Selection Method: VID alone	Vehicle Selection Method: RSD alone	Vehicle Selection Method: VID+RSD together	Adding RSD to VID-alone causes:
Targeted Vehicles [c] at 30% Targeting (N)		4,016,421	681,484	4,016,421	
Targeted Vehicles that Fail ASM at Decision Point (N)		87,352	7,251	81,376	5,976 fewer failing vehicles to be exempted
ASM Fail Rate at Decision Point (%)		2.2%	1.1%	2.0%	
Benefits	**Δ Failed Miles Driven (miles/2years) [d]**	An increase of **224,627,821** failed miles driven	An increase of **47,212,657** failed miles driven	An increase of **198,425,423** failed miles driven	The reduction of an additional **26,202,398** failed miles driven are preserved
Benefits	**Total ΔFTP HC+NOx (tons/2years) [f]**	An increase of **4,087** tons	An increase of **840** tons	An increase of **3,908** tons	An additional **179** tons of emissions reductions are preserved
Total Costs ($/2years)		A savings of **$ 113,422,873**	**$ 46,216,380** spent	A savings of **$ 50,374,488**	A further increase of **$ 63,048,388** spent
Cost Effectiveness ($/ton HC+NOx) [h]		A savings of **$ 27,749** for each ton of emissions increased	**$ 55,021** spent for each ton of emissions increased	A savings of **$ 12,888** for each ton of emissions increased	An additional **$ 352,324** spent for each additional ton of emission reductions not lost through exemption

[a] The costs and benefits presented in this table are for a large RSD measurement program that obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

Table A-13. Exempting at 40% Targeting[a]

		Vehicle Selection Method: VID alone	Vehicle Selection Method: RSD alone	Vehicle Selection Method: VID+RSD together	Adding RSD to VID-alone causes:
Targeted Vehicles [c] at 40% Targeting (N)		5,355,228	908,645	5,355,228	
Targeted Vehicles that Fail ASM at Decision Point (N)		128,372	11,935	120,197	8,174 fewer failing vehicles to be exempted
ASM Fail Rate at Decision Point (%)		2.4%	1.3%	2.2%	
Benefits	**Δ Failed Miles Driven (miles/2years) [d]**	An increase of **349,047,547** failed miles driven	An increase of **75,338,487** failed miles driven	An increase of **316,520,128** failed miles driven	The reduction of an additional **32,527,419** failed miles driven are preserved
Benefits	**Total ΔFTP HC+NOx (tons/2years) [f]**	An increase of **6,155** tons	An increase of **1,199** tons	An increase of **5,942** tons	An additional **214** tons of emissions reductions are preserved
Total Costs ($/2years)		A savings of **$ 151,344,918**	**$ 39,583,341** spent	A savings of **$ 88,488,431**	A further increase of **$ 62,856,489** spent
Cost Effectiveness ($/ton HC+NOx) [h]		A savings of **$ 24,588** for each ton of emissions increased	**$ 33,013** spent for each ton of emissions increased	A savings of **$ 14,893** for each ton of emissions increased	An additional **$ 294,104** spent for each additional ton of emission reductions not lost through exemption from exemption

[a] The costs and benefits presented in this table are for a large RSD measurement program that obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

Table A-14. Scrapping for an $8 Million Biennial Vehicle Purchase Budget[a]

		Vehicle Selection Method			
		VID alone	**RSD alone**	**VID+RSD together**	**Adding RSD to VID alone causes:**
Targeted Vehicles [c] (N)		33,470	19,763	32,131	
Targeted Vehicles that Fail ASM at Decision Point (N)		13,117	9,014	13,090	27 fewer vehicles to fail
ASM Fail Rate at Decision Point (%)		39.2%	45.6%	40.7%	
Benefits	**Δ Failed Miles Driven (miles/2years) [d]**	A decrease of **107,628,709** failed miles driven	A decrease of **81,605,569** failed miles driven	A decrease of **109,328,588** failed miles driven	A further decrease of **1,699,879** failed miles driven
Benefits	**Total ΔFTP HC+NOx (tons/2years) [f]**	A decrease of **2,071** tons	A decrease of **1,338** tons	A decrease of **2,119** tons	A further decrease of **48** tons
Total Costs ($/2years)		**$ 11,201,238** spent	**$ 74,256,998** spent	**$ 74,664,085** spent	A further increase of **$ 63,462,848** spent
Cost Effectiveness ($/ton HC+NOx) [h]		**$ 5,410** spent for each ton of emissions reduced	**$ 55,479** spent for each ton of emissions reduced	**$ 35,240** spent for each ton of emissions reduced	An additional **$ 1,317,563** spent for each additional ton of emissions reduced
Average Market Value of Targeted Vehicles ($)		$ 609	$ 875	$ 607	

[a] The costs and benefits presented in this table are for a large RSD measurement program that obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

Table A-15. Scrapping for a $16 Million Biennial Vehicle Purchase Budget[a]

		Vehicle Selection Method			
		VID alone	**RSD alone**	**VID+RSD together**	**Adding RSD to VID alone causes:**
Targeted Vehicles [c] (N)		58,908	31,803	56,230	
Targeted Vehicles that Fail ASM at Decision Point (N)		22,936	14,384	22,820	116 fewer vehicles to fail
ASM Fail Rate at Decision Point (%)		38.9%	45.2%	40.6%	
Benefits	**Δ Failed Miles Driven (miles/2years) [d]**	A decrease of **190,210,114** failed miles driven	A decrease of **133,180,660** failed miles driven	A decrease of **194,587,521** failed miles driven	A further decrease of **4,377,407** failed miles driven
Benefits	**Total ΔFTP HC+NOx (tons/2years) [f]**	A decrease of **3,478** tons	A decrease of **2,034** tons	A decrease of **3,527** tons	A further decrease of **49** tons
Total Costs ($/2years)		**$ 18,728,744** spent	**$ 81,325,746** spent	**$ 82,276,673** spent	A further increase of **$ 63,547,930** spent
Cost Effectiveness ($/ton HC+NOx) [h]		**$ 5,385** spent for each ton of emissions reduced	**$ 39,978** spent for each ton of emissions reduced	**$ 23,326** spent for each ton of emissions reduced	An additional **$ 1,286,021** spent for each additional ton of emissions reduced
Average Market Value of Targeted Vehicles ($)		$ 683	$ 1,053	$ 691	

[a] The costs and benefits presented in this table are for a large RSD measurement program that obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

Table A-16. Scrapping for a $32 Million Biennial Vehicle Purchase Budget[a]

		Vehicle Selection Method			Adding RSD to VID alone causes:
		VID alone	**RSD alone**	**VID+RSD together**	
Targeted Vehicles [c] (N)		109,782	54,519	101,749	
Targeted Vehicles that Fail ASM at Decision Point (N)		41,237	23,990	40,288	949 <u>fewer</u> vehicles to fail
ASM Fail Rate at Decision Point (%)		37.6%	44.0%	39.6%	
Benefits	**Δ Failed Miles Driven (miles/2years) [d]**	A decrease of **339,431,965** failed miles driven	A decrease of **226,232,699** failed miles driven	A decrease of **342,477,697** failed miles driven	A further decrease of **3,045,732** failed miles driven
Benefits	**Total ΔFTP HC+NOx (tons/2years) [f]**	A decrease of **5,992** tons	A decrease of **3,218** tons	A decrease of **5,960** tons	A <u>smaller</u> decrease by **33** tons
Total Costs ($/2years)		**$ 34,850,021** spent	**$ 96,920,654** spent	**$ 97,990,372** spent	A further increase of **$ 63,140,351** spent
Cost Effectiveness ($/ton HC+NOx) [h]		**$ 5,816** spent for each ton of emissions reduced	**$ 30,122** spent for each ton of emissions reduced	**$ 16,442** spent for each ton of emissions reduced	An additional **$ 1,936,926** spent for each additional ton of emissions <u>increased</u>
Average Market Value of Targeted Vehicles ($)		$ 774	$ 1,293	$ 788	

[a] The costs and benefits presented in this table are for a large RSD measurement program that obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

Table A-17. Scrapping for a $64 Million Biennial Vehicle Purchase Budget[a]

		Vehicle Selection Method			
		VID alone	**RSD alone**	**VID+RSD together**	**Adding RSD to VID alone causes:**
Targeted Vehicles [c] (N)		200,821	95,408	174,045	
Targeted Vehicles that Fail ASM at Decision Point (N)		70,526	39,381	65,795	4,731 fewer vehicles to fail
ASM Fail Rate at Decision Point (%)		35.1%	41.3%	37.8%	
Benefits	**Δ Failed Miles Driven (miles/2years) [d]**	A decrease of **566,689,602** failed miles driven	A decrease of **369,211,603** failed miles driven	A decrease of **552,304,396** failed miles driven	A smaller decrease by **14,385,205** failed miles driven
Benefits	**Total ΔFTP HC+NOx (tons/2years) [f]**	A decrease of **9,505** tons	A decrease of **5,019** tons	A decrease of **9,120** tons	A smaller decrease by **385** tons
Total Costs ($/2years)		**$ 67,128,457** spent	**$ 128,456,684** spent	**$ 125,864,923** spent	A further increase of **$ 58,736,466** spent
Cost Effectiveness ($/ton HC+NOx) [h]		**$ 7,062** spent for each ton of emissions reduced	**$ 25,594** spent for each ton of emissions reduced	**$ 13,801** spent for each ton of emissions reduced	An additional **$ 152,386** spent for each additional ton of emissions increased
Average Market Value of Targeted Vehicles ($)		$ 906	$ 1,593	$ 908	

[a] The costs and benefits presented in this table are for a large RSD measurement program that obtains valid, DMV-matched RSD readings on 50% of the on-road vehicles driving in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

Appendix B
Effects of Varying RSD Program Coverage

Table B-1. Four-Strategy Package for a 10% Any-VSP RSD Coverage Program [b1]

		Vehicle Selection Method			Adding RSD to VID-alone causes:
		VID alone	RSD alone	VID+RSD together	
Calling-In	Targeted Vehicles [c] at 5% Targeting (N)	669,403	22,716	669,403	
Calling-In	Targeted Vehicles that Fail ASM at Decision Point (N)	222,039	9,890	223,582	
Calling-In	ASM Fail Rate at Decision Point (%)	33.2%	43.5%	33.4%	
Directing	Targeted Vehicles [c] at 40% Targeting (N)	5,355,228	181,729	5,355,228	
Directing	Δ[i] Targeted Vehicles that Fail ASM at Decision Point (N)	115,080	4,621	115,713	
Directing	Δ[i] ASM Fail Rate at Decision Point (%)	2.1%	2.5%	2.2%	
Exempting	Targeted Vehicles [c] at 20% Targeting (N)	2,677,614	90,865	2,677,614	
Exempting	Targeted Vehicles that Fail ASM at Decision Point (N)	58,371	793	57,522	
Exempting	ASM Fail Rate at Decision Point (%)	2.2%	0.9%	2.1%	
Scrapping	Targeted Vehicles [c] for 16M$ Purchase Budget (N)	58,908	22,716	58,908	
Scrapping	Targeted Vehicles that Fail ASM at Decision Point (N)	22,936	9,186	23,128	
Scrapping	ASM Fail Rate at Decision Point (%)	38.9%	40.4%	39.3%	

[b1] The small RSD program (10% any-VSP RSD coverage) will provide VSP-qualified RSD readings on 454,323 vehicles subject to I/M in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[i] Inspecting targeted vehicles at high-performing stations rather than at average-performing stations causes these <u>increases</u> in the number of targeted vehicles that fail and corresponding increases in ASM fail rates.

Table B-1 (continued).

		Vehicle Selection Method			Adding RSD to VID-alone causes:
		VID alone	**RSD alone**	**VID+RSD together**	
Benefits	**Δ Failed Miles Driven (miles/2years)** [d]	A decrease of **1,613,638,558** failed miles driven	A decrease of **114,371,969** failed miles driven	A decrease of **1,627,408,320** failed miles driven	A further decrease of **13,769,763** failed miles driven
	Total ΔFTP HC+NOx (tons/2years) [f]	A decrease of **10,053** tons	A decrease of **1,302** tons	A decrease of **10,166** tons	A further decrease of **112** tons
Total Costs ($/2years)		**$ 32,599,772** spent	**$ 25,655,686** spent	**$ 38,545,543** spent	A further increase of **$ 5,945,772** spent
Cost Effectiveness ($/ton HC+NOx) [h]		**$ 3,243** spent for each ton of emissions reduced	**$ 19,712** spent for each ton of emissions reduced	**$ 3,792** spent for each ton of emissions reduced	An additional **$ 52,857** spent for each additional ton of emissions reduced

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

Table B-2. Four-Strategy Package for a 30% Any-VSP RSD Coverage Program[b2]

		Vehicle Selection Method			
		VID alone	**RSD alone**	**VID+RSD together**	**Adding RSD to VID-alone causes:**
Calling-In	**Targeted Vehicles [c] at 5% Targeting (N)**	669,403	68,148	669,403	
	Targeted Vehicles that Fail ASM at Decision Point (N)	222,039	29,670	226,668	
	ASM Fail Rate at Decision Point (%)	33.2%	43.5%	33.9%	
Directing	**Targeted Vehicles [c] at 40% Targeting (N)**	5,355,228	545,187	5,355,228	
	Δ[i] Targeted Vehicles that Fail ASM at Decision Point (N)	115,080	13,864	116,979	
	Δ[i] ASM Fail Rate at Decision Point (%)	2.1%	2.5%	2.2%	
Exempting	**Targeted Vehicles [c] at 20% Targeting (N)**	2,677,614	272,594	2,677,614	
	Targeted Vehicles that Fail ASM at Decision Point (N)	58,371	2,378	55,823	
	ASM Fail Rate at Decision Point (%)	2.2%	0.9%	2.1%	
Scrapping	**Targeted Vehicles [c] for 16M$ Purchase Budget (N)**	58,908	28,622	57,569	
	Targeted Vehicles that Fail ASM at Decision Point (N)	22,936	12,751	23,026	
	ASM Fail Rate at Decision Point (%)	38.9%	44.5%	40.0%	

[b2] The medium RSD program (30% any-VSP RSD coverage) will provide VSP-qualified RSD readings on 1,362,968 vehicles subject to I/M in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[i] Inspecting targeted vehicles at high-performing stations rather than at average-performing stations causes these increases in the number of targeted vehicles that fail and corresponding increases in ASM fail rates.

Table B-2 (continued).

		Vehicle Selection Method: VID alone	Vehicle Selection Method: RSD alone	Vehicle Selection Method: VID+RSD together	Adding RSD to VID-alone causes:
Benefits	**Δ Failed Miles Driven (miles/2years)** [d]	A decrease of **1,613,638,558** failed miles driven	A decrease of **205,495,527** failed miles driven	A decrease of **1,651,242,986** failed miles driven	A further decrease of **37,604,428** failed miles driven
Benefits	**Total ΔFTP HC+NOx (tons/2years)** [f]	A decrease of **10,053** tons	A decrease of **2,189** tons	A decrease of **10,328** tons	A further decrease of **275** tons
Total Costs ($/2years)		**$ 32,599,772** spent	**$ 44,748,009** spent	**$ 56,738,287** spent	A further increase of **$ 24,138,516** spent
Cost Effectiveness ($/ton HC+NOx) [h]		**$ 3,243** spent for each ton of emissions reduced	**$ 20,445** spent for each ton of emissions reduced	**$ 5,494** spent for each ton of emissions reduced	An additional **$ 87,928** spent for each additional ton of emissions reduced

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.

Table B-3. Four-Strategy Package for a 50% Any-VSP RSD Coverage Program[b3]

		Vehicle Selection Method			
		VID alone	**RSD alone**	**VID+RSD together**	**Adding RSD to VID-alone causes:**
Calling-In	**Targeted Vehicles [c] at 5% Targeting (N)**	669,403	113,581	669,403	
	Targeted Vehicles that Fail ASM at Decision Point (N)	222,039	49,450	229,754	
	ASM Fail Rate at Decision Point (%)	33.2%	43.5%	34.3%	
Directing	**Targeted Vehicles [c] at 40% Targeting (N)**	5,355,228	908,645	5,355,228	
	Δ[i] Targeted Vehicles that Fail ASM at Decision Point (N)	115,080	23,107	118,245	
	Δ[i] ASM Fail Rate at Decision Point (%)	2.1%	2.5%	2.2%	
Exempting	**Targeted Vehicles [c] at 20% Targeting (N)**	2,677,614	454,323	2,677,614	
	Targeted Vehicles that Fail ASM at Decision Point (N)	58,371	3,963	54,125	
	ASM Fail Rate at Decision Point (%)	2.2%	0.9%	2.0%	
Scrapping	**Targeted Vehicles [c] for 16M$ Purchase Budget (N)**	58,908	31,803	56,230	
	Targeted Vehicles that Fail ASM at Decision Point (N)	22,936	14,384	22,820	
	ASM Fail Rate at Decision Point (%)	38.9%	45.2%	40.6%	

[b3] The large RSD program (50% any-VSP RSD coverage) will provide VSP-qualified RSD readings on 2,271,613 vehicles subject to I/M in the five largest AQMDs.

[c] of 13,388,069 vehicles in the I/M fleet.

[i] Inspecting targeted vehicles at high-performing stations rather than at average-performing stations causes these increases in the number of targeted vehicles that fail and corresponding increases in ASM fail rates.

Table B-3 (continued).

		Vehicle Selection Method			Adding RSD to VID-alone causes:
		VID alone	**RSD alone**	**VID+RSD together**	
Benefits	**Δ Failed Miles Driven (miles/2years)** [d]	A decrease of **1,613,638,558** failed miles driven	A decrease of **275,561,141** failed miles driven	A decrease of **1,673,813,774** failed miles driven	A further decrease of **60,175,216** failed miles driven
Benefits	**Total ΔFTP HC+NOx (tons/2years)** [f]	A decrease of **10,053** tons	A decrease of **2,793** tons	A decrease of **10,461** tons	A further decrease of **408** tons
Total Costs ($/2years)		**$ 32,599,772** spent	**$ 86,054,087** spent	**$ 97,438,659** spent	A further increase of **$ 64,838,889** spent
Cost Effectiveness ($/ton HC+NOx) [h]		**$ 3,243** spent for each ton of emissions reduced	**$ 30,811** spent for each ton of emissions reduced	**$ 9,314** spent for each ton of emissions reduced	An additional **$ 158,877** spent for each additional ton of emissions reduced

[d] of 30,624,179,635 total Failed Miles Driven over 2 years by 13,388,069 vehicles in the I/M fleet.

[f] of 605,088 total tons of FTP HC + NOx emissions in 2 years by 13,388,069 vehicles in the I/M fleet.

[h] Compare cost-effectiveness values to the Carl Moyer criterion of $14,300 spent for each ton of HC+NOx emissions reduced.