Eastern Research Group, Inc.

Estimating Benefits and Costs of Improvement Strategies for the California I/M Program: Implementation Options for Using RSD

REPORT
Version 9 (final)

Prepared for:

California Air Resources Board and California Bureau of Automotive Repair

Prepared by:

Eastern Research Group, Inc.

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Table of Contents

List of Tables

List of Figures

Glossary

Average-Performing Station – A hypothetical category of I/M inspection stations that have the average ASM inspection performance of all stations in the California I/M system (including Test-Only, Test-and-Repair, Gold-Shield, Referee, etc. stations), on all vehicles inspected, and for the study's historical VID data period for ASM inspections (July 1998 through April 2005) taken as a whole.

Call-In ASM – A mid-cycle ASM test performed to determine if a vehicle needs to be repaired before its next regular I/M test.

Calling-In No-Sticker – An I/M program improvement strategy in which high-risk vehicles are requested mid-cycle to get an ASM test. Vehicles are not given a new 24-month certification for meeting call-in ASM requirements. In this instance, vehicles must follow the reinspection requirements of their existing certification even though they have participated in the call-in process.

Calling-In Sticker – An I/M program improvement strategy in which high-risk vehicles are requested mid-cycle to get an ASM test. In this instance, vehicles that meet call-in requirements are issued a new 24-month certification at the time of the call-in ASM. The vehicles are, therefore, on a new reinspection schedule and would be expected to receive their next-cycle inspection in about 24 months after the call-in ASM.

CN – Calling-In No-Sticker

CS – Calling-In Sticker

Cprob – The cumulative I/M completion probabilities. The probability that a vehicle will receive its next-cycle certification within a given number of months after its previous-cycle certification.

Decision Point – The date when a decision is made to intervene in the Normal I/M Process or not.

DI – Directing

Directing – An I/M program improvement strategy in which vehicles that are expected to soon appear for their biennial inspection are sent to high-performing stations instead of allowing the vehicle owner to choose the inspection station. In general, high-risk vehicles are directed.

EX – Exempting

Exempting – An I/M program improvement strategy in which vehicles that are expected to soon appear for their biennial inspection are allowed to skip the inspection and receive a standard 24-month certification. In general, low-risk vehicles are exempted.

FMD – Failed Miles Driven. An acronym to describe miles driven in an ASM-failed status over the 24 months following a decision point. The value is calculated by summing the monthly estimate of overall ASM failure probability times the number of miles driven in the month. It is a probabilistic value because the ASM failure probability is an estimate of the fraction of vehicles with the same vehicle description, VID history, and/or RSD measurements that would fail an ASM test.

ΔFMD – Change in estimated failed miles driven over the 24 months following the decision point. ΔFMD is a measure of the change in estimated failed miles driven caused by a selected intervention. A negative ΔFMD indicates that the intervention caused the estimated failed miles driven to drop in comparison with the Normal I/M Process.

Fprob – The probability that a vehicle will fail a test. Fprob is also equivalent to the fraction of vehicles that would fail the test for those vehicles in the same circumstance. All Fprobs in this study are fractions.

ΔFTP/$ – The change in estimated FTP mass emissions over the 24 months after a Scrapping decision in comparison with the Normal I/M Process divided by the market value of the vehicle.

High-Performing Station – A hypothetical category of California I/M inspection stations that would perform more-accurate I/M inspections and therefore would be able to provide greater emissions reductions than average-performing stations. In the analysis we did not attempt to determine which stations or which types of stations (Test Only, Test-and-Repair, Gold Shield, etc.) were average-performing or high-performing. Instead, based on station-performance information from BAR, the analysis assumes that the hypothetical high-performing stations have fail rates that are 20% higher and after-repair emissions levels that are 20% lower than those of average-performing stations.

Intervention – The act of taking special action that is beyond the Normal I/M Process. Examples of intervention include sending letters to I/M program participants for Directing, Exempting, Calling-In, or Scrapping.

NIM – Normal I/M Process

Normal I/M Process – The process by which vehicles that participate in the California I/M program voluntarily get their vehicles inspected at I/M program stations in accordance with the rules for 24-month certifications. The Normal I/M Process includes biennial inspections and change of ownership inspections. The Normal I/M Process does not include, for discussion purposes in this study, Directing, Exempting, Calling-In, or Scrapping.

NX – One or more of the oxides of nitrogen. Although NO and NOx are measured differently and are different chemically, we make no distinction here.

RSD – Remote Sensing Device. An instrument that measures the instantaneous tailpipe emissions concentrations of HC, CO, and NX of on-road vehicles by shining a light beam across the road so that it intercepts the plume from the vehicle's tailpipe.

Scrappage ASM – A mid-cycle ASM test performed to determine if the State should purchase the vehicle to retire it.

Scrapping – An I/M program improvement strategy in which high-risk vehicles are purchased from their owners by the State and destroyed. High-priority Scrapping candidates are those that produce a large mass of emissions and have a low market value.

SP – Scrapping

VID – An I/M program's vehicle information database, which contains a specified list of variables that characterize all past inspections of vehicles participating in the I/M program.

VID History – The entire list of records from the VID for an individual vehicle that describes all of the interactions between the vehicle and the I/M program throughout the period during which the vehicle was participating in the I/M program.

VSP – Vehicle specific power. A measure of the instantaneous power required per unit of vehicle mass required to move the vehicle at a given instant. The units of VSP in this study are kilowatts/megagram (kW/Mg). In this study we haven chosen to use 5 to 25 kW/Mg as the emissions-representative VSP range.

1.0 Introduction

This report estimates the incremental benefits and costs of adding remote sensing device (RSD) measurement capabilities to the existing California I/M Program. RSD is a technology that measures the emissions of vehicles as they pass the RSD instruments on the side of the roadway. This report will use estimated costs of RSD implementation and estimated benefits to evaluate different implementation strategies. The benefits of adding RSD to the I/M program are determined by an evaluation of the estimated fleet benefits when vehicles are ranked by variables that include RSD information (which requires on-road data collection) and by variables that include data already collected by the I/M program (VID History), but do not include RSD information.

In the modeling report [1], we described how the RSD evaluation was developed. In this implementation report we will describe specific strategies that could use RSD and other techniques to enhance the I/M program. The modeling report described the benefits for the sampled fleet of 69,629 vehicles. In this report we project the costs and benefits to the 2004 California fleet. Costs and benefits are calculated for a mix of strategies to examine the incremental impact of RSD technology.

It should be noted that RSD and other strategies can be used in many different ways. We have tried to select the most appropriate uses of the RSD technology and present the costs and benefits of these in this report.

2.0 Intervention Activities Evaluated in This Report

The analysis in this document specifically addresses the first four questions from Task 1 of the work assignment. *The primary objective of this study is to assess the effectiveness of remote sensing technology as a supplemental tool to enhance California's inspection and maintenance program. Specifically, the pilot study shall determine:*

a. Whether remote sensing technology can be used to improve the state's high emitter profile (HEP), used to direct vehicles to high-performing stations.

In this study this intervention activity is called Directing. Directing occurs for vehicles that are expected to soon receive their biennial inspection. For Directing, the vehicles that represent the greatest risk to the state would be required to be inspected at high-performing stations in the I/M program. Directing is already being performed in the I/M program as an intervention activity and is 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 average-performing stations are.

The benefit of directing vehicles to high-performing stations depends on the difference in performance between high-performing and average-performing stations. In this report we have assumed that average-performing stations, in general, are 80% as effective as high-performing stations. This is an assumption based on previous work by BAR but can be modified in our analysis if new estimates become available. We apply this assumption as an adjustment to the base benefit calculations made in the modeling report. If average-performing stations are just as likely to perform a proper ASM inspection, then the net benefit of Directing is zero. Nevertheless, Directing is a measure that can be applied to the riskiest, or most high emissions potential vehicles. Directing vehicles may cause a higher level of customer inconvenience since they are required to have their vehicles tested at specified stations. If we use a method that finds the vehicles that have the largest future increase in failed miles driven, then the riskiest vehicles have a better chance of being properly inspected while causing only small increases in customer inconvenience.

b. Whether remote sensing technology can be an effective tool to "clean screen" vehicles and exempt them from the next scheduled smog check inspection thus reducing program costs.

We have performed benefits calculations for this intervention activity which we call Exempting. Exempting would normally occur shortly before vehicles are expected to appear for their biennial inspection. Vehicles that are expected to be of 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 increase emissions and failed miles driven. The goal of the vehicle prioritization is to preferentially exempt vehicles that would have the smallest increases, which would represent the smallest risk to the airshed.

For Exempting we want to identify vehicles that would drive the smallest number of miles in a failed status over the 24 months after the Exempting decision. The Exempting decision is made in the month that vehicles are scheduled to receive their next inspection. When vehicles are exempted, they receive a new certification sticker but are not required to get an ASM emissions test. Accordingly, all exempted vehicles as a group – even those that would pass – continue on their average trend of ever increasing emissions. In addition, vehicles that would fail are mistakenly not inspected and therefore not repaired. For both reasons, Exempting causes the failed miles driven and the FTP emissions over the next 24 months to be higher than if Exempting were not practiced. Nevertheless, if we can use a method that finds the vehicles that have the lowest future increases in these two quantities, then the increases can be minimized while achieving large increases in customer convenience.

c. *Whether remote sensing technology can be an effective tool to identify high-emitting vehicles between regular inspection cycles and to document the emission reduction benefits of such a program.*

In the analysis in this report, we call this intervention activity Calling-In, in which vehicles are considered for Calling-In at anytime in the I/M program cycle. We performed benefit calculations for one Calling-In option called Calling-In No-Sticker where vehicles would be given an I/M station ASM test and if they failed the test the vehicle would be required to be repaired and to pass a follow up ASM test. However, for this effort 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 called in for an intervention test performed at a regular I/M station and would be required to be repaired and to pass a follow-up ASM test. However, the vehicle would then be issued a new biennial certification. This would put the vehicle on a new regular I/M schedule.

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

In this document we call this intervention activity Scrapping. In this analysis, we consider 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 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 for scrappage. 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 decrease in FTP 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 the candidate vehicles.

The estimation of benefits for scrapping differs somewhat from that of Directing, Exempting, and Calling-In. Vehicle rankings and the selection of the top candidates from the rankings are different because when a vehicle is scrapped all of the emissions of the vehicle – not just the excess emissions – drop to zero.[1]

The essence of Scrapping is that the mass emissions to be emitted during the vehicle's remaining life are "purchased" by the State. If we assume that California's annual scrappage budget is $8,000,000, we want to rank vehicles for scrapping such that the vehicles that constitute the best "bargains" are at the top of the list. Accordingly, to estimate how good a bargain a vehicle is, for each vehicle we divide the benefits to be realized by scrapping the vehicle by the estimated value of the vehicle. Each scrappage ranking is then used by "purchasing" vehicles from the top of the ranking until the $8,000,000 is spent. Depending on the values of the vehicles at the top of each ranking, different numbers of vehicles may be purchased for different rankings. The mass

[1] For the purposes of ranking vehicles, we do not need to consider the emissions of the owner's replacement vehicle. For evaluating the emissions benefits of Scrapping, by assuming that the replacement vehicle has zero emissions, we are calculating the maximum emissions benefits that could be achieved by a Scrapping program.

emissions over the remaining life of the purchased vehicles is the mass emissions bought with the $8,000,000.

2.1 Basic Ranking Methods

In the modeling report [1], we developed 35 methods that can be used to rank vehicles for various intervention strategies. Table 2-1, which is taken from that report, summarizes the 35 ranking methods (Column 2) in terms of the basic ranking criterion (Column 1), the type of data required (Column 3), and the strategies that each can be applied to (Column 4) as shown by an X or a large dot. For the cost-benefit analysis described in this report we have chosen five basic sets of ranking method inputs to evaluate: A (Model Year), B (Vehicle Description), C (VID History), D (VID History + RSD), and F (RSD). Three of the sets of inputs do not use RSD and two do. Based on the evaluations performed in the modeling report, for further investigation in this report, we selected only the best performing methods for the strategies and for each of the five sets of ranking method inputs. Under each strategy heading in the last column of Table 2-1, the chosen vehicle ranking methods are shown by a large dot.

Model Year Inputs – FprobDP by A (Method 18) ranks vehicles for selection for Directing, Exempting, and Calling-In No-Sticker by a vehicle's overall ASM failure probability at the Decision Point. This one-point-in-time probability takes into account only the model year of the vehicle. This method does not distinguish among rankings for different types of interventions. For Scrapping, the corresponding ranking method of choice is FprobDP/$ by A (Method 24) since we know from the modeling report that using vehicle value in the denominator greatly improves Scrapping ranking performance.

Vehicle Description Inputs – FprobDP by B (Method 19) ranks vehicles for selection for Directing, Exempting, and Calling-In No-Sticker by a vehicle's overall ASM failure probability at the Decision Point. This one-point-in-time probability takes into account only the vehicle description, which is made up of model year, make, car or truck, engine, and emission control system. This method does not distinguish among different types of interventions. For Scrapping, the corresponding ranking method of choice is FprobDP/$ by B (Method 25).

RSD Inputs – FprobDP by F (Method 23) ranks vehicles for selection for Directing, Exempting, and Calling-In No-Sticker by a vehicle's overall ASM failure probability at the Decision Point. This one-point-in-time probability takes into account only the vehicle's recent RSD HC, CO, and NX measurements. This method does not distinguish among different types of interventions. For Scrapping, the corresponding ranking method of choice is FprobDP/$ by F (Method 29).

Table 2-1. Categorization of the 35 Ranking Methods

Description of Vehicle Ranking Criterion	Vehicle Ranking Method		Model On Which the Vehicle Ranking is Based (Type of Data Required)	Strategy That Ranking Method Can Be Used For				
				DI	EX	CN	CS	SP
Change in Failed Miles Driven Over 24 Months after the Decision Point (ΔFMD)	1	DI ΔFMD by C	C (VID History)	●				
	2	EX ΔFMD by C	C (VID History)		●			
	3	CN ΔFMD by C	C (VID History)			●		
	4	CS ΔFMD by C	C (VID History)				X	
	5	DI ΔFMD by D	D (VID History + RSD)	●				
	6	EX ΔFMD by D	D (VID History + RSD)		●			
	7	CN ΔFMD by D	D (VID History + RSD)			●		
	8	CS ΔFMD by D	D (VID History + RSD)				X	
Change in FTP Mass Emissions Over 24 Months after the Decision Point per Vehicle Value Dollar (ΔFTP/$)	9	ΔFTP HC/$ by C	C (VID History)					X
	10	ΔFTP CO/$ by C	C (VID History)					●
	11	ΔFTP NX/$ by C	C (VID History)					X
	12	ΔFTP HC/$ by D	D (VID History + RSD)					X
	13	ΔFTP CO/$ by D	D (VID History + RSD)					●
	14	ΔFTP NX/$ by D	D (VID History + RSD)					X
	15	ΔFTP HC/$ by E	E (ASM Cutpoints + RSD)					X
	16	ΔFTP CO/$ by E	E (ASM Cutpoints + RSD)					X
	17	ΔFTP NX/$ by E	E (ASM Cutpoints + RSD)					X
Fprob at Decision Point (FprobDP)	18	FprobDP by A	A (Model Year)	●	●	●	X	X
	19	FprobDP by B	B (Vehicle Description)	●	●	●	X	X
	20	FprobDP by C	C (VID History)	X	X	X	X	X
	21	FprobDP by D	D (VID History + RSD)	X	X	X	X	X
	22	FprobDP by E	E (ASM Cutpoints + RSD)	X	X	X	X	X
	23	FprobDP by F	F (RSD)	●	●	●	X	X
Fprob at Decision Point per Vehicle Value Dollar (FprobDP/$)	24	FprobDP/$ by A	A (Model Year)					●
	25	FprobDP/$ by B	B (Vehicle Description)					●
	26	FprobDP/$ by C	C (VID History)					X
	27	FprobDP/$ by D	D (VID History + RSD)					X
	28	FprobDP/$ by E	E (ASM Cutpoints + RSD)					X
	29	FprobDP/$ by F	F (RSD)					●
One-Time Observed RSD Emissions Concentration	30	RSD [HC]	No Model (Measured [RSD])	X	X	X	X	X
	31	RSD [CO]	No Model (Measured [RSD])	X	X	X	X	X
	32	RSD [NX]	No Model (Measured [RSD])	X	X	X	X	X
One-Time Observed RSD Emissions Concentration per Vehicle Value Dollar	33	RSD [HC]/$	No Model (Measured [RSD])					X
	34	RSD [CO]/$	No Model (Measured [RSD])					X
	35	RSD [NX]/$	No Model (Measured [RSD])					X

DI = Directing
CS = Calling-In Sticker
EX = Exempting
SP = Scrapping
CN = Calling-In No-Sticker

VID History Inputs – ΔFMD by C ranks vehicles for selection by the Model-C-estimated change in the estimated number of miles the vehicle will drive in an ASM-failed status over the 24 months after the Decision Point if the vehicle participated in the strategy. Model C is our best non-RSD method. This integrated estimate of risk to the I/M program takes into account the ASM cutpoints, vehicle age, previous-cycle initial-ASM-test pass/fail result, time since the previous-cycle initial test, as well as the vehicle description, which is made up of model year, make, car or truck, engine, and emission control system. This method also takes into account the details of different types of interventions and can create rankings that distinguish among them. Accordingly, the VID history ranking method for Directing is DI ΔFMD by C (Method 1), for Exempting is EX ΔFMD by C (Method 2), and for Calling-In No-Sticker is CN ΔFMD by C (Method 3). For Scrapping, the VID history ranking method of choice is ΔFTP CO/$ by C (Method 10) since FTP mass emissions is the focus of Scrapping.

RSD/VID Inputs – ΔFMD by D also ranks vehicles for selection by the Model-D-estimated change in the number of miles the vehicle will drive in an ASM-failed status over the 24 months after the Decision Point if the vehicle participated in the strategy. Model D is our best method that includes RSD measurements. This integrated estimate of risk to the I/M program takes into account a vehicle's recent RSD HC, CO, and NX, as well as the ASM cutpoints, vehicle age, previous-cycle initial-ASM-test pass/fail result, time since the previous-cycle initial test, and the vehicle description, which is made up of model year, make, car or truck, engine, and emission control system. This method also takes into account the details of different types of interventions and can create rankings that distinguish among them. Accordingly, the RSD/VID ranking method for Directing is DI ΔFMD by D (Method 5), for Exempting is EX ΔFMD by D (Method 6), and for Calling-In No-Sticker is CN ΔFMD by D (Method 7). For Scrapping, the VID history ranking method of choice is ΔFTP CO/$ by D (Method 13) since FTP mass emissions is the focus of Scrapping.

2.2 Measures of Benefits and Other Practical Quantities

For each fleet ranking method, we need to calculate quantities that can be used to judge the value of adding intervention activities to the I/M program. Value is ultimately determined by considering costs and benefits; however, other quantities of a practical nature can also be used to evaluate. In this cost-benefit analysis, we consider three quantities. The first two are benefits:

- Change in estimated failed miles driven (FMD) of the I/M fleet over the 24 months after each vehicle's decision point.

- Change in estimated FTP HC, CO, and NX mass emissions of the I/M fleet over the 24 months after the decision point.

And the third is not an actual benefit, but is a quantity of practical importance:

- Fraction of vehicles that fail the ASM test at the decision point.

2.3 Existing I/M Program Benefits and Annual I/M Program Benefits

At the conclusion of this report, we will estimate the biennial mass emissions benefits of individual I/M program intervention activities. To put those results in perspective, we provide biennial estimates of the total I/M benefit (that is, relative to no I/M program) and the incremental biennial benefit of an annual I/M program over a biennial I/M program.

For comparison purposes the current program has been estimated to reduce HC, CO and NX emissions by the following amounts in Calendar Year 2004 based on “Evaluation of the California Enhanced Vehicle Inspections and Maintenance (Smog Check) Program,” April 2004 Draft Report to the Inspection and Maintenance Review Committee:

- Exhaust HC – 127 tons/day (92,710 tons/2 years)
- CO – 1360 tons/day (992,800 tons/2 years)
- NX – 158 tons/day (115,340 tons/2 years)

ERG also estimated the benefit if the current program were converted to an annual program rather than the existing biennial program, all other aspects being equal. We estimated this change using the latest version of the EMFAC 2.20.8 version for Calendar Year 2004. The estimated additional benefit would be:

- Exhaust HC – 28 tons/day (20,577 tons/2 years)
- CO – 378 tons/day (275,683 tons/2 years)
- NX – 44 tons/day (32,359 tons/2 years)

Thus, the incremental HC plus NX benefit from an annual program over a biennial program is estimated by EMFAC to be 52,936 tons/2years. As we shall see in Section 6, the size of the HC plus NX emissions benefits of a package of supplemental I/M program strategies made up of Calling-In, Directing, Exempting, and Scrapping operating under expected fleet vehicle targeting criteria in the five largest AQMDs is on the order of 10,000 tons/2years. This value is relatively independent of whether RSD is used or not.

3.0 Conditions for Calculating Cost-Effectiveness

The cost-effectiveness calculations presented in this report are specific to each particular scenario. We chose an example scenario with 50% any-VSP coverage to demonstrate the results for large-scale implementation of special strategies that could supplement the I/M program. This scenario is described in Section 3.1. The ability of an RSD measurement program to cover the I/M fleet is key to RSD's usefulness as a supplementary component to the I/M program and is quantified in the remaining parts of Section 3.

Section 3.2 introduces two definitions of coverage and uses EMFAC to describe the 2004 California fleet. Then, Section 3.3 presents the results of the analysis that quantifies the coverage of this pilot study. Section 3.4 describes the development of methods that can be used to determine the coverage characteristics of large RSD programs. Section 3.5 then uses those methods, to quantify the coverage characteristics for small, medium, and large RSD programs for the California situation. Finally, Section 3.6 presents the California-specific problems that the pilot study found for conducting an RSD program in California. These problems could make the implementation of a California RSD program more difficult and more expensive than previously experienced in other states.

The cost and benefits calculated in this analysis are for a two-year time frame, a full I/M fleet basis, and are incremental to the base case. The following describes the rationale for these three choices for the analysis:

- We have chosen a two-year time frame because the I/M program is biennial. The benefits estimated in the modeling report [1] were on a two-year basis, and therefore, we have chosen to bring costs in on the same basis.
- Using a full I/M fleet basis, which is designed to cover all of the vehicles in the I/M fleet, provides a comprehensive evaluation of the costs and benefits. The non-RSD vehicle ranking methods can be applied to almost all fleet vehicles; however, vehicle ranking methods that require RSD measurements can be used on only a portion of the I/M fleet. The reason for this is that even with the largest statewide RSD program, only a portion of the vehicles in the I/M fleet will receive RSD readings that are valid and DMV-matched and are obtained while the vehicle is operating under emissions-representative conditions. Therefore, when evaluating costs and benefits for the full-fleet using ranking methods containing RSD inputs, part of the fleet is ranked with ranking methods that require RSD inputs, and the remainder of the fleet is ranked using non-RSD ranking methods.
- The intent of this evaluation is to determine the cost-effectiveness of adding intervention activities to the I/M program. Therefore, we calculate incremental

costs and benefits relative to the I/M program. We are not attempting to estimate the costs and benefits of the I/M program, and we are not attempting to estimate the costs and benefits of a stand-alone RSD program. Because the costs and benefits are incremental, the costs and benefits can be considered credits or debits relative to the base case I/M program.

3.1 Description of the Example Scenario

The costs, benefits, and cost-effectiveness of supplementing the I/M program with RSD measurements depends on the mix of intervention activities (Calling-In, Directing, Exempting, or Scrapping) that are chosen, on the fleet targeting or penetration chosen for each intervention activity, and on the method chosen to prioritize vehicles for targeting. Since it is not possible to present all possible combinations of these choices in this report, we use one combination that serves as a "test bed" to demonstrate the calculations.

We selected all four intervention activities (Calling-In, Directing, Exempting, and Scrapping) for the mix so that all four types of activities could be costed. In addition, because RSD costs tend to be constant for a given portion of the fleet covered, using the RSD data for as many activities as possible increases the value of the RSD measurement program. Including all four activities, therefore, makes the incremental cost-benefit calculated for adding RSD to the I/M program as attractive as possible.

For the example scenario we needed to select one mix of intervention activities with an I/M fleet penetration for each activity. Penetration is the fraction of the I/M fleet that is selected for targeting for a specific type of intervention activity. Targeted vehicles are those whose selection would most benefit the goals of the I/M program. The fleet penetrations were chosen to be realistic, that is, near the levels that we thought would most likely be used in the California I/M program.

The fleet penetrations used in this cost-benefit analysis were 5% for Calling-In No-Sticker, 40% for Directing, 20% for Exempting, and whatever fleet targeting percentage was needed to spend $16,000,000 to purchase scrappage vehicles over one biennial cycle. This resulted in a penetration for Scrapping of approximately 0.24% to 0.62% of the fleet.

The fleet penetration of 40% for Directing was chosen because it was near the 36% penetration that is currently being used in the I/M program for Directing. In the case of Exempting, the evaluation in the modeling report [1] indicated that emissions and failed miles driven debits would be relatively small for Exempting penetrations up to 20% of the fleet. Note that this 20% for Exempting is beyond the policy exemption of the six newest model years that is already in place in the I/M program. Similarly, for Calling-In No-Sticker, the modeling report indicated that the benefits that could be achieved at a 5% penetration were attractive. Since Calling-In vehicles represents an increased load on the I/M program inspection stations, we did not want to evaluate fleet penetrations higher than 5% at this time. The fleet penetrations used for Scrapping were the result of "spending" $16,000,000 over the two-year I/M cycle for the purchase of scrappage vehicles. The fleet penetration percentage for Scrapping varies by the ranking method. This is a result of the different ranking properties of each of the ranking methods.

3.2 Quantifying Fleet RSD Coverage

The size of an RSD data collection effort is driven by the desired coverage of the fleet. RSD cannot get measurements on all vehicles in the on-road fleet. RSD units can be deployed only in locations meeting special criteria such as the number of vehicles passing at a time, space on the side of the road to safely fit the equipment, and the speed and operating mode of passing vehicles. Also, it is not generally cost effective to measure at sites with little traffic. Unmanned RSD units will get around some of these limitations, but they have their own limitations having to do with installing utilities in remote areas. Since a certain fraction of the fleet will seldom pass by some RSD sites, that fraction of the fleet has little chance of getting an RSD measurement.

As vehicles pass by an RSD unit, the percentage of observations that will produce data that can be used to select vehicles for intervention activities is limited by a number of factors:

- not all of RSD measurements are valid,
- not all produce a license plate image that is usable ,
- not all of vehicles are being operated in a way at the time of the RSD reading that fairly represents the typical emissions of the vehicle, and
- Some of the vehicles have already been measured by RSD.

Small RSD programs can rely on sites where the impact of these effects is relatively small. As program sizes increase, sites where the impacts are greater typically must be included in order to obtain the desired fleet coverage. Therefore, the fractions that we use to account for these effects depend upon the size of the program relative to the size of the fleet. For example, in California it takes much more than five times the effort to get a valid reading on 50% of the fleet than on 10% of the fleet.

Two definitions of RSD fleet coverage – In this analysis, we discuss the coverage of the fleet with RSD measurements using two different definitions of coverage. The reader should understand these two distinct definitions because they affect the calculated costs and benefits of the analysis. Either definition can express RSD coverage relative to either the total number of vehicles in the fleet or the total number of vehicles in the I/M fleet. The important distinction between the two definitions is whether the RSD measurements are taken on a vehicle when it is operating in the emissions-representative VSP range (5 to 25 kW/Mg)[2, 3] or whether it is operating at any VSP. The two definitions are:

- **Any-VSP RSD coverage** – This refers to the number or fraction of vehicles that receive at least one valid RSD reading (as determined by the RSD analyzer software) on a vehicle that is matched by the license plate to a record in the registration database. The vehicle-specific-power associated with these RSD readings could have any value. The RSD readings could be for vehicles that are operating at moderate load, at steady cruise, under deceleration, or under heavy acceleration. RSD data collection vendors typically use this definition of coverage.

- **Usable-VSP RSD coverage** – This refers to the number of vehicles or fraction of vehicles that receive at least one valid (as determined by the RSD analyzer software) RSD reading on a vehicle that is matched by the license plate to a record in the registration database, and the VSP is in the emissions-representative range. These RSD readings are only those associated with vehicles that are operating at moderate load.

Therefore, when speaking with RSD industry representatives, it is important to remember that the fleet RSD coverage values that they typically speak of do not take into account VSP. For the purposes of selecting vehicles for Directing, Exempting, Calling-In, or Scrapping, or for characterizing the emissions of the fleet, only the RSD readings that have in-range VSPs should be used.

Characteristics of the 2004 California fleet – Table 3-1 shows a breakdown of California's registered vehicles for Calendar Year 2004 by the five largest AQMDs for the

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[2] 1 Mg = 10^6 g = 1000 kg = 1 metric ton

[3] In this study we used 5 to 25 kW/Mg as the emissions-representative range. We chose this range based on work by J.L. Jimenez in his 1999 Ph.D. thesis Understanding and Quantifying Motor Vehicle Emissions with Vehicle Specific Power and TILDAS Remote Sensing. ESP uses 3 to 22 kW/Mg as their emissions-representative range. Sierra Research advocates using 4 to 14 kW/Mg as the appropriate emissions-representative range (see Appendix C).

statewide fleet and for the I/M fleet.[4] We treated the area outside of the five largest AQMDs as a single area, which we called Rest of State. In Calendar Year 2004, 1976 to 1998 model year vehicles would be subject to the I/M program. The counts of the I/M vehicles driving in the whole state, as estimated by EMFAC, are shown in the fourth column of Table 3-1. We assumed that 10% of vehicles registered outside of the five largest AQMDs annually travel inside of those AQMDs, and that they would be measured by RSD at about the same rate as vehicles that are registered inside the five largest AQMDs. These are vehicles that would happen to get measured by RSD, even though they are not registered in areas where RSD measurements are being taken. This assumption may slightly over-represent these vehicles because they will likely be commuters who travel during rush hours. The counts of the vehicles that are subject to I/M in the five largest AQMDs and the rest of the state and are driving in the five largest AQMDs are shown in the last column of Table 3-1. In this analysis, we modeled the incremental benefits of RSD only for I/M vehicles operated inside the five largest AQMDs, which covers about 83% (=11,358,066/13,388,069) of the statewide I/M fleet.

Table 3-1. Registered Vehicles in California in 2004

Area	Statewide Fleet		Fleet Subject to I/M	
	Model Years 1965-2004		Model Years 1976-1998	
	Driving in the Whole State	Driving in the 5 Largest AQMDs	Driving in the Whole State	Driving in the 5 Largest AQMDs
Sacramento	825,792	825,792	494,098	494,098
San Diego	1,966,649	1,966,649	1,176,709	1,176,709
San Joaquin	2,056,954	2,056,954	1,230,742	1,230,742
South Coast	9,100,769	9,100,769	5,445,282	5,445,282
Bay Area	4,655,741	4,655,741	2,785,679	2,785,679
Rest of State	3,769,745	376,975	2,255,559	225,556
Total	22,375,650	18,982,879	13,388,069	11,358,066

Proj1/Decision Model/Report/IM_Strategy_Evaluator_071119.xls

Potentially, RSD provides emissions measurements of any vehicles that drive past the RSD equipment, but because some vehicles are out-of-area, out-of-state, or out-of-model-year, only a fraction of the vehicles are I/M-program eligible. Table 3-1 also shows that about 59.8% of the 18,982,879 vehicles driving in the five largest AQMDs, or 11,358,066 vehicles, are vehicles that are subject to biennial I/M inspections.

[4] The values are from EMFAC. Details of the EMFAC run are given in Appendix N of Reference 1. The EMFAC version used was EMFAC2007 working draft V2.20.8 Feb 10, 2005.

3.3 Fleet Coverage Characteristics for this RSD Pilot Study

In many ways, the RSD data collection effort in this pilot study is the best source of information for estimating the attributes of a potential California RSD program that would complement the existing I/M program. However, the pilot study is a small effort compared to the scope of the full-scale RSD program that would be required to cover a large portion of the I/M fleet. Accordingly, our approach was to analyze the pilot data to measure the California characteristics of a small RSD data collection effort with an eye toward extrapolating the characteristics to an application of a much larger RSD program to the fleet. In this subsection we analyze (/proj1/ca_rsd_pilot/QC_field_data/coverage_percs.sas) the coverage characteristics of this pilot study. In Section 3.4 we develop methods that estimate coverage characteristics for any size RSD program in California.

The pilot study was a research study. Therefore, to analyze the data to estimate the characteristics of a standard RSD routine data collection program, we had to screen the observations for pilot study "artifacts" (i.e., data that would be available in the pilot study database that likely would not be available in an actual program implementation). Specifically, in those instances in the pilot study dataset where two RSD units were used simultaneously at one site, we removed one of the observations from the pair for each individual vehicle. Such "back to back" RSD measurements would most likely not be widely used in an actual RSD program. Also, we removed observations where the VSP could not be calculated because of missing road grade information.

We then proceeded to count the number of RSD observations and the number of unique vehicles that the RSD measurements represented for the various data attributes shown in Table 3-2 for the individual AQMDs and for the entire study, which was performed primarily in the five largest AQMDs, in which about 83% (=18,605,905/22,375,650) of the statewide fleet is registered. Because the numbers in Table 3-2 are from RSD data, they are all weighted by how much different types of vehicles drive (unlike the numbers in Table 3-1). For example, new vehicles are driven more than old ones, so the new vehicles in this RSD sample appear more frequently than their incidence in the DMV registration database would indicate.

Of the 2,231,515 raw observations in the pilot study, the bottom of Column G in Table 3-2 shows that 1,229,941 remained after filtering for two RSD units at one site and missing VSP values. The analysis indicated, as shown at the bottom of Column F, that 65.0% of these RSD observations were valid according to the RSD instrumentation software. 83.7% of those RSD observations were able to be matched, using the observed license plates, to records in the DMV

Table 3-2. Counts of Vehicles and RSD Measurements for the Pilot Study

A	B	C	D	E	F	G
	Vehicles			**RSD Measurements**		
	Subject to I/M, In-range-VSP, Unique, Valid, DMV-Matched	**In-range-VSP, Unique, Valid, DMV-Matched**	**Unique, Valid, DMV-Matched**	**Valid, DMV-Matched**	**Valid**	**Raw (modified)**
Area Any-VSP Coverage (% of California vehicles driving in the indicated area that received at least one valid, DMV-matched RSD measurement)	N ***% of In-range VSP, Unique, Valid, DMV-Matched***	N[c] ***% of Unique, Valid, DMV-Matched***	N[b] ***% of Valid, DMV-Matched***	N[a] ***% of Valid***	N ***% of Raw***	N
Sacramento AQMD (6.8%)	12,528 ***49%***	25,803 ***46%***	55,767 ***86%***	65,119 ***81%***	80,749 ***71%***	112,975
San Diego AQMD (2.4%)	18,043 ***46%***	39,282 ***82%***	48,045 ***82%***	58,483 ***78%***	74,817 ***78%***	95,433
San Joaquin AQMD (1.0%)	6,254 ***49%***	12,837 ***63%***	20,427 ***94%***	21,721 ***81%***	26,933 ***67%***	39,950
South Coast AQMD (4.3%)	124,969 ***48%***	258,219 ***66%***	392,355 ***83%***	474,605 ***84%***	568,338 ***63%***	909,072
Bay Area AQMD (0.4%)	4,211 ***49%***	8,654 ***52%***	16,657 ***95%***	17,514 ***79%***	22,044 ***71%***	30,876
All Areas in Study (3.0%)	173,821 ***48.0%***	362,145 ***64.6%***	560,883 ***83.9%***	668,873 ***83.7%***	799,077 ***65.0%***	1,229,941

[a]Used to determine RSD data collection cost.
[b]Used to determine Any-VSP RSD Coverage.
[c]Used to determine Usable-VSP RSD Coverage.

registration database to produce the 668,873 RSD measurements shown at the bottom of Column E.

For a standard RSD data collection program, RSD vendors usually base their data collection fees on the number of valid, DMV-matched RSD measurements that they provide their clients. Thus, in a typical RSD program the number of counts in Column E are used to determine RSD data collection costs. The number of RSD measurements in Columns F and G are not relevant to the costs. However, the number of raw observations can be used to estimate the number of RSD units that need to be put in the field to collect the raw measurements. In typical jurisdictions, that is, ones with abundant freeway on-ramps that provide good RSD data collection sites, one RSD unit can collect approximately one million raw RSD measurements in one year.

As the bottom of Columns D and E indicate, the 668,873 valid, DMV-matched RSD measurements represented 560,883 individual vehicles. We define the ratio of the number of unique vehicles in Column D to the number of valid, DMV-matched RSD measurements in Column E as the uniqueness. Uniqueness is an important characteristic of an RSD program. The uniqueness for this dataset is 83.9% as shown at the bottom of Column D. The average number of valid, DMV-matched RSD measurements per vehicle is the reciprocal of the uniqueness. For this dataset this is an average of 1.19 valid, DMV-matched RSD measurements/vehicle (= 1/0.839 = 668,873/560,883).

The any-VSP RSD coverage is obtained by dividing the number of counts in Column D by the number of vehicles driving in the five largest AQMDs. Therefore, the any-VSP coverage of the pilot study was about 3.0% since from Table 3-1 the estimated number of California vehicles driving in the five largest AQMDs is 18,982,879.

To be able to use the RSD measurements obtained on the vehicles in Column D for selecting vehicles for special strategies, the RSD measurements must be associated with a vehicle specific power value that is in the emissions representative range. Table 3-2 shows at the bottom of Column C that 362,145 vehicles or 64.6% of those at the bottom of Column D had at least one RSD measurement with an in-range VSP. The usable-VSP RSD coverage is obtained by dividing the number of counts in Column C by the number of vehicles driving in the five largest AQMDs. Thus, for the RSD pilot study, the usable-VSP RSD coverage is 1.9% (= 362,145/18,982,879). This means that the RSD pilot study obtained RSD measurements that can be used to characterize the emissions of about 1.9% of the vehicles driving in the five largest AQMDs.

Finally, only about 48% of the vehicles in Column C, or 173,821 vehicles, are subject to I/M. We determined this by counting the number of vehicles in Column C that had model years from 1976 through 1998, which are the model years for the I/M program's biennial inspection at the time of the study.

In the above discussion, we have used the data for the entire RSD pilot study to populate the bottom row of Table 3-2. However, Table 3-2 also shows counts and the various characteristic percentages for those portions of the RSD pilot data that were obtained in each of the five largest AQMDs. In parentheses below each of the area titles in Column A, we indicate the any-VSP coverage in each of the AQMDs. The values show that in the pilot study, coverage was larger than average for the Sacramento and South Coast AQMDs and lower than the 3% average for the other three AQMDs. A strictly defined 3% coverage of the five largest AQMDs would have had 3% coverage in each of them rather than the coverage imbalance among the AQMDs that we see for the pilot study.

We believe that this imbalance in the coverage among the AQMDs will have only a slight influence on the results of the study because the pilot study's observed values of in-range VSP (64.6%) and uniqueness (83.9%) are near the perfectly balanced 3% coverage study values of in-range-VSP (63%) and uniqueness (86%). We estimated the percent in-range VSP and percent uniqueness for a perfectly balanced 3%-coverage RSD program by weighting the observed percent in-range VSP (Column C of Table 3-2) and percent uniqueness (Column D of Table 3-2) for each AQMD by the number of registered vehicles driving in each of the AQMDs (Column 2 of Table 3-1).

The percentages of raw measurements given in Column F and the percentages of valid measurements given in Column E show some variability among the datasets obtained in the different AQMDs. However, these percentages do not greatly affect the cost of RSD data collection since RSD costs are based primarily on the numbers of valid, DMV-matched RSD observations. The percent uniqueness shown for the individual AQMDs in Column D are higher for the San Joaquin and Bay Area AQMDs. As we shall demonstrate in the next subsection, the percent uniqueness is generally dependent on the coverage. This dependence will be important in our effort to estimate the effectiveness and costs of a large RSD coverage program in California.

Column C of Table 3-2 shows that the in-range-VSP percentages vary greatly among the five largest AQMDs. Thus, these in-range-VSP percentages have a large influence on the usable-VSP RSD coverage of the fleet. To be able to make a good estimate of the effectiveness and cost of a large RSD program, we must keep in mind that the pilot RSD data were collected in ways that served many research purposes and were not necessarily collected in the same way that an actual RSD program would have collected them. So, we will need to make assumptions to be able to estimate reasonable values for in-range-VSP percentage that would be obtained in a California RSD program.

Finally, the percentage of vehicles that are subject to biennial inspections in the I/M program are shown in Column B. The values among the five AQMDs are all near 48%. They do not vary greatly; however, as we will discuss in the next section, we expect that the fraction of I/M vehicles in an RSD dataset is dependent on the coverage of the RSD program.

3.4 Estimating Fleet Coverage Characteristics for California RSD Programs

The analysis of the pilot study RSD measurements as presented in the previous section in Table 3-2 demonstrated that:

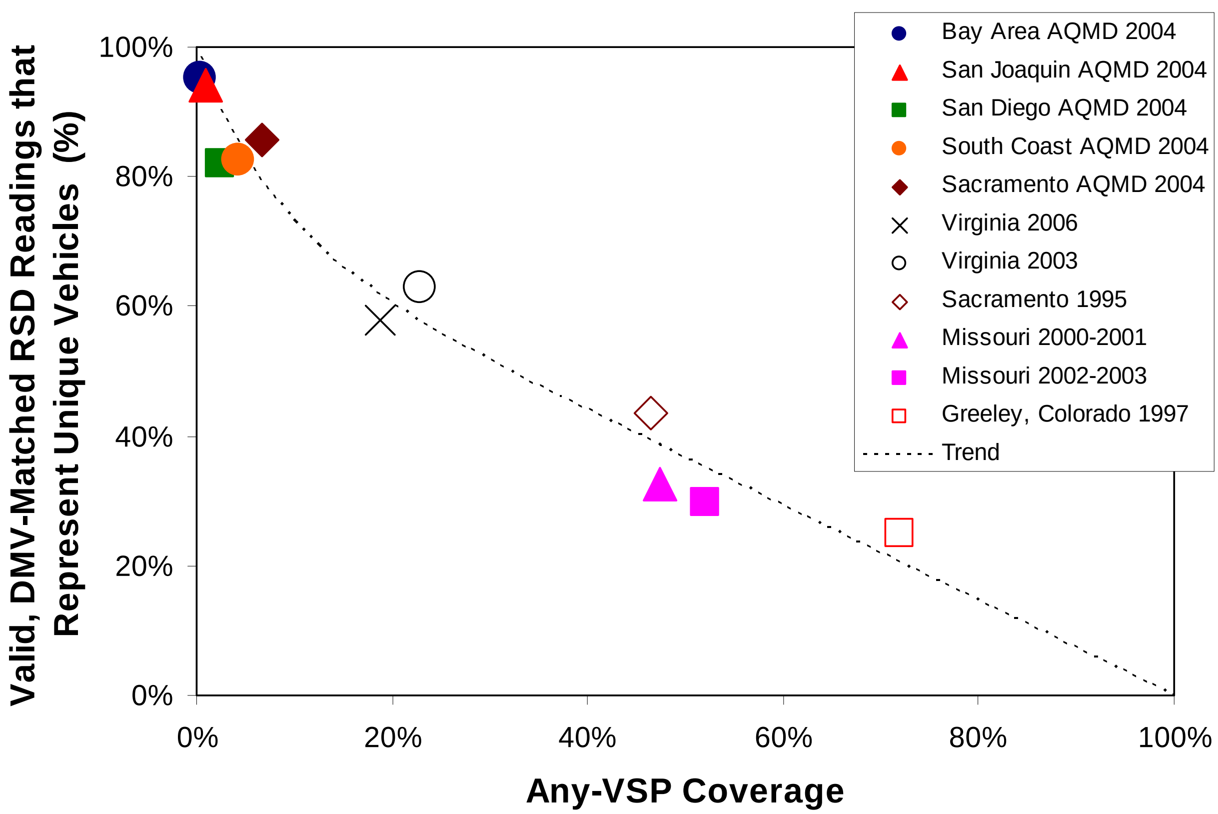
1) the percent uniqueness,
2) the percent in-range VSP, and
3) the percent subject to I/M

all affect the number of usable RSD measurements collected on I/M vehicles. For connecting RSD data collection cost with coverage of vehicles subject to I/M, the percent of raw RSD measurements that are valid and the percent of valid RSD measurements that are DMV-matched are not relevant because, as shown in Table 3-2, the number of valid, DMV-matched RSD measurements (upon which collection costs are based) are "downstream" of the raw RSD and valid RSD counts. In this section, we will present methods that we used to estimate the three RSD data collection program characteristics over a wide range of RSD coverages. Then, in Section 3.5 we will apply these methods to estimating the coverage characteristics of the 50% any-VSP RSD coverage program being evaluated in this analysis.

Percent uniqueness – An RSD program can identify vehicles for special strategies only for those vehicles that receive an RSD measurement. Unfortunately, to obtain at least one valid, DMV-matched RSD measurement on a substantial portion of the vehicles driving in the program area, more RSD measurements than the number of vehicles must be collected. This is because a portion of the RSD readings are actually replicate RSD measurements on the same vehicles obtained as vehicles repeatedly move (e.g., commute) past an RSD measurement site. We define the uniqueness of an RSD program as the ratio of the number of unique vehicles to the number of valid, DMV-matched RSD measurements taken on them. From another perspective, uniqueness is also the reciprocal of the average number of valid, DMV-matched RSD measurements per vehicle.

RSD measurement uniqueness depends on several factors including the quality of the RSD measurement sites, the number of RSD measurement sites in the program area, the length of time that an RSD measurement unit spends at each RSD site, and the any-VSP RSD coverage level that the data collection effort achieves. Figure 3-1 shows how the uniqueness has trended with any-VSP RSD coverage for the five largest AQMDs in this pilot study and for several other different RSD data collection efforts. For this pilot study, the values for any-VSP coverage and for uniqueness were taken from Columns A and D of Table 3-2.

Figure 3-1. RSD Measurement Uniqueness for Several RSD Efforts



CoverageCalcsForPilotDataset.xls
Virginia 2006: Reference 5, pages 20-21
Virginia 2003: Reference 6, page 21
Sacramento 1995: Reference 7, pages 3-7 and 3-12
Missouri 2000-2001: Reference 8
Missouri 2002-2003: Reference 8
Greeley, Colorado 1997: Reference 9, pages 21 and 64

In Figure 3-1 the five points in the upper left corner represent the uniqueness and coverage of the RSD data taken in the five AQMDs in the pilot study. The other six points are from the other RSD programs or studies and have any-VSP coverages of 20% to 72%, which are substantially higher than the pilot study any-VSP coverages. The 1995 Sacramento and 1997 Greeley efforts were RSD studies. The Virginia and Missouri efforts were ongoing RSD programs. While the Sacramento RSD pilot study was performed about 10 years before the current pilot study, our intensive examination of potential RSD sites during the current pilot study in the Sacramento area indicated that, from an RSD perspective, Sacramento has changed as changes to the highway infrastructure (e.g., metering of freeway on-ramps) have degraded many formerly good RSD sites.

Two additional theoretical points serve to round out the uniqueness vs. any-VSP coverage trend seen in Figure 3-1. At the limit of 0% coverage, the uniqueness would be 100% since the first few vehicles at each RSD measurement site would receive only one RSD measurement. This point is the upper left corner of Figure 3-1. Similarly, at the limit of 100% coverage, the uniqueness would be 0% since a very large number of RSD measurements would be required to cover all of the vehicles in a fleet. This point is the lower right corner of Figure 3-1.

When we consider all of the eleven data points and the two theoretical points together in Figure 3-1, we see a clear and relatively compact trend. We believe that we can use the higher coverage values to estimate the uniqueness that would be associated with California RSD programs that are substantially larger than the pilot study. The following function describes the trend line that passes through the data points subject to the constraints of the two theoretical end points of the trend:

$$\text{Uniqueness (fraction)} = 0.73 - 0.73 * \text{Coverage} + 0.27 * \exp(-13 * \text{Coverage})$$

where Coverage = Any-VSP Coverage (fraction).

The locations of the data points in Figure 3-1 are based on uniqueness levels achieved in practice by RSD vendors by the particular design chosen for each particular RSD measurement program. We would expect that RSD vendors would chose program designs that tended to be most efficient for a given area and highway infrastructure, and therefore we believe that the trend in the figure represents typical RSD programs.

However, it is certainly possible that constraints could cause RSD measurement programs that are atypical. Every RSD data collection program chooses a balance for stay-versus-move:

Stay: Collect RSD data at fewer sites for a longer time at each site

vs.

Move: Collect RSD data at more sites for a shorter time at each site.

For moderate variations in the balance, both approaches will cost about the same since RSD data collection cost is based on the number of valid, DMV-matched RSD measurements. However, the two approaches have different coverage and uniqueness characteristics. An extreme example will serve to illustrate the point.

Suppose that a program wanted to collect 1,000,000 valid, DMV-matched RSD measurements in an AQMD. An extreme version of the Stay approach would be to choose the RSD site thought to be the best one in the AQMD and collect all data at that location. Initially, all RSD measurements would be obtained on unique vehicles, but after about the first day more and more RSD measurements would be obtained on vehicles that had already been measured. After several days, almost all new RSD measurements would be made on the same set of vehicles. At the end of the measurement program, the coverage of the fleet in the AQMD would be quite low because the set of vehicles with RSDs would be only a small portion of all vehicles driving in the AQMD. In addition, the uniqueness would be quite low because the average number of RSDs per vehicle would be quite high. Consequently, this approach to the RSD program would produce a data point on Figure 3-1 that would be somewhere near the lower left corner of the plot – a position that is far below the trend line in the figure.

On the other hand, an extreme version of the Move approach would be to measure RSDs for only a few hours at a site and then to move to another site that is far away from all other sites that are to be visited. Additionally, the sites would include many types of roadways, including freeway ramps, surface streets, and back roads, so that all fleet vehicles have a good chance of being measured. Therefore, the coverage of the program would be as high as allowed by the constraint that only 1,000,000 valid, DMV-matched measurements would be obtained. Because each site would be measured for a short time, the vehicles measured at each site, and therefore for all sites taken together, would almost always get just one RSD measurement. Therefore, the uniqueness for the entire program would be very high. Consequently, this approach to the RSD program would produce a data point on Figure 3-1 that would be somewhere near the upper center of the plot – a position that is far above the trend line in the figure.

Clearly, the real costs of these two approaches to the hypothetical RSD program would be quite different. The real costs for the Stay approach would be low, and the real costs for the

Move approach would be quite high. The important point of the example is to demonstrate that the characteristics of an RSD program as described by uniqueness and coverage do not necessarily go hand in hand. That is, the uniqueness and coverage characteristics do not necessarily have to fall on the trend line in Figure 3-1. Their relationship depends on the design of the RSD program and the characteristics of the fleet and infrastructure in the area. While the data point for a given RSD program could fall almost anywhere on Figure 3-1, the fact is that actual RSD programs do seem to fall near the trend line. Thus, the trend line seems to describe the usual relationship between uniqueness and coverage for RSD programs.

Thus, we see that taking a moderate approach, that is, by neither staying too long at a site nor moving too quickly to the next site, an RSD program can achieve moderately high coverage and moderately high uniqueness at a moderate real cost. For this moderate approach, the uniqueness vs. coverage characteristics will remain on or near the trend line in Figure 3-1 as they have for historical RSD programs. However, it is possible that at some point in the effort to reach ever increasing coverage levels, the RSD effort will run into one of two constraints that can cause the characteristics to move below the trend line:

1) The *density* of good-quality RSD sites may get too high, or

2) The supply of good-quality RSD sites may become exhausted.

If the program experiences the first constraint, when new good-quality RSD sites are close to already sampled RSD sites, sampling at the new site would be obtaining RSDs on essentially the same locally driven fleet that had been measured at earlier-sampled sites in the same neighborhood. Thus, when the density of RSD sites gets too high relative to the size of the geographical area that vehicles typically drive in, coverage does not increase substantially and uniqueness decreases.

If the program experiences the second constraint, when new good-quality RSD sites are no longer available, the RSD program will face a situation of higher cost for decreasing amounts of new data. RSD units will be forced to either stay longer at the limited number of good sites or move to the lower productivity sites. Low productivity could be caused by low traffic flow or by a low percent of in-range VSPs. With either approach, the coverage will only slightly increase as the uniqueness drops rapidly. If high-quality RSD measurement sites were in short supply, then for a high coverage RSD program the uniqueness vs. coverage data point could be far below the trend line in Figure 3-1 – even though the data point for a low coverage program is on the trend. We think that this is an important consideration in California that is not currently a consideration in existing RSD programs in other states.

The point at which an RSD program in a given area will run into one of these constraints and which constraint will be encountered first might be learned only by attempting to perform an RSD program that continually increases in size. Alternatively, it might be determined by an examination of potential RSD sites as we have done in California as described in Section 3.6.

Percent of vehicles with at least one in-range VSP – For an RSD measurement to be usable for vehicle selection, the RSD measurement must be a fair representation of the vehicle's emissions. Accordingly, the VSP associated with the measurement must be in the representative VSP range. When vehicles get more than one RSD measurement, the chance of having at least one in-range VSP increases. We define a 1-hitter as a vehicle that has received a single valid RSD measurement, a 2-hitter as a vehicle that has received two valid RSD measurements, etc. Table 3-3 shows the counts of 1-hitters to 7-hitters with valid, DMV-matched RSD measurements in the pilot dataset, which, although it was not conducted as a normal RSD program, has approximately a 3.0% any-VSP coverage. The distribution of n-hitters in the study is shown in Columns B and C. The distribution of n-hitters is a characteristic of the measurement site and depends on the relative numbers of vehicles that routinely drive past the site (e.g., commuters). The distribution of n-hitters with at least one in-range VSP is shown in Column E and F. The distribution of fractions of at least one in-range VSP depends on the range and shape of the distributions of VSPs that vehicles operate in at each RSD site.

From the table we can see that across all of the measurements in the pilot study, 85.84% of the vehicles that received at least one valid RSD measurement were 1-hitters. About 61.26% of the 1-hitters had an in-range VSP. The table shows that there were far fewer 2-hitters, but the fraction of vehicles having at least one in-range VSP within that group was higher at 82.41%. The trend continues to higher-hitters. For example, 2.39% of the vehicles that received at least one valid RSD measurement and could be DMV-matched were 3-hitters, that is, they received 3 valid RSD measurements. Of all of the 3-hitters, 90.1% had at least one of the RSD measurements with an in-range VSP.

Table 3-3. Observed Counts and In-Range-VSP Occurrence of Multiple-RSD-Hit Vehicles in the California Pilot Study

A	B	C	D	E	F
RSD N-Hitter	**Fraction of N-Hitters**	**Number of N-Hitters**	**RSD Hits**	**Fraction of Vehicles with At Least One In-Range VSP**	**Vehicles with At Least One In-Range VSP**
1	0.8584	481483	481483	61.26%	294956
2	0.1074	60217	120434	82.41%	49625
3	0.0239	13407	40221	90.10%	12080
4	0.0067	3769	15076	93.92%	3540
5	0.0022	1219	6095	96.06%	1171
6	0.0008	458	2748	96.94%	444
7	0.0003	164	1148	98.78%	162
Total		560883	667205		361978

Uniqueness	Average Hits/Vehicle	Overall Fraction of Vehicles with At Least One In-Range VSP
0.8406	1.19	64.54%

The overall fraction of vehicles having at least one in-range VSP, which is calculated as the sum of Column F divided by the sum of Column C, is 64.54%. Note that this is slightly higher than the fraction of 1-hitters that had an in-range VSP. To be able to predict the characteristics of standard, full-scale RSD programs in California that are larger than the pilot study, we need to be able to calculate this overall fraction of vehicles having at least one in-range VSP. Without an in-range VSP the RSD measurement is useless for selecting vehicles for a special strategy. As it turns out and as we discuss below, the overall in-range-VSP percentage can be easily estimated from the percent uniqueness and the percent of 1-hitters that have in-range VSPs. Even so, since the pilot study was not conducted as a normal RSD program would have been, the resulting averages must be interpreted in order to be projected to a large RSD program.

The values observed and the calculations performed in Table 3-3 for the pilot study demonstrate that the distribution of n-hitters (Column B) and the distribution of the fraction of vehicles with at least one in-range VSP (Column E) are sufficient to calculate the overall fraction of vehicles having at least one in-range VSP. Therefore, if we can estimate the values in

Columns B and E from some simple RSD sampling statistics, we can estimate the overall fraction of vehicles having at least one in-range VSP.

The fraction of vehicles with at least one in-range VSP for a given n-hitter should depend on the probability that a 1-hitter has an in-range VSP.[5] This makes sense because as the number of RSD hits for a given vehicle increases, the likelihood that at least one of the hits would have an in-range VSP increases. The likelihood of at least one in-range VSP reading for a vehicle passing by a particular site depends on the number of hits and on the probability that a 1-hitter has an in-range VSP. Table 3-4 shows these values for the five largest AQMDs separately and together as determined by the data from this pilot study. Keep in mind that the values in Table 3-4 reflect the mix of specific RSD sites chosen for the pilot study and the traffic conditions that were experienced at those sites on the days of RSD data collection. As will be discussed in Section 3.6, state and local agencies permitted RSD data collection in the pilot study only at certain sites and at certain hours. We expect that the RSD sites and traffic conditions for a full-scale RSD program would undoubtedly be different. Therefore, the percent of in-range VSP values for 1-hitters in other RSD data collection efforts could have different values.

Table 3-4. In-Range-VSP Percentages for One-Hitters in the Pilot Study

Area	% In-Range VSP for 1-Hitters
Sacramento	43.27%
San Diego	78.96%
San Joaquin	61.64%
South Coast	62.26%
Bay Area	52.08%
California Overall	61.26%

The symbols in Figure 3-2 show the trend of the percent in-range VSP with the number of RSD hits for California overall and for four of the five largest AQMDs. We left the Bay Area values off the plot because the low numbers of 2- and more-hitters for that area caused a large amount of noise in the trend. We fit the trends to the following equation:

In-Range VSP for an N-hitter (fraction) = 1- (1 – FracIRVSPone)**($N^{0.833}$)

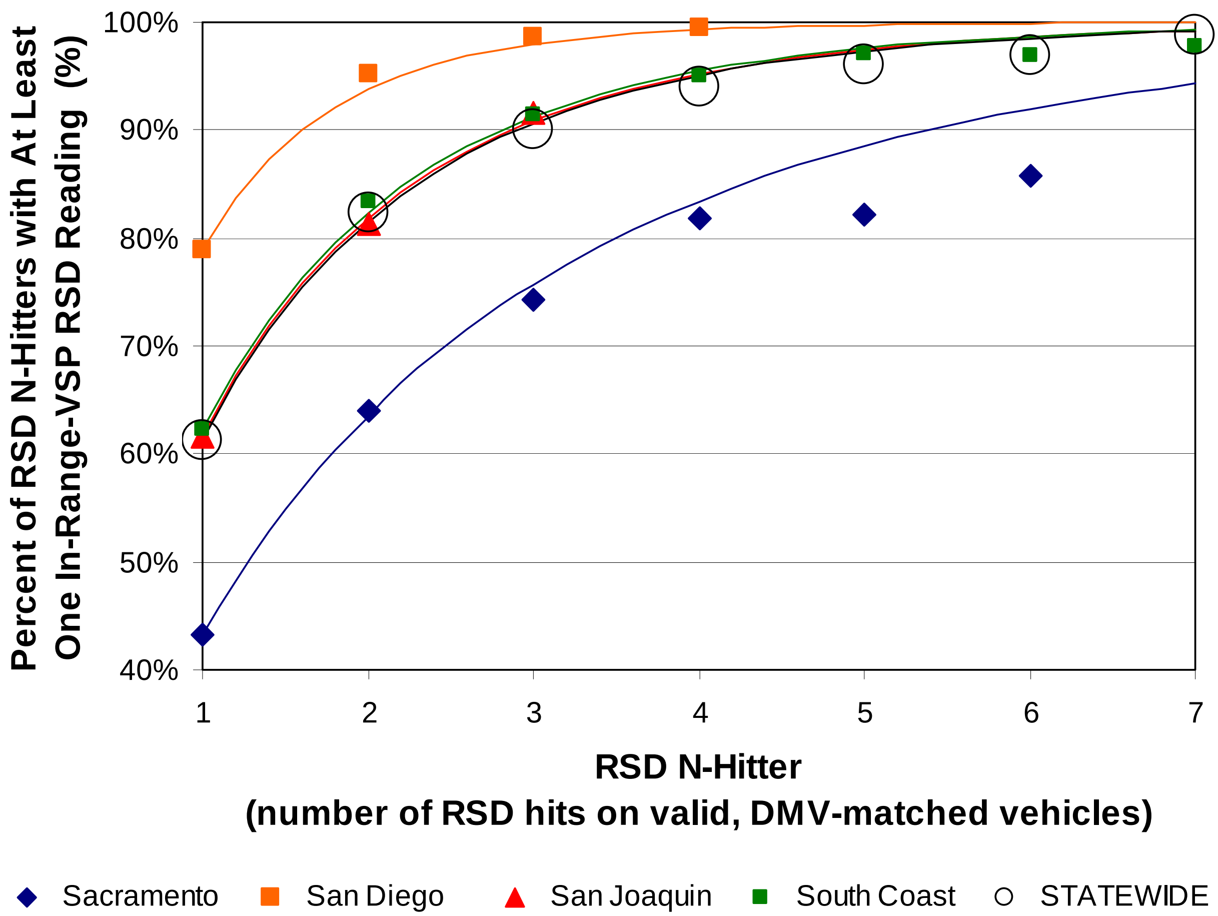
where N = the n-hitter for which the fraction in-range VSP is to be calculated, and

[5] We examine a relevant example: Suppose the probability of getting a baby boy in one pregnancy is 0.52. What is the probability of getting at least one baby boy in three successive pregnancies? If the probabilities of getting a baby boy in successive pregnancies are independent of each other, then the probability of getting at least one baby boy in N pregnancies is $1 - (1 - 0.52)^N$. Thus, for one, two, and three successive pregnancies the probabilities of getting at least one baby boy are 0.52, 0.77, and .89, respectively. However, as we shall see, the probabilities of successive RSDs having in-range VSPs are not completely independent. So, the approach in this example does not quite work.

FracIRVSPone = the fraction in-range VSP for a one-hitter.

For example, the equation calculates that 75.7% of 3-hitters in the Sacramento AQMD, which from Table 3-4 has a FracIRVSPone of 0.4327, would have in-range VSPs. The measured value is 74.3%.

Figure 3-2. In-Range-VSP Percentages for Multiple-RSD Hits in the Pilot Study



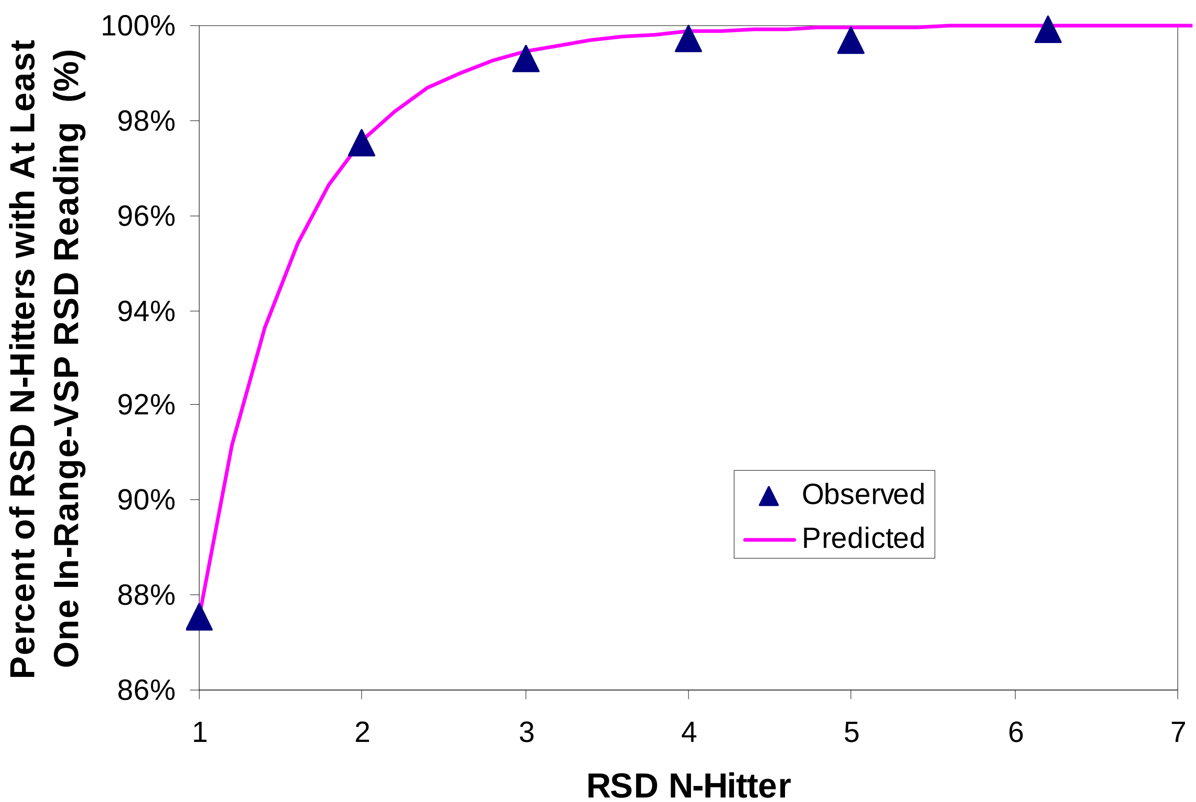
CoverageCalcsForPilotDataset.xls

The exponent of N in the equation is related to the independence of VSPs for multiple passes of an individual vehicle through an RSD site. A value of 1 for N's exponent would indicate that the VSPs for an individual vehicle are independent of each other. A value of 0 would indicate that they are completely dependent on each other. The empirically determined N exponent of 0.833 therefore indicates that the VSPs for an individual vehicle are mostly independent of each other, but there is a small tendency for some dependence. We believe that this is a result of the tendency of drivers to pass by a given RSD site in approximately the same vehicle operating mode time after time.

The curves in Figure 3-2 show the equation fits of the trends for the four AQMDs and the entire pilot study dataset taken together, which is labeled STATEWIDE and has large open circle symbols. The equation fits the trend reasonably well, but the fit is neither perfect nor theoretically derived. Nevertheless, the equation is more than adequate for calculating the characteristics of a large RSD program in California. Note that the pilot dataset is dominated by RSD observation from the South Coast AQMD. This is the reason that the statewide data and the South Coast data are very near each other in the figure.

As an independent validation of the equation, we calculated the observed percent in-range VSPs for the n-hitters in the Colorado RSD program during 2004-2005. Figure 3-3 shows a comparison of the observed in-range VSP values and values predicted by the equation. Note that the 1-hitter value is an input to the equation.

Figure 3-3. In-Range-VSP Percentages for Multiple-RSD Hits in the 2004-2005 Colorado RSD Program



We also need to model the distribution of n-hitters for an RSD program. For the pilot study this is Column B in Table 3-3. We create this model by inspection with the following logic. Suppose that X percent of the vehicles are 1-hitters. Then, we assume that X percent of the remaining vehicles that are not 1-hitters would be 2-hitters, and that X percent of the remaining vehicles that are not 1-hitters or 2-hitters would be 3-hitters. If we follow this algorithm to a high number of hitters, we can calculate the number of vehicles in each n-hitter category, the number of RSD hits for each n-hitter category, and finally the uniqueness (just as the calculations in Table 3-3 for Columns C and D do). This procedure produces a distribution of n-hitters that follows an exponential decay. We know that the measured distribution of n-hitters in the pilot study is not exactly an exponential decay, but the real distribution is close enough to make the exponential decay useful. Finally, we adjust the value of X so that the uniqueness matches the uniqueness that we want or that is expected from the curve in Figure 3-1 for the any-VSP coverage.

We can use these methods to simulate the distribution of n-hitters and the distribution of in-range VSPs for the pilot study data in Table 3-3. The resulting simulation is in Table 3-5. The simulation is based entirely on two values: the fraction of 1-hitters in the dataset is 0.8406, and the fraction of 1-hitters with an in-range VSP is 61.26%. These values are outlined in bold in Table 3-5. Table 3-5 can be compared with Table 3-3 to determine the accuracy of the simulation. Figure 3-4 compares the observed and fit values for the fractions of n-hitters in the RSDed fleet in the pilot study. The observed values are from Column B of Table 3-3, and the fit values are from Column B of Table 3-5. For both the data and the simulation, the average number of hits per vehicle is 1.19. The overall fraction of vehicles with at least one in-range VSP is 64.54% for the data and 64.74% for the simulation.

Additionally, Table 3-5 shows that when the distribution of the fraction of n-hitters (Column B) is an exponential decay, the fraction of 1-hitters in the distribution is identical with the uniqueness. For simulation this is an advantage because it means that if we start with the desired any-VSP coverage, we can get the corresponding uniqueness from the curve in Figure 3-1. Then, we use the value of the uniqueness as the fraction of the RSDed vehicles that are 1-hitters, which is the first element of Column B in Table 3-5. This value in turn is used to generate all of the other values in Column B, the values in Column C, and finally the uniqueness at the bottom of the table, which is exactly the uniqueness value that we wanted to obtain for the simulation.

The only other value the simulation requires is the percent of 1-hitters with an in-range VSP, and this is a characteristic of the RSD sites used to collect the data. Therefore, it does not change with the size of the RSD program, unless moving to a different size RSD program causes the characteristics of the sites to change.

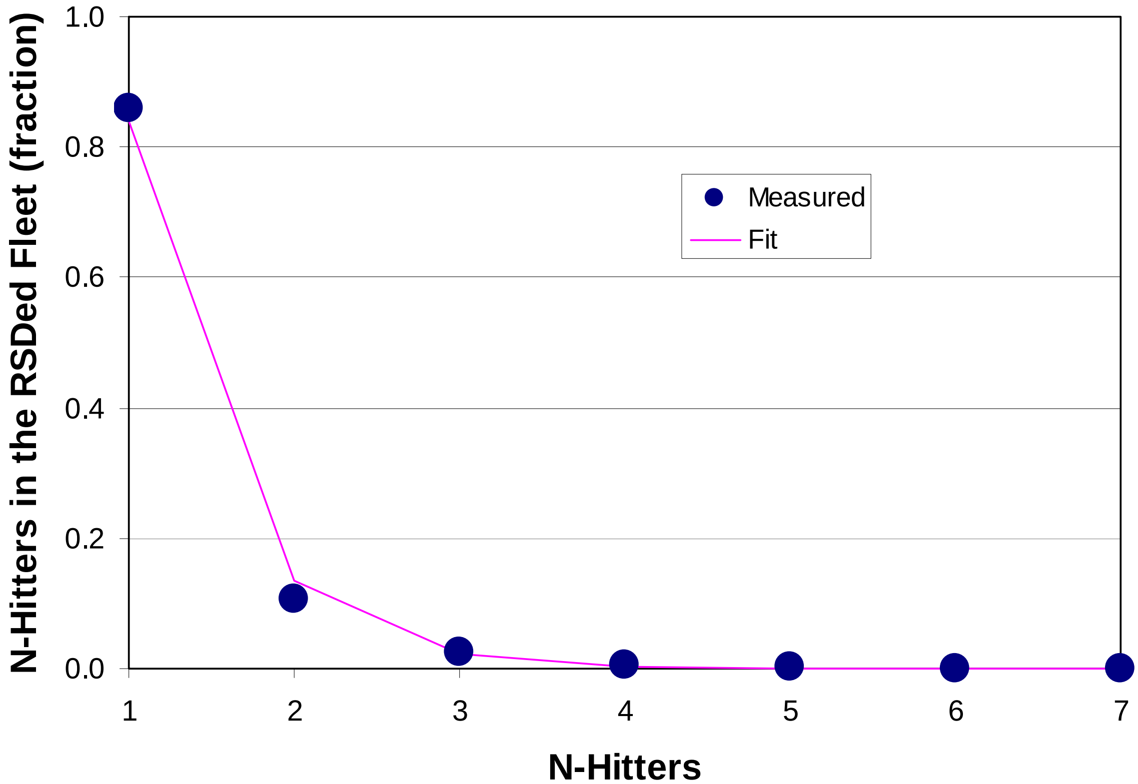
Table 3-5. Simulated Counts and In-Range-VSP Occurrence of Multiple-RSD-Hit Vehicles in the California Pilot Study

A	B	C	D	E	F
RSD N-Hitter	Fraction of N-Hitters	Number of N-Hitters	RSD Hits	Fraction of Vehicles with At Least One In-Range VSP	Vehicles with At Least One In-Range VSP
1	0.8406	471478	471478	61.26%	288828
2	0.1340	75154	150307	81.53%	61276
3	0.0214	11979	35938	90.63%	10857
4	0.0034	1910	7638	95.07%	1815
5	0.0005	304	1522	97.33%	296
6	0.0001	49	291	98.53%	48
7	0.0000	8	54	99.17%	8
Total		560883	667229		363128

Uniqueness	Average Hits/Vehicle	Overall Fraction of Vehicles with At Least One In-Range VSP
0.8406	1.19	64.74%

Percent of vehicles subject to I/M – According to EMFAC, 59.8% of the vehicles driving in the 5 largest AQMDs are subject to biennial I/M inspections. This fraction is based upon registration data and does not take into account the fact that some vehicle groups are driven more than others. Because RSD data collection tends to see frequently driven vehicles more often, and because younger vehicles, most of which are not subject to I/M, are driven more than older vehicles, the percent of RSDed vehicles that are I/M vehicles would approach 59.8% only as the any-VSP coverage of the fleet approached 100%. The reason for this is that at 100% coverage, every vehicle in the fleet would have at least one RSD. It would not matter if some vehicles had 100 RSDs and other vehicles had only 1 RSD. Thus, the tendency of RSD to observe vehicles with high VMT goes away at high coverages. At lower RSD coverages, the fraction of the RSDed vehicles that are I/M vehicles would be lower than 59.8% because vehicles with low VMT would tend to not be seen by RSD. We know that 48.0% of the RSDed vehicles in the 3.0% any-VSP coverage pilot study were I/M vehicles. Due to the lack of data between these points, we assume that the relationship between the any-VSP coverage and the percent of RSDed vehicles that are I/M vehicles is linear. Since, in any case, the range of values of percent of vehicles subject to I/M is narrow, the error introduced by this assumption is minimal.

Figure 3-4. Comparison of the Measured and Fit Fractions of Multiple-RSD-Hit Vehicles in the California Pilot Study



Trends over a wide range of coverage – The values for percent uniqueness, percent in-range VSP, and percent subject to I/M are all functions of the any-VSP coverage. Table 3-6 shows how the values change with any-VSP coverage for the California situation.

The table shows that as coverage increases, the percent subject to I/M increases, the percent in-range VSP increases, and the percent uniqueness decreases. Overall, the percent subject to I/M is limited by the fraction of the registered fleet that is in the I/M program (59.8%). This value would be achieved at 100% coverage, but at lower coverages the percent subject to I/M drops because vehicles with low VMT are less likely to be seen by RSD. The percent in-range VSP increases with coverage because at low coverages most vehicles receive a single RSD hit with its associated low chance of having an in-range VSP while at high coverages most vehicles receive multiple RSD hits and therefore each vehicle has a much better chance of having at least one in-range VSP. At 100% coverage, all vehicles would have at least one in-range VSP. The percent uniqueness decreases with coverage. Near 0% coverage, the first few

RSDs are on unique vehicles. Near 100% coverage, huge numbers of RSD measurements are needed to find the last few vehicles in the fleet.

The net combined effects of these three characteristics can best be understood by considering specific cases. We do this in the next subsection.

Table 3-6. Estimated Effects of Coverage on California RSD Program Characteristics

Any-VSP Coverage	Subject to I/M	In-Range VSP	Uniqueness
Percent	Percent of In-range VSP, Unique, Valid, DMV-Matched Vehicles	Percent of Unique, Valid, DMV-Matched Vehicles	Percent of Valid, DMV-Matched RSD Measurements that are Unique Vehicles
0%	47.6%	61.3%	100.0%
3%	48.0%	63.6%	89.1%
10%	48.9%	67.5%	73.1%
30%	51.3%	73.9%	51.6%
50%	53.7%	79.5%	36.5%
70%	56.2%	86.2%	21.9%
90%	58.6%	94.7%	7.3%
100%	59.8%	100.0%	0.0%

3.5 Fleet Coverage Characteristics for Large California RSD Programs

For this report we want to estimate the characteristics of an RSD measurement program that could annually achieve 50% any-VSP RSD coverage of the 18,982,879 vehicles driving in the five largest AQMDs. This program is about 16 times larger than the pilot study RSD program. We used the methods developed in the previous subsection to produce an estimate of the characteristics of such a program. The results are shown in Table 3-7. The calculations optimistically assume abundant availability of RSD data collection sites throughout California that are just as good as the sites used in the pilot study. The values in the table are anchored by the 9,491,440 vehicle count (in bold) at the bottom of fourth column since that is 50% of 18,982,879, which is the size of the California registered fleet driving in the five largest AQMDs (see Table 3-1). Therefore, a 50% any-VSP-coverage RSD program must annually acquire valid, DMV-matched RSD readings on 9,491,440 unique vehicles.

Table 3-7. RSD Measurement Counts for the Large RSD Program in the 5 AQMDs (Any-VSP RSD Coverage = 50.0%) (Usable-VSP RSD Coverage = 39.7%)

Area	Subject to I/M, In-range-VSP, Unique, Valid, DMV-Matched	In-range-VSP, Unique, Valid, DMV-Matched	Unique, Valid, DMV-Matched	Valid, DMV-Matched	DMV-Matched	Raw
	53.7% of In-range VSP, Unique, Valid, DMV-Matched	79.5% of Unique, Valid, DMV-Matched	36.5% of Valid, DMV-Matched	83.7% of Valid	65.0% of Raw	
Sacramento	176,330	328,166	412,896	1,129,965	1,350,018	2,076,951
San Diego	419,936	781,537	983,325	2,691,047	3,215,110	4,946,323
San Joaquin	439,219	817,424	1,028,477	2,814,615	3,362,743	5,173,450
South Coast	1,943,275	3,616,602	4,550,384	12,452,957	14,878,085	22,889,362
Bay Area	994,134	1,850,169	2,327,870	6,370,642	7,611,281	11,709,663
Rest of State	80,495	149,808	188,487	515,830	616,284	948,129
Total	4,053,388	7,543,705[c]	**9,491,440**[b]	25,975,057[a]	31,033,520	47,743,878

Proj1/Decision Model/Report/IM_Strategy_Evaluator_071119.xls

[a]Used to determine RSD data collection cost.

[b]Used to determine Any-VSP RSD Coverage.

[c]Used to determine Usable-VSP RSD Coverage.

The values for percent uniqueness (36.5%), percent in-range VSP (79.5%), and percent subject to I/M (53.7%) were taken from the methods described in Section 3.4 for a 50% any-VSP coverage program. We used the percent valid (65.0%) and the percent DMV-matched (83.7%) from the values obtained in the pilot study. We suspect that these two percentages may increase in a routine RSD application, as opposed to this pilot study, as the RSD vendor takes advantage of RSD data collection efficiency-improvement opportunities. However, even if these two percentages change, the changes will not affect the cost of RSD data collection since the costs of "turn-key" RSD data are typically determined using the number of valid, DMV-matched RSD observations.

To achieve 50% any-VSP RSD coverage, the state would need to annually pay for 25,975,057 valid measurements that could be matched to vehicle registration records, according to the bottom of the fifth column of Table 3-7. This RSD program would annually provide 7,543,705 RSD measurements that could be used to characterize the emissions of the on-road fleet, which includes I/M vehicles and non-I/M vehicles. However, only about 60% of the vehicles driving in the five largest AQMDs are biennially inspected I/M vehicles. Additionally, because RSD tends to preferentially measure vehicles that drive more miles, because these vehicles tend to be newer vehicles, and because the newest six model years are exempt from biennial I/M inspection, we expect that a 50% any-VSP RSD coverage program will cover about 53.7% (as shown at the top of the second column) of the biennially inspected I/M fleet rather than 60%. Therefore, this RSD program would annually provide 4,053,388 usable RSD measurements on I/M vehicles. This is 30% of the 13,388,069 I/M vehicles driving in the state. These measurements could be used to select vehicles for special I/M strategies such as Calling-In, Directing, Exempting, and Scrapping. However, since only 30% of the vehicles in the I/M fleet would have usable RSD measurements, 70% of the I/M vehicles in the fleet would not have RSD measurements available to help with vehicle selection.

The bottom of the table shows that in this high coverage scenario only about 1 out of 6 vehicles passing the RSD units would produce a usable data point (7,543,705 usable out of 47,743,878 sensed). That is because this scenario requires that 50% of the fleet receive a valid, DMV-matched RSD measurement while operating in the emissions-representative VSP range. Although this level of coverage has been achieved in an actual RSD program, for various reasons discussed later, we believe California would find that goal difficult to reach.

The scenario described by Table 3-7 is the large RSD coverage scenario we used for the example scenario calculations in this report. We have also calculated the needs for smaller RSD programs with 10% any-VSP coverage, 30% any-VSP coverage, and for a fleet characterization RSD program that provides 1,000,000 valid, DMV-matched RSD observations in each of the five largest AQMDs. The coverage numbers for these other scenarios are shown in Appendix A. Appendix B discusses several RSD data collection issues.

3.6 California-Specific Issues Affecting a High Coverage RSD Program

As we shall see in the remainder of this report, actual RSD programs would need to have high coverage – perhaps on the order of 50% any-VSP coverage – to begin to be effective at targeting a substantial portion of the IM fleet for special strategies. In the previous subsections, we used the pilot study data and other RSD programs to estimate the effects of a high coverage program on percent uniqueness, percent in-range VSP, and percent subject to I/M. With these estimated quantities, we will be able to estimate the mass emissions benefits and costs of a 50% coverage program in Sections 4, 5, and 6. Those calculations will assume that California has a sufficient supply of RSD sites of the same quality as those used in the pilot study. However, we believe that certain special characteristics of the California situation, which are difficult to quantify with the existing data for a large RSD program, can have important influences on the ability of a California RSD program to achieve high coverages as easily as those achieved in other jurisdictions up to the current time. Specifically, we believe that achieving high RSD coverages in California will be more difficult and therefore more expensive than in most other jurisdictions. This is primarily a result of the frequent use of metered, multiple-lane freeway on-ramps used throughout California in locations where traffic volume is high.

The pilot study achieved about 3% coverage in California's largest five AQMDs taken together. This was done using mainly freeway on-ramps in the Bay area and Sacramento, but in other areas RSD sites were mainly at surface streets because the applicable agency would not always issue permits for RSD testing on freeway ramps. We expect that in a regular RSD program the permit problems could be resolved.

The question is, "What would happen in a real RSD program in California that is operating at 50% coverage?" A 50% coverage program would be 16 times larger then the pilot program. With such a large increase in size, there is no guarantee that a sufficient number of good RSD sites would be available to provide 50% coverage of the fleet. With respect to a high coverage RSD program, California is different from previous RSD programs in other jurisdictions. Many high volume freeway on-ramps in California are metered and have multiple lanes. In addition, the California situation is different because it is a large area in a large state and the area is made up of multiple large metropolitan areas. Previous RSD programs in Missouri, Georgia, Virginia, and Colorado covered single large metropolitan areas.

To help determine if the 50% coverage program could be done in California, Sierra Research, a member of the pilot project team, conducted an extensive field study of the Sacramento metropolitan area to determine if there were limitations to achieving 50% coverage. Sacramento was used as a surrogate for the California fleet and infrastructure. An abridged version of Sierra's report is included in Appendix C.

That coverage evaluation study found that because of a shortage of suitable freeway ramps that simultaneously have high volume, a large fraction of vehicles driving in an acceptable VSP range, adequate separation between vehicles, and the physical space for RSD equipment, only 19% of the fleet can be observed using the suitable freeway ramps. Their analysis indicates that 49% coverage could eventually be achieved by adding RSD measurements at unsuitable ramps over a long period of time:

> "Based on a detailed survey conducted in the Sacramento, California metropolitan area, only about 19% of passenger cars and light-duty trucks registered in the area use freeway ramps that have operating conditions suitable for the measurement of exhaust emissions by remote sensing devices most of the time. Most vehicles use

ramps that are either physically unsuitable for remote sensing (e.g., multiple lanes) or that usually have operating conditions (e.g., high congestion levels) that are unsuitable for remote sensing due to inadequate separation between passing vehicles or vehicle operating conditions that are poorly correlated with average emissions in stop-and-go driving.

An estimated 49% of the fleet can eventually be measured on freeway ramps under suitable operating conditions if monitoring is done for an extended period of time (i.e., many weeks) at all ramps that are physically suitable. This estimate is based on the fact that there is a finite, non-zero probability of measuring a vehicle under suitable operating conditions even at ramps that routinely have unsuitable vehicle operating conditions. The other half of the fleet either does not frequently use the freeway system or uses ramps that are physically incompatible with the use of remote sensing.

Given the practical problems associated with making emissions measurements on surface streets, the potential for measuring vehicle emissions with remote sensing devices is more limited than has been previously realized. The most significant factor affecting our conclusions is that the study area, like most other metropolitan areas in California, has more extensive use of multilane on-ramps with ramp metering. Such ramps are not suitable for remote sensing for two reasons. First, two separate lanes of traffic make it impractical to identify individual vehicle exhaust plumes. Second, ramp meters routinely produce vehicle operating conditions (deceleration and queues approaching the meter and hard acceleration after the meter) that are outside the range of operation that correlates with average emissions in stop-and-go driving.

Merging of the instrumented vehicle survey results with trip information derived from a regional traffic model showed that a typical deployment of remote sensing equipment, rotated between the sites identified as suitable, would result in approximately 19% of the light-duty vehicle fleet receiving a representative measurement by a remote sensing device in a relatively short period of time. Because ramps considered unsuitable would occasionally produce representative vehicle operating conditions, representative measurements could be obtained for a higher fraction of the fleet if remote sensing equipment were deployed at additional ramps. The longer the deployment, the greater the number of vehicles that could eventually be measured under representative conditions. However, because many of the ramps were physically unsuitable (regardless of congestion levels), and because a significant fraction of the fleet does not routinely use the freeway system, the upper limit for fleet coverage on freeway ramps is only about 49%.

The inability of remote sensing devices to collect representative emissions measurements for the majority of the vehicle fleet limits the extent to which remote sensing can be used to either replace or augment a conventional vehicle I/M program. This limitation does not affect the ability to use remote sensing for emissions inventory or I/M program evaluation purposes, as long as any sample bias resulting from the feasible measurement sites is addressed.

Surface streets are generally impractical for remote sensing because there are few roadways with a single lane of travel in each direction and a median strip where remote sensing equipment can be located. In addition, such roadways typically handle a relatively low volume of traffic. Based on the detailed review of hundreds of road routes extracted from transportation models for metropolitan areas, a very small fraction of the vehicle population routinely uses roadways with median strips and a single lane of traffic traveling in each direction. The ability of RSDs to make usable emissions measurements on a high fraction of the vehicle fleet therefore depends on the extent to which motorists routinely use freeway ramps and the few surface streets meeting the above descriptions under traffic conditions that allow for measurements to be made."

Sierra did not evaluate the possibility of using surface streets for supplemental RSD data collection. However, we know that surface streets can be used because we used surface streets in the pilot study – although the pilot study was performed at only 3% coverage, not at 50% coverage. In addition, in the pilot study we used four lane surface streets with a center median and blocked off one lane on one side to provide a single lane RSD site. This approach is adequate for a pilot study but such a configuration could cause a restriction of traffic on a high volume street. Therefore, we do not believe that this approach would be viable for a large regular RSD program.

In any case, if suitable freeway RSD sites are as limited in the rest of California as the Sierra report indicates that they are in Sacramento, special methods would be needed to achieve high RSD coverage levels. These special methods would include measuring at less suitable freeway ramps and at surface street sites. Both types of sites will tend to produce lower daily rates of unique I/M vehicles with valid, in-range-VSP RSD measurements. The use of such special methods to try to achieve high coverage will tend to put pressure towards a higher cost for valid RSD readings. This pressure in turn would tend to increase the price per valid, DMV matched RSD reading that California would be asked to pay.

We did not attempt to quantify how much these California-specific issues would increase the price of each valid, DMV-matched RSD reading. Therefore, the calculations in the remainder of this report are made assuming that these California-specific issues have <u>no effect</u> on cost and cost-effectiveness. Consequently, we expect that the true costs of an RSD program would be greater than the values reported in this document.

4.0 Calculation of Benefits

Section 4.1 retrieves estimates of the relative changes in estimated emissions, changes in estimated failed miles driven, and the estimated failure rate of targeted vehicles from the modeling report [1]. Then, in Section 4.2 these relative changes are "ratioed up" to the size of the statewide I/M program fleet. In Section 4.3 the benefits for ranking methods are combined to produce benefits for full-fleet ranking methods. This produces a table of counts of targeted vehicles, targeted failing vehicles, and estimated benefits (changes in tons of emissions and failed miles driven) based on the entire I/M fleet for different intervention activities and vehicle ranking methods.

4.1 Estimated Relative Changes in Benefits for Selected Basic Ranking Methods

The estimated percent changes in the evaluation criteria for selected fleet penetrations and for each of the intervention activities and basic ranking methods are shown in Table 4-1. These values were obtained by picking points from the appropriate evaluation performance curves in the modeling report [1]. We used only those data from the evaluations in the report where the evaluation criteria were calculated using Model D, which uses VID history and RSD measurement inputs and which we believe is the most accurate Fprob model. In addition, the benefits calculated using Model D will give maximum advantage to the influence of RSD measurements. Again, if adding RSD to the I/M program is not cost-effective under these conditions, then RSD's true incremental cost-effectiveness is probably lower.

Finally, we assume that the participation of vehicles in the special strategies is 100%. This means that we assume that all vehicles that are directed go to the high-performing stations, that all vehicles that are exempted will not come in for their regular I/M inspections, that all vehicles that are called-in will actually come in for their call-in ASM off-cycle test and if they fail they will receive repairs and meet the follow-up ASM requirements, and that all vehicles that are targeted for a scrappage ASM test will come in and receive the test and if they fail the scrappage ASM test, they will accept the scrappage offer and sell their vehicle to the State. To the extent that this 100% participation in the strategies is not achieved, the benefits of the strategies will be reduced. This means that for Calling-In, Directing, and Scrapping the real changes in failed miles driven, the real changes in FTP mass emissions, and the real fail rates at the Decision Point will be reduced relative to the values calculated in this report. For Exempting, the benefit of lower program costs would be reduced. It follows that the incremental

Table 4-1. Estimated Percent Changes in Evaluation Criteria for Selected Fleet Penetrations (Truth ≈ Model D)

Basic Ranking Method	Fleet Sample Penetration (%)	Benefits: %ΔFTP Emissions (%) — Change in FTP Mass Emissions as a percentage of the Normal I/M Process FTP Mass Emissions			Benefits: %ΔFMD (%) — Change in Failed Miles Driven as a percentage of the Normal I/M Process Failed Miles Driven	Targeted Vehicle Failure Rate (%) — Targeted Vehicles That Would Fail an ASM at the Decision Point
		HC	CO	NX		
Calling-In No-Sticker						
FprobDP by A	5	-0.39	-0.45	-0.23	-0.83	29.3
FprobDP by B	5	-0.41	-0.43	-0.23	-1.00	34.6
ΔFMD by C	5	-1.02	-0.57	-0.55	-3.18	33.2
FprobDP by F	5	-0.87	-0.47	-0.29	-1.40	43.5
ΔFMD by D	5	-1.21	-0.65	-0.64	-3.61	40.0
	100	-4.16	-2.88	-2.78	-8.40	10.2
Directing						
FprobDP by A	40	-6.91	-4.91	-3.81	-12.81	18.9
FprobDP by B	40	-6.93	-4.97	-3.84	-14.19	20.1
ΔFMD by C	40	-7.57	-5.05	-4.40	-15.66	17.3
FprobDP by F	40	-7.85	-4.97	-4.10	-14.98	20.5
ΔFMD by D	40	-8.62	-5.57	-4.75	-17.52	20.1
	100	-11.28	-7.61	-7.35	-20.21	10.2
Exempting						
FprobDP by A	20	0.91	0.57	0.83	1.06	1.7
FprobDP by B	20	1.08	0.69	1.03	0.70	1.0
ΔFMD by C	20	0.59	0.48	0.66	0.76	3.5
FprobDP by F	20	0.81	0.64	0.85	0.84	1.4
ΔFMD by D	20	0.34	0.29	0.45	0.10	2.0
	100	11.28	7.61	7.35	20.21	10.2
Scrapping						
FprobDP/$ by A	0.62	-0.917	-1.022	-0.461	-0.587	31.5
FprobDP/$ by B	0.48	-0.808	-0.923	-0.410	-0.610	36.9
ΔFTP CO/$ by C	0.44	-0.788	-0.942	-0.409	-0.621	38.9
FprobDP/$ by F	0.94	-1.875	-2.164	-1.032	-1.707	45.6
FprobDP/$ by F	0.43	-0.970	-1.104	-0.483	-0.722	44.9
ΔFTP CO/$ by C	0.43	-0.774	-0.926	-0.403	-0.610	39.0
ΔFTP CO/$ by D	0.41	-1.022	-1.214	-0.494	-0.812	48.6
ΔFTP CO/$ by C	0.41	-0.743	-0.892	-0.385	-0.584	39.0
	100.00	-22.524	-20.558	-17.446	-31.622	10.2

changes produced by the addition of RSD information to other information that is used to select vehicles for these strategies will be smaller than the estimates of the RSD influences that are reported here. Thus, the size of the RSD influences that are reported here are the largest that we expect they could ever be in a real situation where an RSD measurement component is added to the existing California I/M program.

We know, for example, that based on the experience of other jurisdictions that only a fraction of vehicles that are called in would actually show up. Accordingly, the benefits calculated for the Calling-In strategy would be substantially less than calculated in this report. Similarly, one could expect that only a fraction of vehicle owners would respond to a request to bring in their vehicle for a scrappage ASM test and only a portion of those who do come in would accept the scrappage offer. The state of California already has experience with a Directing program and, therefore, has an estimate of the level of success that can be achieved with that strategy. In the case of Exempting, since it requires little action on the part of the vehicle owner, we expect that this strategy could achieve high participation rates.

Table 4-1 shows the estimated percent changes in the estimated FTP mass emissions (ΔFTP), changes in the estimated failed miles driven (ΔFMD), and the failure rate of the targeted vehicles for each of the five different sets of vehicle ranking method inputs. The first three basic ranking methods (FprobDP by A, FprobDP by B, and ΔFMD by C) are methods that rank vehicles using model year, vehicle description, and VID history, respectively. None of these three methods use RSD information. As a result, most vehicles in the I/M fleet can be ranked by these methods. The other two basic ranking methods (FprobDP by F and ΔFMD by D) use RSD measurements for at least some of their inputs. These methods can be used for only that portion of the fleet where RSD measurements are available and will never apply to the entire fleet. In this and subsequent tables, ranking methods in bold denote ranking methods that require RSD inputs.

The best basic ranking methods for Calling-In and Directing are those in Table 4-1 that have the largest negative values for benefits (ΔFTP and ΔFMD), representing percent reductions in the estimated FTP emissions and miles driven in a failing condition. The best basic ranking methods for Exempting are those in Table 4-1 that have the smallest positive values for benefits (ΔFTP and ΔFMD), representing percent increases in the estimated FTP emissions and miles driven in a failing condition. For Calling-In, Directing, and Exempting, ΔFMD by D is invariably the best performer. Specifically, for Calling-In and Directing, this method produces the largest reductions in estimated FTP emissions and estimated failed miles driven, and conversely, for Exempting, it allows the smallest quantity of emissions and failed miles driven to be exempted from inspection and repair. In the case of Scrapping, it is not possible to compare the relative performances of the basic ranking methods using Table 4-1 since spending $16 million biennially to purchase vehicles for Scrapping in different implementation situations produces different penetrations, which greatly influence the apparent performances of the basic ranking methods.

4.2 Estimated Absolute Changes in Benefits for Selected Basic Ranking Methods

Estimates of statewide I/M program fleet characteristics are needed to convert the relative changes in benefits, which were summarized in the previous subsection, into the absolute incremental costs and benefits of adding intervention activities to the I/M program. To arrive at these characteristics, we made an EMFAC run for the 2004 calendar year, which is the period during which most of the RSD measurements were taken in this study. Table 4-2 shows a summary of the EMFAC results[6] for LDAs, LDT1s, LDT2s, and MDVs, which are the vehicle types that are eligible for the I/M program.

Table 4-2. Fleet Characteristics for Calendar Year 2004.

Model Years	Exhaust HC	CO	NX	Vehicles	VMT
	(tons/day)	(tons/day)	(tons/day)		(miles/day)
1965-2004	391.5	6,332	601.4	22,375,650	726,291,667
1976-2004	311.4	5,444	548.1	21,736,869	715,766,772
1976-1998	281.8	4,644	466.4	13,388,069	385,661,051

Table 4-2 shows that the statewide fleet for these vehicle types is made up of 22,375,650 vehicles. During this study in 2004, the I/M fleet covered 1976 to 1998 model years. Table 4-2 indicates that the I/M fleet has 13,388,069 I/M-eligible vehicles that emit 281.8 tons of exhaust HC, 4,644 tons CO, and 466.4 tons NX per day.

Accounting for Evaporative Emissions Benefits – When vehicles participate in special strategies they are selected because of measurements or forecasts regarding their tailpipe emissions. However, when vehicles participate in special strategies, they may additionally get evaporative emissions repairs since evaporative emissions component inspection is a routine part of vehicle inspections in the I/M program. The repairs may be considered “inadvertent” because the set of the vehicles that are selected for elevated tailpipe emissions are merely correlated with

[6] Additional details of the EMFAC run are given in Appendix N of Reference 1. The EMFAC version used was EMFAC2007 working draft V2.20.8 Feb 10, 2005.

the set of vehicles that have elevated evaporative emissions. Nevertheless, we would like to estimate the effect on benefits of vehicle participation in the special strategies so that the strategy can take credit for the reduction in evaporative HC emissions. According to EMFAC, the exhaust emissions levels of the I/M fleet are given by the last row in Table 4-2. In addition, EMFAC calculates that the evaporative HC emissions of the I/M fleet is 218 tons/day. However, only a portion of the I/M fleet would be targeted for participation in special strategies, and because only a portion of the targeted vehicles would have elevated evaporative emissions, those targeted vehicles would be responsible for perhaps only a small portion of this 218 tons of evaporative emissions. We can use EMFAC to make a rough estimate of the portion of the 218 tons of evaporative emissions that the targeted vehicles would be responsible for. Potentially, this portion of the evaporative emissions would be reduced during validation inspections for the special strategies.

After a regular I/M inspection, the evaporative and exhaust emissions of vehicles in the fleet tend to increase again from their reduced levels. This occurs naturally in the biennial period between regular I/M inspections. We surmise that the ratio of the increase in evaporative emissions to the increase in exhaust emissions following an inspection cycle is relatively constant. If we could estimate the ratio by using EMFAC, then we could estimate the tons of evaporative emissions available for reduction by the special strategies by multiplying the ratio by the tons of exhaust emissions benefits of the special strategies estimated by our exhaust emissions models. Unfortunately, EMFAC does not calculate the increases in emissions if the I/M program is discontinued or for the biennial period between inspection cycles. However, EMFAC does calculate the decreases in exhaust and evaporative emissions for situations when the I/M program is started in different past years. We can use this EMFAC capability to make an estimate of the ratio of changes in evaporative emissions to exhaust emissions.

Table 4-3 shows the results of two EMFAC runs for the 2004 calendar year I/M fleet – one run for the No-IM case and one run for the case where the I/M program was started in 2002. By comparing the estimated fleet emissions of these two cases, the table shows that for every 204 tons of HC + NX tailpipe emissions reduction, 22 tons of evaporative HC emissions reduction is expected. If we apply this ratio to the exhaust HC + NX inventory value of 748 (= 281.8 + 466.4) tons/day from Table 4-2, we expect that the amount of evaporative HC emissions that is available for selection by special strategies is 80.7 tons/day (= 748 * 22 / 204). This estimate of 80.7 tons is 37% of EMFAC's estimated evaporative HC emissions inventory value. Accordingly, the estimated total amount of HC available for capture by special strategies is 362.5 tons/day, which is the exhaust HC of 281.8 tons plus the evaporative HC of 80.7 tons.

Table 4-3. EMFAC Emissions Estimates of 2004 I/M Fleet

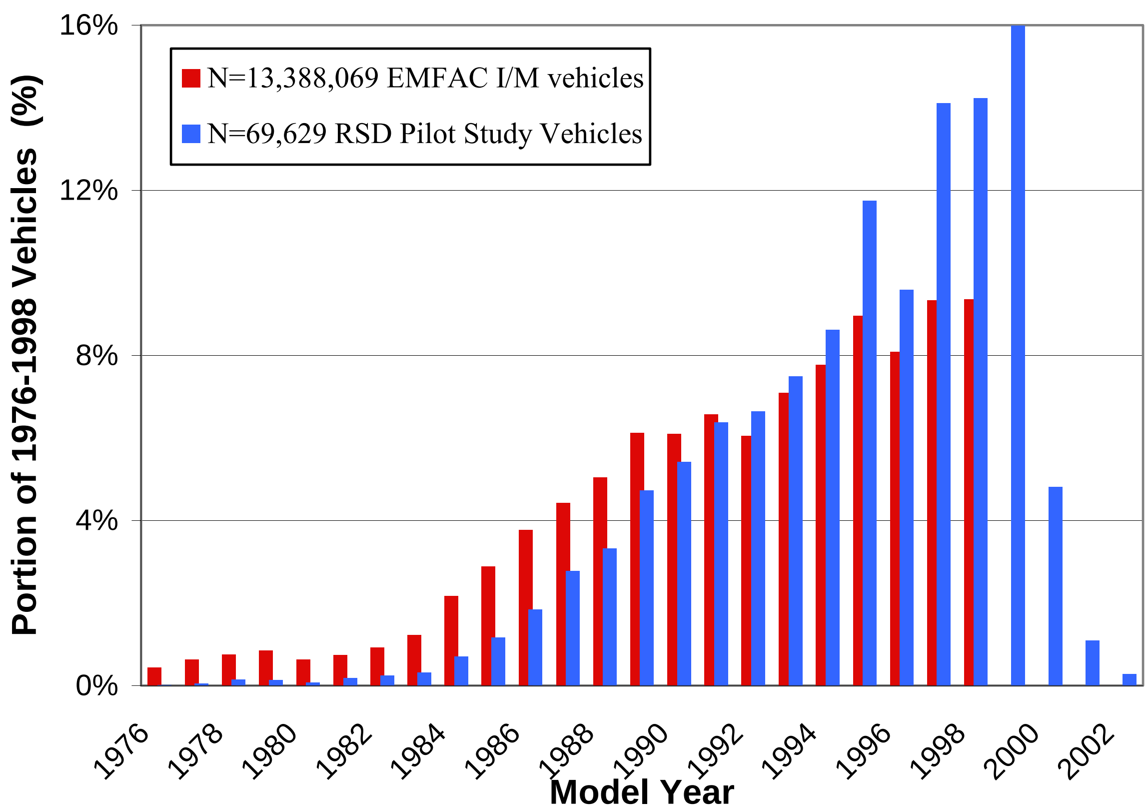
	Exhaust Emissions (tons/year)				Evaporative Emissions (tons/year)	Change with respect to the No-IM Case	
IM Case	**TOG**	**CO**	**NX**	**TOG +NX**	**Evap HC**	**TOG +NX**	**Evap HC**
No-IM	413	6101	650	1063	303		
2002 Start Biennial	327	5061	531	858	281	204	22

Comparison of the Modeling Set and the I/M Fleet – Before we apply the benefits calculated for the 69,629-vehicle dataset to the 13,388,069-vehicle I/M fleet, we need to consider the properties of the study's modeling dataset (N = 69,629). These particular observations were arrived at by a series of filterings of the raw data that were necessary to qualify the observations for use in evaluating the incremental costs and benefits of an RSD component to the existing I/M program.

Of the original 2,231,515 raw RSD readings taken from March 15, 2004 through January 24, 2005, 827,487 had valid RSD readings and had in-range VSPs. To ensure proper matching to the registration and VID databases and to allow for the determination of vehicle description including engine and emission control system technologies, we further required that these observations had to have non-erroneous VIN decodes. This reduced the number of observations to 486,286. To be able to use the observations for modeling, the RSD measurement had to be followed by an initial-cycle, naturally occurring ASM measurement. Because the analysis of the study occurred only about five months after the last RSD measurement was taken, most of the vehicles that had an RSD measurement did not have a long period of time during which a regular I/M inspection would have naturally occurred. Accordingly, the imposition of this requirement caused the 486,286 observations to drop to 90,574 observations. It should be noted that if the analysis would be performed today, which is more than two years after the end of RSD measurements, we expect that approximately 250,000 observations would be in the dataset. Also, the RSD had to be taken after the completion of a previous I/M cycle to ensure that the vehicle was not still undergoing repairs at the time of the RSD. Finally, all observations had to be able to produce forecasted failure probabilities using all of the types of models developed in the study. This meant that the observations had to have RSD measurements and unambiguous VID records for the cycles before and after the RSD measurement. These last two requirements caused the number of observations to drop to the final 69,629.

In these calculations, we are using the 69,629-vehicle dataset to represent the I/M fleet. However, the dataset needs to represent more than just the I/M fleet. It also needs to represent the sort of data that would be collected in an RSD program in California. It is well known that newer model years are more abundant in RSD datasets than they are in the I/M fleet. This is because newer vehicles are driven more and are therefore more likely to be seen at various locations, including on-ramps to busy highways. Figure 4-1 shows a model year comparison for the 69,629-vehicle dataset and the 2004 calendar year I/M fleet as modeled by EMFAC. For the 2004 calendar year, the I/M eligible vehicles have model years from 1976 to 1998. The figure shows the portion of each of the sets that is present in each model year in comparison with the number of vehicles in the I/M-eligible model year range from 1976 to 1998. A comparison of the model year distributions in Figure 4-1 reveals two main trends.

Figure 4-1. Comparison of the Model Year Distribution of the EMFAC I/M Fleet and the Study Modeling Set



First, the RSD pilot study vehicles have observations for model years 1999, 2000, 2001, and 2002. These model year vehicles would not normally be considered part of the routinely biennially inspected I/M vehicles since the newest six model years are exempt from biennial participation in the I/M program. However, some newer model year vehicles will participate in the change of ownership portion of the I/M program. We believe that this may be the reason that 2000, 2001, and 2002 ASM inspections were performed on some of the vehicles in the dataset. A large number of 1999 vehicles also appear in the dataset. We believe that these vehicles may appear because they were the first inspections of vehicles beginning to participate in the biennial I/M program since their six year exemption period had just ended. This was a consequence of the RSD measurement portion of the pilot study ending in January 2005.

The second noticeable feature in the comparison of model year distributions in Figure 4-1 is that the 69,629-vehicle dataset is less abundant for vehicles with model years older than about 1990 in comparison with the I/M fleet. An argument can be made that because these two distributions do not have abundances that agree in the older model years, then the 69,629 vehicle dataset does not represent the I/M fleet. However, it is important to recognize that the modeling dataset is largely a consequence of the new-vehicle bias that will be present in any real RSD data. If we would increase the abundance of observations in the modeling dataset for vehicles with model years older then 1990 so that it matched the distribution of the I/M fleet, this would bias the benefits that could be achieved by adding an RSD component to the existing I/M program. The reason for this is that, in practice, increasing the abundance of RSD measurements on old vehicles with respect to the abundance of RSD measurements in new vehicles can only be obtained by using RSD data collection strategies that are different from the strategies used in this study and in other standard RSD data collection efforts. For example, one such strategy would be to collect RSD data at locations that older model vehicles frequent such as back roads away from busy highways. We expect that such an approach would drive the unit cost of each valid, DMV-matched RSD measurement high because the traffic volume in those locations would be low.

Accordingly, rather than make any adjustments to the abundance of model years within the 69,629-vehicle dataset, we chose to use the dataset as it was and to ratio the benefits and costs calculated for that dataset up to the 13,388,069-vehicle I/M fleet.

Estimating Absolute Benefits – The 69,629-vehicle set used to estimate the benefits for the intervention activities is a sample of the 13,388,069-vehicle I/M fleet. Accordingly, the estimates of relative benefits for intervention activities that were calculated on the 69,629-vehicle set will be applied to the I/M fleet emissions shown in Table 4-4.

Table 4-4. I/M Fleet Emissions Available to Special Strategies for Calendar Year 2004

Model Years	HC (tons/day)	CO (tons/day)	NX (tons/day)	Vehicles	VMT (miles/day)
1976-1998	362.5	4,644	466.4	13,388,069	385,661,051

The result of applying the EMFAC model run results to relative benefits in Table 4-1 are the absolute benefits shown in Table 4-5. In the third column of the table, the total number of targeted vehicles is simply the fleet penetrations times 13,388,069 vehicles. Since the 13,388,069-vehicle I/M fleet is inspected once every two years, we must calculate the mass emissions for two years and recognize that Table 4-5 applies to one biennial cycle. The ΔFTP HC, CO, and NX are a result of multiplying the emissions in the bottom row of Table 4-4 times the percent ΔFTP values in Table 4-1 and converting the units from days to two years. Then, in Table 4-5, the ΔFTPs for HC and NX are added together to create the column labeled HC + NX.

The ΔFMD values in Table 4-5 were obtained by ratioing up the calculated ΔFMD values for the 69,629-vehicle dataset to the 13,388,069 vehicles in the I/M fleet. The number of targeted vehicles that failed the ASM at the decision point shown in Table 4-5 is calculated by multiplying the total number of targeted vehicles by the targeted vehicle fail rate given in Table 4-1.

Table 4-5. Estimated Absolute Changes in Evaluation Criteria Over One Biennial Cycle

Basic Ranking Method	Fleet Sample Penetration (%)	Total Number of Targeted Vehicles	Benefits: ΔFTP Emissions (tons/2-years)				Benefits: ΔFMD (miles/2-years)	Targeted Vehicles That Would Fail an ASM at the Decision Point
			HC	CO	NX	HC + NX		
Calling-In No-Sticker								
FprobDP by A	5	669,403	(1,036)	(15,376)	(783)	(1,819)	(255,391,460)	196,205
FprobDP by B	5	669,403	(1,079)	(14,502)	(776)	(1,855)	(306,632,874)	231,709
ΔFMD by C	5	669,403	(2,711)	(19,397)	(1,884)	(4,595)	(972,447,180)	222,039
FprobDP by F	5	669,403	(2,294)	(15,919)	(990)	(3,284)	(428,918,410)	291,441
ΔFMD by D	5	669,403	(3,189)	(22,033)	(2,166)	(5,355)	(1,106,109,594)	267,510
	100	13,388,069	(11,005)	(97,598)	(9,451)	(20,456)	(2,573,103,949)	1,367,197
Directing								
FprobDP by A	40	5,355,228	(18,289)	(166,368)	(12,970)	(31,259)	(3,923,356,374)	1,013,987
FprobDP by B	40	5,355,228	(18,351)	(168,606)	(13,077)	(31,429)	(4,344,129,965)	1,079,009
ΔFMD by C	40	5,355,228	(20,023)	(171,066)	(14,969)	(34,992)	(4,796,437,902)	928,068
FprobDP by F	40	5,355,228	(20,766)	(168,549)	(13,944)	(34,709)	(4,587,782,887)	1,098,278
ΔFMD by D	40	5,355,228	(22,805)	(188,665)	(16,173)	(38,978)	(5,364,493,225)	1,078,481
	100	13,388,069	(29,842)	(257,953)	(25,023)	(54,864)	(6,190,213,623)	1,367,197
Exempting								
FprobDP by A	20	2,677,614	2,404	19,216	2,824	5,228	323,553,009	44,901
FprobDP by B	20	2,677,614	2,865	23,274	3,493	6,357	215,246,821	26,507
ΔFMD by C	20	2,677,614	1,553	16,309	2,251	3,803	231,898,446	94,147
FprobDP by F	20	2,677,614	2,138	21,531	2,889	5,026	255,910,070	37,671
ΔFMD by D	20	2,677,614	897	9,927	1,520	2,417	30,687,305	53,780
	100	13,388,069	29,842	257,953	25,023	54,864	6,190,213,622	1,367,197
Scrapping								
FprobDP/$ by A	0.62	83,006	(2,426)	(34,641)	(1,571)	(3,997)	(179,679,066)	26,182
FprobDP/$ by B	0.48	64,263	(2,138)	(31,290)	(1,395)	(3,533)	(186,801,268)	23,710
ΔFTP CO/$ by C	0.44	58,908	(2,084)	(31,943)	(1,394)	(3,478)	(190,210,114)	22,936
FprobDP/$ by F	0.94	125,848	(4,961)	(73,348)	(3,514)	(8,476)	(522,835,049)	57,431
FprobDP/$ by F	0.43	57,569	(2,566)	(37,419)	(1,643)	(4,210)	(221,091,610)	25,828
ΔFTP CO/$ by C	0.43	57,569	(2,048)	(31,385)	(1,371)	(3,419)	(186,914,495)	22,474
ΔFTP CO/$ by D	0.41	54,891	(2,706)	(41,148)	(1,681)	(4,387)	(248,681,368)	26,682
ΔFTP CO/$ by C	0.41	54,891	(1,966)	(30,245)	(1,310)	(3,276)	(178,977,156)	21,430
	100.00	13,388,069	(59,601)	(696,953)	(59,400)	(119,001)	(9,683,917,176)	1,367,197

4.3 Biennial Incremental Benefits for Full-Fleet Ranking Methods

As mentioned earlier, because two basic ranking methods (FprobDP by F and ΔFMD by D) require RSD inputs, they cannot be used to rank the majority of vehicles in the fleet. They are not full-fleet ranking methods. The reason for this is that for a large RSD measurement program in California, usable-VSP RSD measurements can be obtained on no more than about 30% of the I/M vehicles driving statewide.

We want to evaluate the costs and benefits of ranking methods that will cover the full I/M fleet. For the 30% of the I/M fleet with usable-VSP RSD measurements, vehicles can be targeted by using basic ranking methods that take advantage of the RSD information, but the remaining 70% of the I/M fleet vehicles can be targeted only with basic ranking methods that do not use RSD information. Because the two basic ranking methods that require RSD information can cover, at most, 30% of the statewide I/M fleet, we need to create two full-fleet ranking methods from them. These two "mixed" methods allocate 30% of vehicle ranking by basic ranking methods that require RSD inputs and 70% of the vehicles by the best basic ranking method that does not require RSD information (ΔFMD by C). When we apply this mixing to the estimated absolute changes in benefits shown in Table 4-5, Table 4-6 is produced.

The table shows the full-fleet ranking methods that require RSD input information as the bold text in the first column. The first mixed ranking method, which is made up of 30% of FprobDP by F and 70% of Nothing, reflects the benefits that could be achieved if only RSD measurements are used to select vehicles for the intervention strategies. The second mixed ranking method is made up of 30% of FprobDP by F and 70% of ΔFMD by C. The third mixed ranking method is 30% by ΔFMD by D plus 70% of ΔFMD by C. All of the values in Table 4-6 are simple linear combinations of the values in Table 4-5 using 30% and 70% as weighting factors.

Table 4-7 shows the biennial incremental benefits for the full-fleet ranking methods that are derived from the benefits shown in Table 4-6. In Table 4-7 we no longer use full-fleet ranking method descriptions based on the technical name, which uses ranking variable and model identifier. Instead, we use descriptions that reflect the inputs that are used to make the vehicle rankings. Table 4-7 becomes a key table for the estimation of costs and benefits for the five different full-fleet ranking methods.

Table 4-6. Changes in Evaluation Criteria Over One Biennial Cycle for Full-Fleet Ranking Methods

Full-Fleet Ranking Method	Fleet Sample Penetration (%)	Total Number of Targeted Vehicles	Benefits: ΔFTP HC + NX Emissions (tons/2-years)	Benefits: ΔFMD (miles/2-years)	Targeted Vehicles That Would Fail an ASM at the Decision Point
Calling-In No-Sticker					
FprobDP by A	5	669,403	(1,819)	(255,391,460)	196,205
FprobDP by B	5	669,403	(1,855)	(306,632,874)	231,709
ΔFMD by C	5	669,403	(4,595)	(972,447,180)	222,039
30.28% FprobDP by F + 69.72% Nothing	5	202,669	(994)	(129,859,872)	88,237
30.28% FprobDP by F + 69.72% ΔFMD by C	5	669,403	(4,198)	(807,887,733)	243,051
30.28% ΔFMD by D + 69.72% ΔFMD by C	5	669,403	(4,825)	(1,012,914,979)	235,806
	100	13,388,069	(20,456)	(2,573,103,949)	1,367,197
Directing					
FprobDP by A	40	5,355,228	(31,259)	(3,923,356,374)	1,013,987
FprobDP by B	40	5,355,228	(31,429)	(4,344,129,965)	1,079,009
ΔFMD by C	40	5,355,228	(34,992)	(4,796,437,902)	928,068
30.28% FprobDP by F + 69.72% Nothing	40	1,621,355	(10,509)	(1,389,002,858)	332,516
30.28% FprobDP by F + 69.72% ΔFMD by C	40	5,355,228	(34,906)	(4,733,265,250)	979,601
30.28% ΔFMD by D + 69.72% ΔFMD by C	40	5,355,228	(36,199)	(4,968,423,039)	973,607
	100	13,388,069	(54,864)	(6,190,213,623)	1,367,197
Exempting					
FprobDP by A	20	2,677,614	5,228	323,553,009	44,901
FprobDP by B	20	2,677,614	6,357	215,246,821	26,507
ΔFMD by C	20	2,677,614	3,803	231,898,446	94,147
30.28% FprobDP by F + 69.72% Nothing	20	810,678	1,522	77,479,651	11,405
30.28% FprobDP by F + 69.72% ΔFMD by C	20	2,677,614	4,174	239,168,235	77,048
30.28% ΔFMD by D + 69.72% ΔFMD by C	20	2,677,614	3,384	170,979,511	81,925
	100	13,388,069	54,864	6,190,213,622	1,367,197
Scrapping					
FprobDP by A / $	0.62	83,006	(3,997)	(179,679,066)	26,182
FprobDP by B / $	0.48	64,263	(3,533)	(186,801,268)	23,710
ΔFTP CO by C / $	0.44	58,908	(3,478)	(190,210,114)	22,936
30.28% FprobDP/$ by F + 69.72% Nothing	0.94	38,102	(2,566)	(158,294,190)	17,388
30.28% FprobDP/$ by F + 69.72% ΔFTP CO/$ by C	0.43	57,569	(3,658)	(197,262,001)	23,489
30.28% ΔFTP CO/$ by D + 69.72% ΔFTP CO/$ by C	0.41	54,891	(3,612)	(200,080,890)	23,020
	100.00	13,388,069	(119,001)	(9,683,917,176)	1,367,197

Table 4-7. Biennial Incremental Benefits for Full-Fleet Ranking Methods

	Full-Fleet Ranking Method Description	Intervention Activity			
		Calling-In No-Sticker	Directing [1,2]	Exempting [2]	Scrapping
ΔFTP HC+NX Emissions (tons/ 2years)	Model Year [a]	(1,819)	(3,876)	3,241	(3,997)
	Vehicle Description [b]	(1,855)	(3,897)	3,942	(3,533)
	VID History [c]	(4,595)	(4,339)	2,358	(3,478)
	RSD [f] + Nothing	(994)	(1,303)	944	(2,566)
	RSD [f] + VID History [c]	(4,198)	(4,328)	2,588	(3,658)
	VID/RSD [d] + VID History [c]	(4,825)	(4,489)	2,098	(3,612)
ΔFMD (miles/2years)	Model Year [a]	(255,391,460)	(486,496,190)	200,602,866	(179,679,066)
	Vehicle Description [b]	(306,632,874)	(538,672,116)	133,453,029	(186,801,268)
	VID History [c]	(972,447,180)	(594,758,300)	143,777,037	(190,210,114)
	RSD [f] + Nothing	(129,859,872)	(172,236,354)	48,037,384	(158,294,190)
	RSD [f] + VID History [c]	(807,887,733)	(586,924,891)	148,284,306	(197,262,001)
	VID/RSD [d] + VID History [c]	(1,012,914,979)	(616,084,457)	106,007,297	(200,080,890)
Targeted Vehicles That Would Fail an ASM at the Decision Point	Model Year [a]	196,205	125,734	27,839	26,182
	Vehicle Description [b]	231,709	133,797	16,435	23,710
	VID History [c]	222,039	115,080	58,371	22,936
	RSD [f] + Nothing	88,237	41,232	7,071	17,388
	RSD [f] + VID History [c]	243,051	121,471	47,770	23,489
	VID/RSD [d] + VID History [c]	235,806	120,727	50,794	23,020

[1]We assume that average-performing stations have 80% of the accuracy of high-performing stations. Therefore, high-performing stations will produce 20% more fails than average-performing stations. Accordingly, the incremental benefits caused by Directing are estimated at 20% of the full values for ΔFTP, ΔFMD, and number of targeted vehicles that would fail an ASM at the decision point found in Table 4-6.

[2]We assume that 62% of the vehicles would be eligible for Directing and Exempting about a month before their biennial anniversary. This is mainly caused by vehicles that receive change-of-ownership inspections earlier in the cycle. Accordingly, the incremental benefits caused by Directing and Exempting are estimated at 62% of the full values for ΔFTP, ΔFMD, and number of targeted vehicles that would fail an ASM at the decision point found in Table 4-6.

Basic Ranking Method	CN, DI, EX	SP
[a] Model Year	= FprobDP by A	= FprobDP/$ by A
[b] Vehicle Description	= FprobDP by B	= FprobDP/$ by B
[c] VID History	= ΔFMD by C	= ΔFTP CO/$ by C
[d] VID/RSD	= ΔFMD by D	= ΔFTP CO/$ by D
[e] RSD	= FprobDP by F	= FprobDP/$ by F

Adjustments for the benefits of Directing and Exempting – The benefits for Calling-In and Scrapping in Table 4-7 are exactly the same as those in Table 4-6. However, two adjustments for Directing and one adjustment for Exempting are required because of the way we estimated the base benefits in the modeling report.

The first adjustment affects the Directing values for ΔFTP, ΔFMD, and number of failed vehicles. The size of the benefit of Directing is proportional to the difference in performance of the station from which and to which a vehicle is directed. Clearly, if there is no difference in station performance, directing a vehicle provides no benefit. In the modeling report [1], for the purposes of estimating the base benefits for Directing, we assumed that high-performing stations performed accurate inspections and we assumed that average-performing stations performed completely useless inspections with no repairs being made. We do not believe either of these assumptions is actually true, but making the assumptions made the calculations simpler. The result of these assumptions is that the values for the three criteria for Directing in Table 4-6 over-estimate the benefits of Directing. Accordingly, for Table 4-7 we now need to correct for the over-estimations that were the result of the assumptions.

BAR has done several studies that rank stations by performance and compare the ranges of performance [2, 3, 4]. Based on the trends observed in those studies, in this study we have assumed that average-performing stations are about 80% as effective as high-performing stations in terms of emissions reductions, failed miles driven, and fail rates. Thus, we estimate that the difference in performance of the station from which and to which a vehicle is directed is 20% (= 100% - 80%). Therefore, the estimated benefits in Table 4-6 are multiplied by 0.2 (=20%) to produce the values for Directing in Table 4-7, which are thereby corrected for the over-estimation of Directing benefits calculated in the modeling report.

The second adjustment affects Directing and Exempting values for ΔFTP, ΔFMD, and number of failed vehicles. In the modeling report [1], for the purposes of estimating the base benefits for Directing and Exempting, we assumed that all vehicles for model years 1976-1998 would be eligible for Directing and Exempting. Vehicles that are actually eligible for Directing and Exempting are only those vehicles that have not already gotten an inspection about a month before their biennial anniversary. Thus, vehicles that already received change-of-ownership inspections or were newly registered vehicles would not be eligible. To the extent that a portion of the vehicles have already gotten an I/M inspection or are otherwise ineligible for Directing and Exempting, the base benefits of Directing and Exempting calculated in the modeling report are an over-estimation of the true benefits. The result of this assumption is that the values for the three criteria for Directing and Exempting in Table 4-6 over-estimate the benefits of Directing and Exempting. Accordingly, for Table 4-7 we now need to correct for the over-estimations that were the result of the assumption.

Based on partial 2005 initial I/M inspection results, BAR estimated that 27.5% of the vehicles in the I/M fleet had change-of-ownership initial inspections and 10.3% of the vehicles had initial-registration initial inspections. Only the remaining 62.2% of the vehicles received biennial initial inspections and were eligible for Directing and Exempting. Accordingly, the incremental benefits of Directing and Exempting shown in Table 4-7 need to be reduced to 62% of the values to account for Directing and Exempting eligibility.

In summary, for Directing the values in Table 4-7 are reduced to 20% times 62% of the values in Table 4-6. For Exempting the values in Table 4-7 are reduced to 62% of the values in Table 4-6.

Table 4-7 shows the estimated benefits of the four intervention activities in terms of ΔFTP and ΔFMD over one biennial cycle. To put these changes in perspective, we show Table 4-8, which gives estimates of the biennial total FTP emissions [from the EMFAC run results in Appendix N of Reference 1], total failed miles driven (FMD), and total vehicle miles traveled (VMT) for the 13,388,069-vehicle I/M fleet as it operated in 2004.

Table 4-8. Biennial Estimates of FTP Emissions, Failed Miles Driven, and Vehicle Miles Traveled for the I/M Fleet

FTP Emissions (tons/2years)	**HC**	205,714
	CO	3,390,120
	NX	340,472
	HC + NX	546,186

FMD (miles/2years)	30,624,179,635
VMT (miles/2years)	331,568,758,801

The Influences of Other Effects on Benefits – Other behaviors in the I/M program can affect the calculation of emissions benefits of special strategies such as Directing, Exempting, Calling-In, and Scrapping. These include the effects of pre-inspection repairs and the effects of high-performing stations versus average-performing stations.

Pre-inspection repairs, which are repairs performed by vehicle owners in preparation for regularly scheduled Smog Check inspections, are frequently mentioned as a source of emissions benefits that are not quantified in I/M evaluations. While we acknowledge that they do occur, and have some impact on the failure rate of vehicles at Smog Check stations, we do not believe their impact on the results of the study is substantial. Using an analysis of VID repair data and roadside data, recent BAR estimates indicate that a) pre-inspection repairs do not occur as often as generally believed, b) most pre-inspection repairs do not lead to a passing test result, and c) while pre-inspection repairs do lower the failure rate, the reduction is only a small fraction of the expected failures. Overall, the preliminary BAR analysis suggests that pre-inspection repairs lower the failure rate for RSD-directed vehicles on the order of 1%. Because the minimal benefit anticipated and the difficulty of accurately estimating pre-inspection influences, we have chosen not to include estimated benefits of pre-inspection repairs in the calculated incremental benefits of adding an RSD component to the I/M program for this pilot study.

In addition, BAR has found, based on Roadside ASM testing, that about 17% of vehicles that initially passed and about 46% of vehicles that initially failed and finally passed, failed Roadside ASMs shortly after being certified at average Smog Check stations. BAR concludes that many of the high emitting vehicles improperly passed their emissions test when inspected at a Smog Check station. Thus, BAR's analysis indicates that the failure rate of RSD-identified high-emitters at average Smog Check stations is suppressed primarily due to inaccurate inspections at Smog Check stations – rather than due to the much smaller pre-inspection repair effect.

As we shall see in the accuracy section (Section 9) of the final report, a comparison of RSD measurements with Roadside ASM test results obtained immediately after the RSD reading indicate that 40% of vehicles that are declared "high emitters" by RSD (when using RSD cutpoints that are equivalent to ASM cutpoints) will fail an <u>immediate</u> Roadside ASM test. However, our analysis of the VID data for the pilot study indicates that only 25% of vehicles declared "high emitters" by RSD would <u>later</u> fail an ASM test at the average Smog Check station.

The difference between the ASM fail rate immediately after an RSD (40%) and the later ASM fail rate at average Smog Check stations (25%) could be accounted for by a combination of pre-inspection repairs and Smog Check station inaccuracies. The question is how much of the difference is due to pre-inspection repairs and how much is due to station inaccuracies. BAR's analysis, which was discussed above, suggests that the pre-inspection repair portion is small and the station inaccuracy portion is large. The pre-inspection repair portion being small is supported by BAR's analysis of VID repair data and roadside data. The station inaccuracy portion being large is supported by the observations of high roadside failure rates on vehicles immediately after they were certified as passing by the stations.

Whether the difference between the higher on-road failure rates as measured by RSD and Roadside ASM and the lower Smog Check station failure rates is dominated by pre-inspection repairs or by station inaccuracies, the difference in failure rates should not be used as a reason to denigrate either the accuracy of RSD measurements or the accuracy of the Fprob models built for this analysis. The fact is that the on-road failure rates are higher than the Smog Check station failure rates. The RSDs and Roadside ASMs measure the on-road failure rates, and the Fprob models built for this analysis reflect the lower failure rates observed in the Smog Check stations.

The implications for the pilot analysis are that vehicles that are declared as high emitters by RSD should be sent to high-performing stations, such as referee stations, for confirmatory ASM testing rather than being sent to average Smog Check stations. We have used this approach in setting up the Directing strategy. That is, vehicles targeted for Directing were sent to high-performing stations for confirmatory testing. In the current I/M program vehicles are directed to Test/Only stations. However, for Calling-In and Scrapping, confirmatory testing was modeled as being performed at average-performing stations. Thus, the emissions benefits calculated for Calling-In and Scrapping are under-estimated in comparison with a strategy where targeted vehicles would be sent to high-performing stations for confirmatory testing. Sending all vehicles to high-performing stations – especially referee stations – raises the issue of the available capacity that the referee stations would need to have and the associated costs to handle the volume of vehicles needing confirmatory ASM testing for the Directing, Calling-In, and Scrapping strategies.

5.0 Calculation of Costs

Sections 5.1 through 5.5 discuss RSD measurement unit costs, central office costs, the estimated value of vehicles targeted for scrappage, vehicle repair costs, and other costs for components needed by any intervention activities in the California I/M program. These unit costs are retrieved from a cost analysis study. We supplement these costs results with the experiences of other jurisdictions that have been making RSD measurements. In Section 5.6, we use the example scenario, which has the chosen mix of intervention activities to be investigated, and the base case scenario, which has no intervention strategy, to define the level of cost item use required to implement each intervention activity. Then, in Section 5.7, we multiply the unit cost for each cost item by the needed number of cost items to arrive at the different components of the biennial incremental costs for implementing the example scenario.

5.1 Estimates of RSD Measurement Unit Costs

In this section we describe how the estimates for costs of RSD measurements were arrived at. A number of assumptions are required to estimate the costs of a hypothetical program. Some assumptions come with implications that are not obvious. We have listed the major assumptions that readers should keep in mind as they evaluate the options of using RSD to improve Smog Check:

- Cost and fleet coverage estimates assume the programs have been largely accepted by the public (i.e., drivers do not try to avoid RSD sites or attempt to invalidate the measurement, they respond to the notices for off-cycle inspection, etc.).
- Costs do not include enforcement (e.g., BAR responses to program avoidance, fighting legal challenges of the validity of the RSD measurement, etc.).
- We assume the restrictions CalTrans placed upon our RSD measurement teams will be lifted. We were restricted from taking RSD measurements during rush hour traffic. Experience with other programs has shown that this restriction is unnecessary.
- We assume that the Sacramento area provides a good surrogate for assumptions about the availability of sites, the comparability between freeway and surface street sites, California driving behavior, etc.

Table 5-1 gives the estimated unit costs for five different types of RSD measurement programs. The unit cost of each RSD measurement is based on the volume of quality-assured measurements that are valid and matched to DMV records. The total RSD cost is proportional to the size of the program. The unit cost is for RSD data collection and delivery, which includes labor, RSD data quality assurance, support overhead, equipment maintenance, travel, operations, consumables, site selection, permits, license plate transcription, and matching to DMV records. The major assumptions and a description of the relevant sources for each cost element are listed in Table 5-2.

Table 5-1. Estimated Unit Costs for Different RSD Measurement Programs

Description of Turn-Key RSD Data Collection	Estimate ($/valid, matched)	Notes and Source
Manned, 50% Any-VSP RSD Coverage	$1.00	Projection from other programs for high coverage. Valid (per ESP software) and matched to DMV (including permits, equipment, maintenance, QA, etc.)
Manned, 35% Any-VSP RSD Coverage	$0.75 [a]	Similar to other programs. Valid (per ESP software) and matched to DMV (including permits, equipment, maintenance, QA, etc.)
Manned, low Any-VSP RSD Coverage	$0.50 [a]	Similar to annual 0.5% fleet coverage surveys. Valid (per ESP software) and matched to DMV (including permits, equipment, maintenance, QA, etc.)
Unmanned, 50% Any-VSP RSD Coverage	$0.42 [a,b]	Calculated from manned estimate using ratio of "manned" vs. "unmanned" estimates. Valid (per ESP software) and matched to DMV (including permits, equipment, maintenance, QA, etc.)
Unmanned, 35% Any-VSP RSD Coverage	$0.31 [a,b]	Calculated from manned estimate using ratio of "manned" vs. "unmanned" estimates. Valid (per ESP software) and matched to DMV (including permits, equipment, maintenance, QA, etc.)

[a]Estimates from current programs.
[b]Unmanned calculated as ratio from manned ($/deployed RSD unit) vs. unmanned estimates.

Table 5-2. Cost Elements and Notes on Assumptions

Cost Element	Sources	Notes
Quality Assured RSD data, matched to registration records	Project estimates, Other RSD programs	Includes equipment to collect valid data using manned systems. The project developed "ground-up" estimates for California. The project estimates were modified using experience from the pilot program and from other state programs. Site selection and permits are included.
Required number of RSD sites	Project estimates, Other RSD programs	California specific issues from the project study of Sacramento as typical. Ramps compared to surface streets from pilot program data (RSD-RASM report). Site productivity (valid readings per raw reading, fraction within desired VSP range, etc.) from pilot program data and experience of other RSD programs.

RSD unit cost increases as RSD fleet coverage increases 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. To provide RSD unit cost estimates for manned RSD data collection over a wide range of fleet coverages, we have fit the first three unit costs in Table 5-1 with a second-order equation:

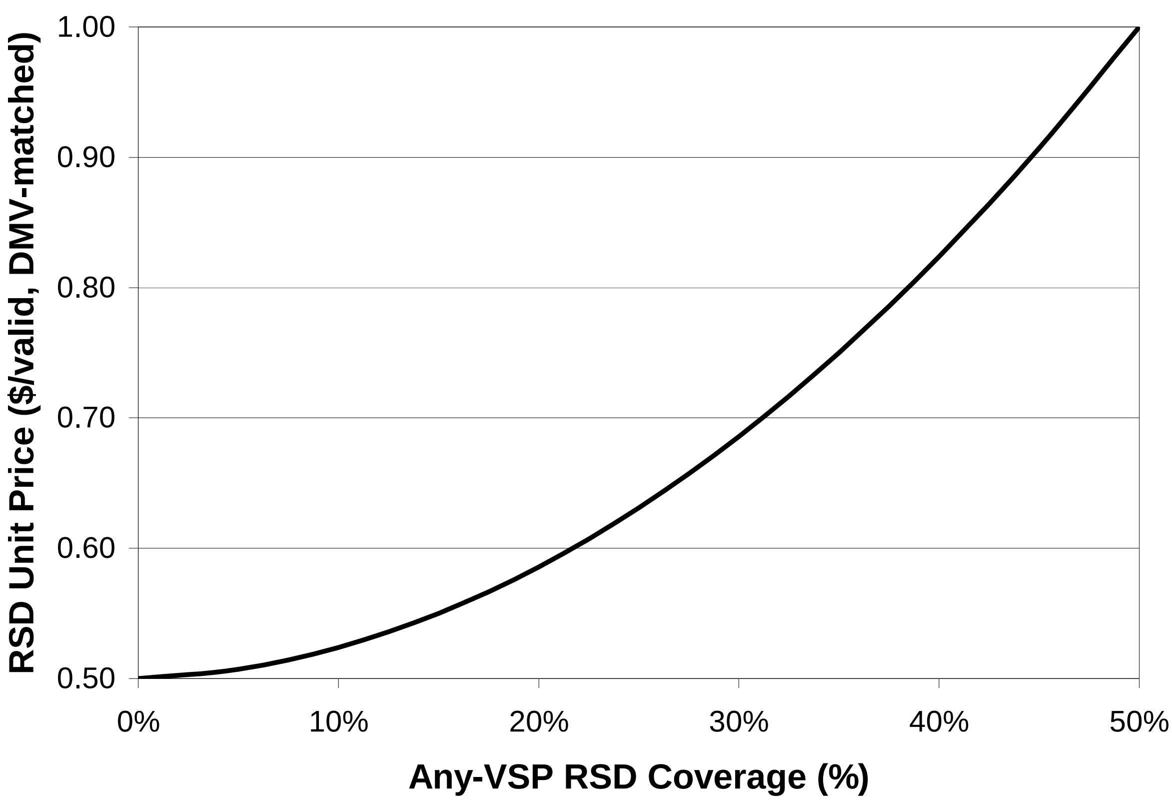
RSD Unit cost ($/valid, DMV-matched)

$$= 0.50 + 0.0475 * \left(\frac{\%\text{FleetCoverage}}{100\%} \right) + 1.9048 * \left(\frac{\%\text{FleetCoverage}}{100\%} \right)^2$$

where: % Fleet Coverage is the Any-VSP RSD Coverage.

A plot of the RSD unit cost function is shown in Figure 5-1.

Figure 5-1. Estimated RSD Unit Price for Turn-Key Measurements



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

In parallel, our team also estimated the costs of RSD data using a "bottom up" method, which estimates the cost of each piece of the RSD data collection effort and then adds them. For example, we estimated the cost of the equipment, maintenance costs, consumables, labor, training, etc. Those estimates are not used verbatim in this report because the results did not come close enough to what we know to be the case from other programs. For example, our bottom up approach estimated a cost of almost $2.50 per valid reading, matched to the registration database for a program with a 10% any-VSP RSD coverage of the fleet.[7] We know from other programs that 30% any-VSP RSD coverage can be achieved for under $0.75 per valid, matched RSD reading. We expect that the bottom-up approach did not capture the efficiencies and real world experience of other RSD programs now in operation. We did, however, use many of the assumptions from our bottom-up estimate because they are unique to California and could not be estimated from the experience of other programs. These assumptions are discussed at the beginning of this sub-section.

Summary of RSD costs – Now that we have estimated the RSD unit costs, we can apply the unit costs to the estimated counts of RSD measurements from Table 3-7 to arrive at a RSD data collection cost. Table 5-3 shows the corresponding cost figures for the large, medium, and small RSD programs described in Appendix A. The table is laid out to follow the logic that would be used to cost the RSD data collection effort of an RSD component to the existing I/M program. Column A indicates the general size of the RSD program. In this report, we have been discussing a large RSD program. Column B quantifies that size in terms of the any-VSP RSD coverage. This coverage applies to the I/M and non-I/M California vehicles driving in the five largest AQMDs. For example, the large RSD program would have an any-VSP RSD coverage of 50%. In terms of the number of vehicles that would be covered, Column C shows the number of unique I/M and non-I/M vehicles with DMV-matched RSD readings. This number is simply determined by multiplying the any-VSP RSD coverage in Column B by the number of California I/M and non-I/M vehicles driving in the five largest AQMDs. To achieve that level of any-VSP RSD coverage, a much larger number of valid, DMV-matched RSD readings is required. This is shown in Column D. The RSD unit costs are applied to these counts to determine the RSD data collection costs for the RSD program. The RSD unit costs, as described earlier in this section,

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[7] The project calculated costs for a small program where readings would be obtained on 34,220 unique vehicles in the Sacramento area, where those vehicles are being operated in a "representative" driving mode. This translates to approximately 214,000 valid readings on vehicles that can be verified as being registered in California, and about 85,600 unique vehicles (about 10% of the 2004 Sacramento fleet). We estimated the cost of such a program at $532,000, or a little less than $2.50 per valid reading matched to the registration database.

Table 5-3. Comparison of RSD Programs of Different Size

A	B	C	D	E	F	G	H	I	J
Desired			**Required**			**Achieved**			
	Any-VSP RSD Coverage	**Number of Unique I/M and non-I/M Vehicles with Valid, DMV-Matched RSD Readings**	**Number of Valid, DMV-Matched RSD Readings**	**RSD Unit Cost**	**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**	**Usable-VSP RSD Coverage 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)**		**($/ valid, DMV-matched RSD reading)**	**($)**		**(% 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	25,975,057	$1.00	$25,973,758	4,053,388	39.7%	30.28%	$6.41
Medium	30%	5,694,864	11,026,614	$0.69	$7,560,751	2,157,461	22.2%	16.11%	$3.50
Small	10%	1,898,288	1,898,288	$0.52	$994,319	625,831	6.7%	4.67%	$1.59

C:/MyDocuments/CA RSD Pilot Decision Report/Implementation Report/Usable RSD Data Costs.xls are a function of the any-VSP RSD coverage percentage. Column E shows these estimated RSD unit costs for the different RSD program sizes. The annual RSD data collection cost, shown in Column F, is simply the value in Column D times the RSD unit cost in Column E.

Columns G through J show what is achieved by operating these different size RSD programs. Column G shows the number of unique I/M vehicles that are driving in the five largest AQMDs that have usable RSD readings, that is, RSD readings that can be used to select vehicles for Calling-In, Directing, Exempting, or Scrapping. When we express these counts in Column G as a percentage of the California I/M vehicles driving in the five largest AQMDs, we get the usable-VSP RSD coverage figures shown in Column H. If we express them in terms of the number of California I/M vehicles driving in the entire state, we get the usable-VSP RSD coverage percentages shown in Column I. Finally, Column J shows the effective RSD cost associated with a usable RSD reading on an I/M vehicle that is driving in the five largest AQMDs.

Overall, the table shows that annually the large RSD program costs almost $30 million to obtain 4 million RSD measurements that could be used to select vehicles for special strategies. Thus the average cost of RSD data collection for each usable RSD measurement is $6.41. Even at this price, this large RSD program provides usable-VSP RSD coverage of only 30% 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. This means that regardless of the size of the RSD program, less than 30% of the statewide I/M fleet is available to be selected for special strategies that use RSD data.

5.2 Estimates of Central Office Costs

This section describes our estimates of the costs for a central office that would select vehicles for Calling-In, Directing, Exempting, and/or Scrapping strategies that would supplement the existing I/M program. In the cost estimates we examined each of the different components of the central office costs. We developed functions that modify the component costs smoothly, but not necessarily proportionately, with the characteristics of the supplemental program. The resulting function 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.

Assumptions – To calculate the central office cost, 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. For example, we did not assume the presence of any branch central offices for separate AQMDs.

Vehicle selection strategies can operate with or without RSD data since VID history information can be used alone to select vehicles for any strategy. However, if RSD data is used, we assumed that an RSD contractor would provide RSD information in a turn-key manner. We assumed that the RSD contractor would provide data records for valid, DMV-matched RSD measurements with at least the following fields: hand-transcribed license plates, RSD measurements, and calculated vehicle specific power. In addition, we assumed that the contractor would provide this information on a weekly basis and that all of the RSD measurements would be fresh.

Finally, we assumed that the costs for purchasing scrappage vehicles, mailing notices, performing inspections, issuing certificates, repairing vehicles, and maintaining the central office's vehicle selection software are not part of the central office costs. Those costs are considered separately from the central office costs in later sections.

Central Office Activities – The central office would receive weekly updates of data from four sources:

- DMV registration updates;
- New 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.

In addition to weekly updates for these data sources, historical records for each of the sources would be required to maintain information datasets for the purposes of calculating vehicle rankings and insuring that new notices are not sent to vehicle owners who have just recently received notices. We expect that the central office would need to keep the most recent two years of DMV registrations, six years of VID records, two years of RSD data, and two years of records of past notices sent and responses of owners to notices.

The central office would hire an RSD contractor to provide turn-key RSD data and its associated information. The cost of RSD data collection is estimated in Section 5.1 and is not a part of the central office cost described here. The central office would also assist the RSD contractor in working out problems that the contractor might have in selecting and gaining access to appropriate sites around the state to be used for RSD data collection. A data analyst at the central office would perform weekly checks on the RSD data obtained to ensure that data quality is maintained.

One of the main jobs of the central office would be to create weekly lists of targeted vehicles for Calling-In, Directing, Exempting, and Scrapping based on current VID history and/or RSD measurement information. 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. Vehicle eligibility would be determined by the specific needs of the strategy. Directing and Exempting would apply only to vehicles that are soon due for their 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 the computer programs developed in this project that forecast the benefits of selecting individual vehicles for specific strategies. This is true even for using RSD data alone since the ranking programs that we have built perform better (get more emissions) than using simple RSD cutpoints.

The first step in ranking vehicles is matching records among the different data sources. If RSD data is available for vehicle ranking, the central office would match RSD information with registration information, VID information, and past-notices-sent information. If RSD data is not available for vehicle ranking, the central office would match observations from registration information, VID information, and past-notices-sent information.

Each week the prior week's data would be used to create vehicle targeting lists for Calling-In, Directing, Exempting, and/or Scrapping. The Directing and Exempting target lists would be transmitted weekly to the agency that sends reminder notices to owners for their upcoming inspection. Vehicles that are directed or exempted would be sent modified notices. The Calling-In and Scrapping target lists would be transmitted to whomever would send those notices. Sending the notices is costed in Section 5.6 and is not a part of the central office cost described here.

The central office would also handle the questions from vehicle owners in response to the letters that they received which discussed Directing, Exempting, Calling-In, and Scrapping. We assumed that the level of effort required to handle owners targeted for Calling-In would be high and, therefore, would require additional central office personnel to handle owners' questions.

Because of the addition of supplemental strategies to the existing I/M program, the central office would also conduct public outreach and education activities.

Components of Central Office Costs – This project estimated different components of central office costs. These estimates were based on a hypothetical central office that would serve the Sacramento area. The cost estimates for serving other areas within California, including the entire state, are based upon these costs. Table 5-4 gives the different components of the costs for different configurations of a central office. Different configurations of the central office are defined by four variables:

- **Size of the program** – The size of the program is proportional to the number of I/M vehicles served by the central office. A value of 1 indicates a statewide program, a value of 0.037 indicates a program big enough to serve the Sacramento area, and a value of 0.4 indicates a program big enough to serve the South Coast AQMD.

- **Full fleet Calling-In penetration** – This value indicates the fraction of the I/M fleet targeted for Calling-In. When this value is zero, no Calling-In is being performed. A value of 0.025 indicates that 2.5% of the I/M fleet would be targeted for Calling-In by sending call-in notices to 2.5% of the I/M fleet.

- **RSD data availability** – This is a binary (yes/no) value. A zero indicates that RSD data is not being used and only VID history information is being used. A one indicates that RSD data is being used, either alone or with VID history, for ranking and selecting vehicles.

- **Percent of vehicles with complete data for the selection method** – This value is the maximum fraction of the statewide I/M vehicles in the program (see "Size of the program," above) that can be evaluated by the selection method being used. A value of 100% indicates that all of the vehicles in the fleet have data that can be used by one vehicle ranking method or the other. The value of 30.28% is the maximum value that can be used for the ranking method using RSD information alone since the usable-VSP RSD coverage for the largest practical RSD program (any-VSP RSD coverage = 50%) is 30.28% of the statewide I/M fleet. A value of 3% is an example of the situation where 3% of the vehicles in the program would have a full set of data available for ranking. This would be the situation, for example, for targeting vehicles for scrappage using RSD alone when only 3% of the vehicles in the area being served have RSD information available.

Table 5-4. Central Office Costs for the Statewide Program for Calling-In, Directing, Exempting, and Scrapping

Full-Fleet Ranking Method Description	Annual Salary @ 40hrs/wk	Model Year		Vehicle Description		VID History		RSD + Nothing		RSD + VID History		VID/RSD + VID History	
Strategies?		D X S C		D X S C		D X S C		D X S C		D X S C		D X S C	
Size of Program (Statewide=1)		1		1		1		1		1		1	
% Sample Fleet Penetration for Calling-In		5%		5%		5%		5%		5%		5%	
With RSD [Yes(1) or No(0)]		0		0		0		1		1		1	
Statewide I/M Vehicles with Complete Data for the Selection Method (%)		100%		100%		100%		30.28%		100%		100%	
Capital Costs													
DMV for Programming, form changes, etc.. (One-time Fee for Calling-In Program)			$500,000		$500,000		$500,000		$500,000		$500,000		$500,000
Central Office Computer Equipment ($20K for server + $2K per person)			$95,000		$95,000		$95,000		$62,138		$97,000		$97,000
Other Capital Costs - central office supplies and equipment			$101,081		$101,081		$101,081		$56,792		$103,777		$103,777
Annual O&M Costs													
Amortized capital costs for DMV for Programming, etc.. (10yrs @10%)			**$81,373**		**$81,373**		**$81,373**		**$81,373**		**$81,373**		**$81,373**
Amortized capital costs for computer equipment (5yrs @10%)			**$25,061**		**$25,061**		**$25,061**		**$16,392**		**$25,588**		**$25,588**
Amortized capital costs for office supplies/equipment (10yrs @10%)			**$16,451**		**$16,451**		**$16,451**		**$9,243**		**$16,889**		**$16,889**
Labor for Central Office													
Position	Annual Salary @ 40hrs/wk												
Program Administrator	$90,970	1.00	$90,970	1.00	$90,970	1.00	$90,970	1.00	$90,970	1.00	$90,970	1.00	$90,970
Program Manager	$70,754	2.50	$176,885	2.50	$176,885	2.50	$176,885	3.00	$212,262	3.00	$212,262	3.00	$212,262
Engineer /Data Analyst/Programmer	$70,754	4.50	$318,393	4.50	$318,393	4.50	$318,393	5.00	$353,770	5.00	$353,770	5.00	$353,770
Attorney	$63,000	3.00	$189,000	3.00	$189,000	3.00	$189,000	1.61	$101,148	3.00	$189,000	3.00	$189,000
Public Information/Communication	$30,323	20.00	$606,460	20.00	$606,460	20.00	$606,460	6.75	$204,755	20.00	$606,460	20.00	$606,460
Administrative Assistant	$48,000	1.00	$48,000	1.00	$48,000	1.00	$48,000	1.00	$48,000	1.00	$48,000	1.00	$48,000
Receptionist	$30,323	1.00	$30,323	1.00	$30,323	1.00	$30,323	1.00	$30,323	1.00	$30,323	1.00	$30,323
Clerical and Secretarial Staff	$30,323	4.50	$136,454	4.50	$136,454	4.50	$136,454	1.71	$51,884	4.50	$136,454	4.50	$136,454
Salary * Person-Years		37.5	$1,596,485	37.5	$1,596,485	37.5	$1,596,485	21.1	$1,093,112	38.5	$1,667,239	38.5	$1,667,239
Overhead and Fringe (100%)			$1,596,485		$1,596,485		$1,596,485		$1,093,112		$1,667,239		$1,667,239
Equipment maintenance (@20%)			$20,216		$20,216		$20,216		$11,358		$20,755		$20,755
Supplies (@10% of Maintenance)			$2,022		$2,022		$2,022		$1,136		$2,076		$2,076
Total Labor for Central Office, fully burdened			**$3,215,207**		**$3,215,207**		**$3,215,207**		**$2,198,718**		**$3,357,308**		**$3,357,308**
Misc. Recurring Costs, Central Office													
Operating supplies ($250/person-yr)			$9,375		$9,375		$9,375		$5,267		$9,625		$9,625
Travel ($250/person-yr)			$9,375		$9,375		$9,375		$5,267		$9,625		$9,625
Hiring and training costs			$17,955		$17,955		$17,955		$10,088		$18,434		$18,434
Total for misc. recurring costs at central office			**$36,705**		**$36,705**		**$36,705**		**$20,622**		**$37,684**		**$37,684**
Other Contract Support (2% of program expenses)			**$67,496**		**$67,496**		**$67,496**		**$46,527**		**$70,377**		**$70,377**
Total Annual CENTRAL OFFICE O&M Costs (including capital recovery)			**$3,442,292**		**$3,442,292**		**$3,442,292**		**$2,372,874**		**$3,589,219**		**$3,589,219**

D = Directing, X = Exempting, C = Calling-In, S = Scrapping
/proj1/DecisionModel/Report/IM_Strategy_Evaluator_071119.xls

Table 5-4 shows that the capital costs for the central office 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 only occur if a Calling-In program were used. The same one-time expense would 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 expect that a server would be required to maintain weekly updates to the large datasets of Registration, VID, RSD, and historical notice datasets. In addition, each employee would need a desktop computer to communicate with the server. We have estimated these costs as $20,000 for the server plus $2,000 for each employee at the central office. The third capital cost is for central office supplies and equipment and is directly proportional to the number of employees at the central office.

The annual operating and maintenance costs have several categories. The first three shown in Table 5-4 are the amortized capital costs. The DMV programming and form change costs were amortized over 10 years at 10%. The computer costs were amortized over 5 years at 10%. The capital costs for office supplies and equipment were amortized over 10 years at 10%.

The major costs for operating the central office are the labor costs. We costed eleven different positions in the central office. For the estimated costs in this study, we have kept the same level of detail, but have grouped them into four categories for discussion:

- **Program Administrator/Program Manager** – The Program Administrator oversees the central office operation. The time that the Program Administrator works in the central office is dependent on the existence of a Calling-In program and the general size of the program. If Calling-In is one of the strategies in the program, then a full Program Administrator is required to oversee the handling of the responses from vehicle owners that have been targeted. If Calling-In is not in the program, that is, if the program contains only Directing, Exempting, and/or Scrapping, then the amount of time the Program Administrator spends in the central office is proportional to the size of the program. More than one Program Administrator is never required.

  If RSD data is used, a Program Manager will be required to maintain communications with the RSD contractor and to ensure that RSD data is quality-checked and is used properly. Additional Program Managers will be required in proportion to the size of the program if the Calling-In strategy is used.

- **Engineer/Data Analyst/Programmer** – These personnel are responsible for weekly acquisition of the registration, VID, RSD, and notice history data. They put the data on the server and run the vehicle ranking and targeting software to produce weekly lists of vehicles to be targeted for Calling-In, Directing, Exempting, and Scrapping. They are also responsible for quality checking the data before and after each weekly run and ensuring that the lists reach their destination for notices to be sent. Because this work must be completed each week, enough personnel must be available to prevent getting behind.

- **Public Information Specialist/Attorney** – These personnel are responsible for handling the public as it responds and inquires about the special strategies. When the special strategies include only Directing, Exempting, or Scrapping, the demand for these personnel will be low. However, when Calling-In is part of the special strategy package, we anticipate that many vehicle owners will be contacting the central office with questions and/or complaints. In this situation, the number of these personnel must be large enough to handle the workload. These personnel will also handle public outreach and education.

- **Administration Assistant/Clerk/Secretary/Receptionist** – The number of these personnel is, in general, proportional to the size of the program. Even the smallest program will require a Secretary/Receptionist. Larger programs will require additional personnel of this type as the need for communication with the public and with other agencies increases.

Table 5-4 shows the sum of the salaries for these personnel and costs for loading the salaries with overhead and fringe benefits, equipment maintenance, and supplies. This produces a total labor cost for the central office that is fully burdened. The table then shows miscellaneous recurring costs for the central office for operating supplies, travel, and hiring and training costs. These costs are based on the number of personnel at the central office. Finally, the last item is an expense for other contract support, which is estimated to be 2% of the other central office costs. The last row in the table gives the total annual central office costs for the different descriptions of central offices.

5.3 Estimates of Scrappage Vehicle Purchase Cost

For the Scrappage strategy, the state buys vehicles and destroys them as a means of eliminating the emissions of those vehicles from the inventory. Of the four 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.

Another important difference between Scrapping and the other strategies is the approach used to calculate the benefits and costs for the strategy. For Directing, Exempting, and Calling-In, we select the fleet penetration that we want to evaluate and then we calculate the benefits that we would get and the costs that would be incurred for targeting that fraction of the I/M fleet. However, selecting the penetration for Scrapping is different. 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, then we can calculate the benefits and the other, non-vehicle-purchase costs incurred. We have used this approach for calculating the benefits and costs for the large RSD program described in this report.

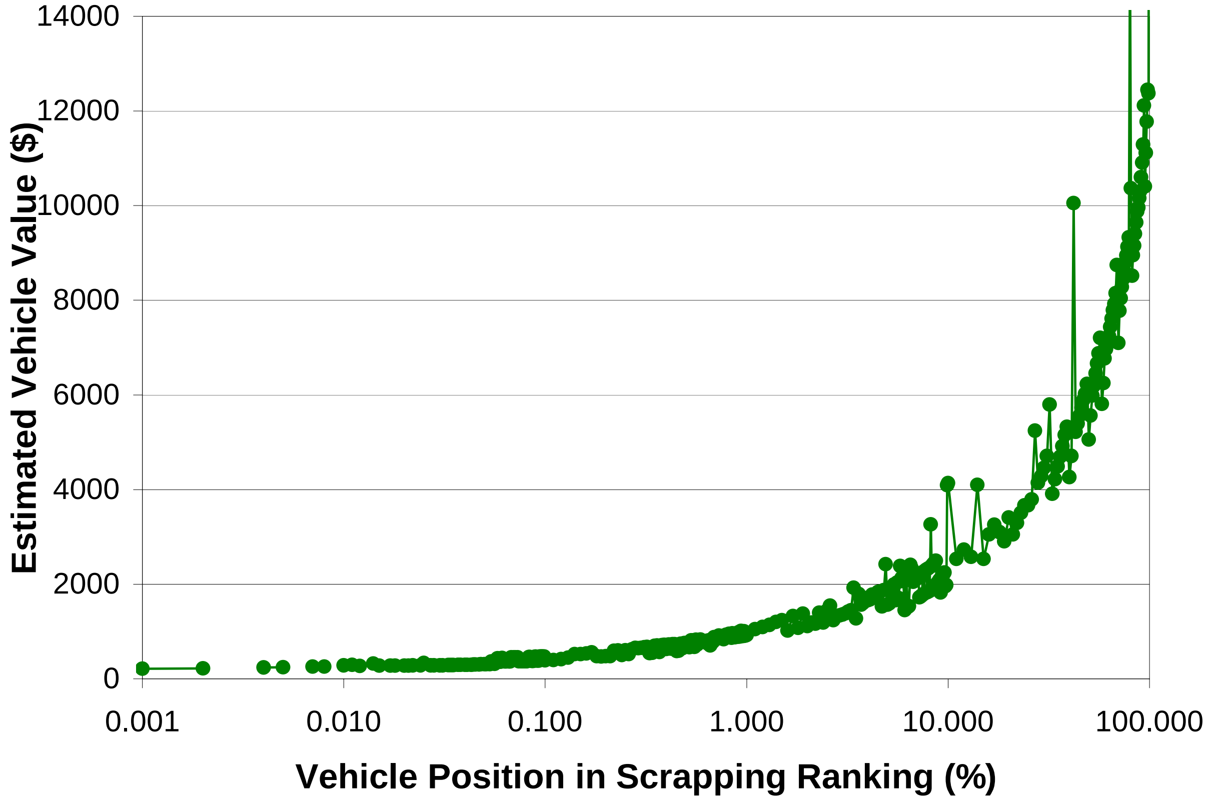
To estimate the purchase cost of vehicles that are targeted for Scrapping, we need to be able to estimate the purchase cost of each individual vehicle. Since potentially any Scrapping penetration needs to be able to be evaluated, we have chosen to estimate the purchase cost of individual vehicles based on an estimate of the value of the individual vehicles. We use the same vehicle value estimating functions, which are based on vehicle make, vehicle type, and vehicle age, as were described in the modeling report. [1]

We recognize that in the past, California has offered a fixed amount to purchase vehicles from owners. By using estimated vehicle value to estimate the purchase cost of a set of targeted vehicles, we are not necessarily advocating that the state negotiate with owners for vehicle purchases. Rather, we believe that using the estimated vehicle value serves as a lower limit on the amount of money that would be needed to purchase the targeted scrappage vehicles; clearly, vehicle owners would not be likely to accept a purchase offer made for an amount that is less than the value of the vehicle. On the contrary, we would expect that vehicle owners would want the state to pay them a premium on top of the value of their vehicle. Consequently, we expect that the state would be able to purchase fewer vehicles than we estimate by the calculations in this study. As a result, our estimates of scrappage vehicle purchase costs will produce higher estimates of emissions reductions than would actually be achieved. The method of estimating scrappage vehicle purchase costs that we are using will err on the side of making the scrappage strategy appear more cost-effective than it will actually turn out to be. Nevertheless, the method that we use for estimating scrappage vehicle purchase cost is consistent across all vehicles in the fleet regardless of their age. In addition, the approach recognizes the influence of market forces in determining whether a vehicle owner will accept the state's scrappage offer or reject it.

We will demonstrate the calculation of scrappage vehicle purchase cost by considering a vehicle ranking using the ranking variable FprobDP/$ by A. This ranking method was found in the modeling report to select vehicles for scrappage with the highest efficiency as measured by mass of HC+NX emissions reduced per dollar of vehicle value. This vehicle ranking variable uses only model year and the estimated value of the vehicle as defined by vehicle make and vehicle type to rank the vehicles for Scrapping.

Figure 5-2 shows a plot of the estimated vehicle value for the individual 69,629 vehicles in the modeling dataset as a function of the Vehicle Position in the Scrapping Ranking by FprobDP/$ by A. Vehicles with the smallest vehicle position are the top candidates for Scrapping. In the figure, we have used a logarithmic scale for the vehicle position since the vehicles that are likely to be scrapped are those in the top 1% of the ranking. The figure shows that vehicles that are ranked highest for Scrapping have low estimated vehicle values of around $250. The vehicles that are ranked lowest for Scrapping have high estimated vehicle values. In fact, the highest estimated vehicle value point which occurs for a vehicle position of 100% is off the vertical scale of the graph but has a value of $30,030. Those are clearly quite new vehicles.

Figure 5-2. Vehicle Value vs. Scrapping Ranking by FprobDP/$ by A



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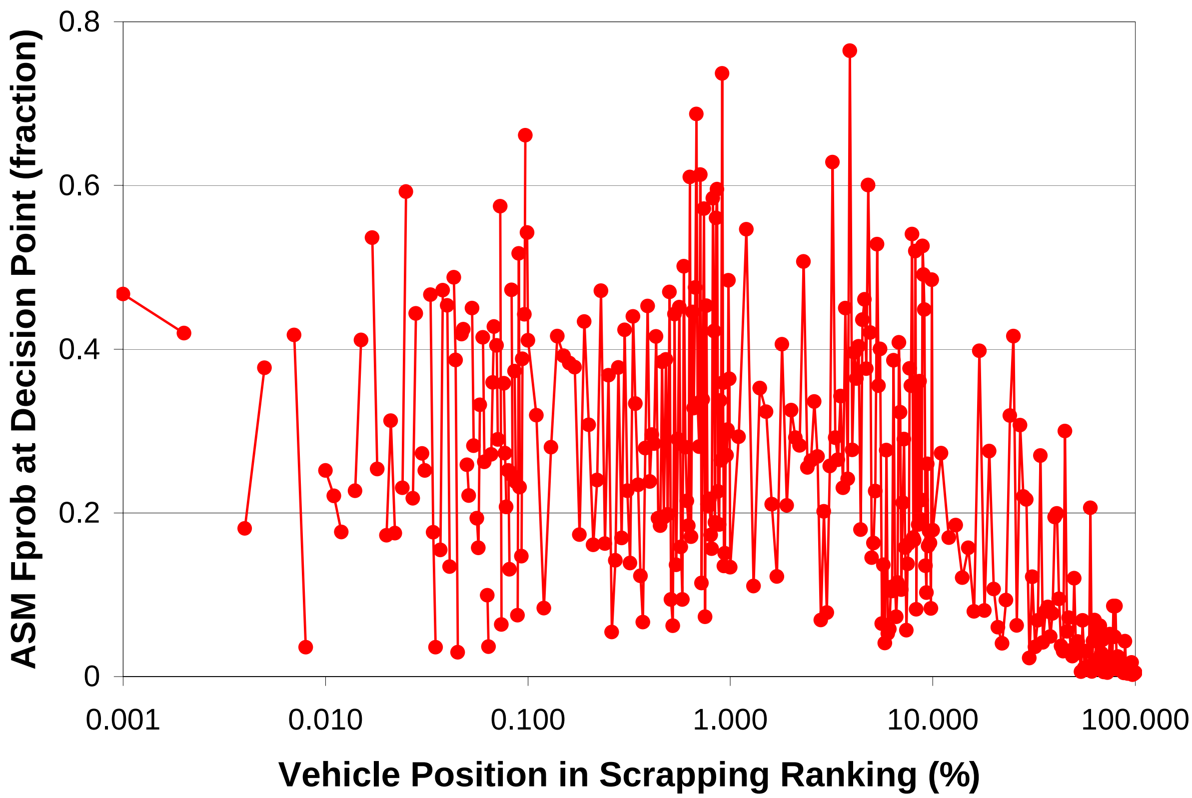
To estimate the size of the state's vehicle scrappage expenditure, we need to consider more than the value of each vehicle. In a scrappage program, the state will not purchase every vehicle that is called in for a scrappage ASM. It will only purchase those vehicles that fail the scrappage ASM. Therefore, we need to consider the probability of ASM failure for each of the individual vehicles in the dataset at the time of a scrappage ASM. These overall ASM failure probabilities for the 69,629-vehicle dataset are shown in Figure 5-3. All of these failure probabilities are estimated using the Model D Fprob model, which uses VID history and RSD readings as inputs. As in other parts of this study, we assume that the true failure probabilities of the vehicles are equal to the Fprobs calculated using Model D. The figure shows that the ASM Fprobs are around 0.3 for the top 10% of the vehicle rankings. For vehicles that are in the bottom 90% of the Scrapping ranking, the ASM Fprobs drop until they are quite low for the vehicles that are at the bottom of the Scrapping ranking, which is at 100%.

Figure 5-3. Overall ASM Failure Probability by Model D vs. Scrapping Ranking by FprobDP/$ by A



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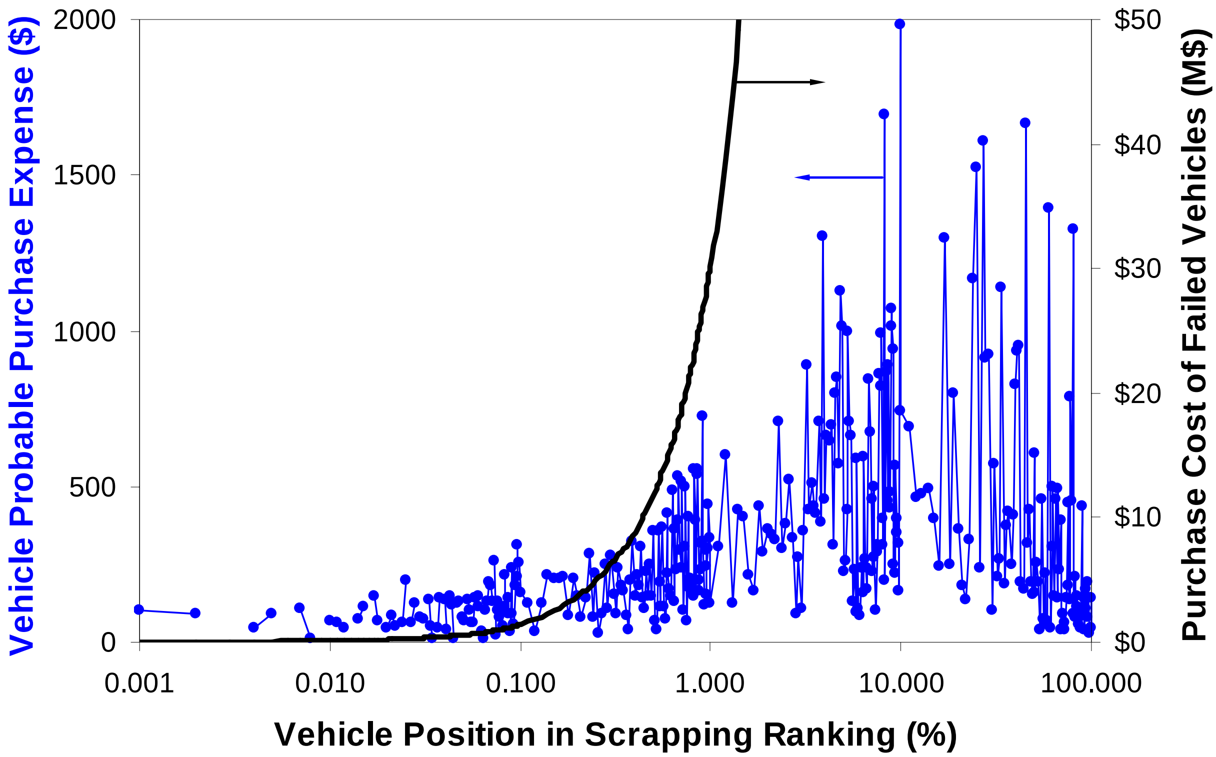
The exposure of the state to purchase an individual vehicle for scrappage is the product of its ASM failure probability and its estimated vehicle value. We call this quantity the Vehicle Probable Purchase Expense. We cannot predict with certainty which vehicles will fail the scrappage ASM test; however, we can calculate the probability that a vehicle will fail. The sum of the values for the vehicles that fail the scrappage ASM test will be close to the sum of the products of the probability of failure and the vehicle value for each tested vehicle. For example, suppose 100 vehicles were candidates for scrappage, each of the vehicles had an ASM failure probability of 20%, and each of the vehicles had a vehicle value of $500. The total expense to the state can be estimated before the vehicles are called in and before the scrappage ASM tests are performed. The vehicle probable purchase expense for each vehicle would be $100 (= 20% of $500) and, therefore, the anticipated purchase cost of the failed vehicles would be $10,000 (= 100 * $100). Based on the ASM failure probability, we would expect that 20 of the vehicles (= 20% of 100) would fail the scrappage ASM test. It would cost the state $10,000 (= 20 * $500) to purchase those vehicles. This is the same value of total expense that was estimated before the scrappage ASM tests were performed.

The blue curve with the circle symbols in Figure 5-4 shows the vehicle probable purchase expense for the 69,629-vehicle dataset. On the left side of the plot, the vehicle probable purchase expense is near $100. These values are for vehicles that have values around $250 and whose Fprobs are approximately 40% (40% * $250 = $100). On the right side of the plot near 100% Scrapping ranking, vehicles also have probable purchases expense values near $100. However, these are high-valued vehicles around $20,000 that have failure probabilities of approximately 0.5% (0.5% * $20,000 = $100). The maximum in the figure for the vehicle probable purchase expense is in the vicinity of 10% Scrapping ranking. These vehicles typically have values, as can be seen from Figure 5-2, of around $3,000 but their failure probabilities are still relatively high at around 25%. Overall, the vehicle probable purchase expense on the left side of Figure 5-4 is dominated by the low vehicle value, on the right side of Figure 5-4 it is dominated by the low failure probability. In the middle of the ranking, the vehicle probable purchase expense is dominated by neither vehicle value nor low failure probability and as a consequence it is higher there.

Figure 5-4. Vehicle Probable Purchase Expense vs. Scrapping Ranking by FprobDP/$ by A



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When the state selects vehicles to call in for scrappage ASM tests, it is selecting vehicles whose probable purchase expenses are represented by data points on the left side of Figure 5-4. How far down the Scrapping ranking the state wants to go depends on the size of the fund set aside to purchase vehicles for Scrapping. To determine how far down the Scrapping ranking the state would need to go to spend the funds, we have shown the cumulative of the vehicle probable purchase expenses of vehicles from the top of the Scrapping ranking in Figure 5-4 as the solid thick black curve. The right axis in Figure 5-4 expresses the cumulative costs in millions of dollars as the purchase cost of the vehicles that would fail the scrappage ASM. We have calculated these purchase costs by scaling up the number of vehicles that would fail in the 69,629-vehicle modeling set to the 13,388,069-vehicle statewide I/M fleet. Thus, the black curve can be used to determine the fraction of the fleet that should be targeted when vehicles are ranked by Fprob DP/$ by A to fit a given scrappage vehicle purchase budget. For example, if the state had a biennial purchase budget of $16 million, Figure 5-4 indicates that approximately the top 0.62% of the vehicles ranked using FprobDP/$ by A should be targeted for a scrappage ASM test. Note that this targeting percentage takes into account the ASM failure probability and the market value of the individual vehicles in the fleet.

5.4 Estimates of Vehicle Repair Costs

When intervention strategies such as Directing, Exempting, Calling-In, and Scrapping 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 modeling report [1], 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 the intervention strategy path. In that report, the failure probability models and the I/M completion probabilities were used to forecast probable repair costs for individual vehicles for the different strategy decision choices: Directing, Exempting, Calling-In No-Sticker, Calling-In Sticker, Scrapping, and the Normal I/M Process.

In the modeling report we used a particular type of vehicle, Ford Tauruses with a 3.0L V6 engine, to demonstrate how we calculate repair costs for the different I/M strategy paths. We "configured" the vehicle with different VID history and RSD measurement characteristics so that the calculations would simulate a probable low emitter and a probable high emitter. The probable 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 probable high emitter was simulated by setting the previous-cycle ASM results to fail for ASM2525 NX and other ASM results to pass and the recent RSD measurements to low values for HC and CO but the RSD NX measurement to 7,800 ppm.

The low emitter configuration was used to estimate the repair costs for Exempting in comparison with the Normal I/M Process. The higher emitter configuration was used to examine the repair costs for Directing, Calling-In No-Sticker, and Scrapping in comparison with the Normal I/M Process.

Table 5-5 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 5-5. 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
Probable Low Emitter	$7.78	$10.54	-	-	-
Probable High Emitter	$98.32	-	$117.98	$140.80	$32.85

The table shows that the repair costs incurred by Exempting the probable low emitter are higher than if the probable 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. Vehicles that are exempted are those that have a low, but not a zero, failure probability. When we exempt them, we suspect that they are low emitters, but we do not know they are low emitters since no ASM test is done. Whether the exempted vehicles are low emitters or a few are high emitters does not really matter because the failure probability of all emitters tends to go up with time. Two years after the exemptions, the failure probability of all exempted vehicles will be higher. Therefore, the expected repair costs two years after the exemption will be higher than the expected repair costs at the time of the exemption.

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 than at an average-performing station.

The table shows that in the case of Calling-In No-Sticker, the probable repair costs are also higher than the repair cost 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. The repair cost calculations also indicated that even if the vehicle received this additional ASM test and potentially needed a repair, because the vehicle was a high emitter, it would have a higher tendency to need an additional repair at the regular ASM inspection in comparison with a low emitter.

In the case of Scrapping, the probable repair cost for a probable 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 cost for vehicles that fail the scrappage ASM test would be zero – because those vehicles would be scrapped. However, there is always a probability that the probable high emitter would pass the scrappage ASM test and, therefore, continue in the I/M program. It would thereby incur future repair costs. However, 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.

Those results from the modeling report were for particular configurations of vehicles that had the Ford Taurus description. To estimate the probable repair costs of the California I/M fleet we needed to generalize those 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 knew how to perform the calculations for repair costs at the same level of detail that was used to calculate the benefits of the special strategies. However, project budget and schedule constraints forced us to take the following alternate route to approximate the incremental repair costs of the special strategies. As it turns out, the overall cost and cost-effectiveness of the special strategies is not very sensitive to small errors in the estimation of the incremental repair costs.

We developed a dedicated simulator to provide detailed cost and benefit results for the Ford Taurus 3.0L vehicle as a function of RSD measurements and VID history. We made numerous runs of this simulator to determine how the incremental repair costs change for different configurations of low emitter, high emitter, and time since the previous I/M cycle. After performing numerous simulation calculations, we selected repair cost adjustment factors for each of the different special strategies that generalize the effect of the strategy on the change in repair cost. These repair cost adjustment factors are shown in Table 5-6. They indicate that the probable repair costs for Exempting, Directing, Calling-In No-Sticker, and Scrapping are 45% above, 20% above, 70% above, and 75% below the probable repair costs for the Normal I/M Process. We will leave the more detailed calculation of incremental repair costs for the I/M fleet for the special strategies to future work.

Table 5-6. Repair Cost Adjustment Factors

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

5.5 Estimates of Other Unit Costs

We arrived at unit cost estimates for the various other cost items required for operating and otherwise administering the various intervention strategies. The unit cost estimates are summarized in Table 5-7. The unit costs for all of these items, except for scrappage and model maintenance, are based on communications with BAR.

Table 5-7. Estimated Unit Costs for Other Cost Items

Cost Item ($-basis)	Estimate	Notes and Source
Model update and maintenance ($/yr)	$200,000	Estimate by ERG. Independent of type of model.
Notices ($/notice mailed)	$3	BAR
Inspect ($/vehicle)	$50	BAR
Certificate ($/vehicle)	$8.25	BAR
Repair ($/repair)	$194	BAR

The situations in which the unit costs presented in Table 5-7 represent incremental costs with respect to the base case scenario are discussed in the next section.

5.6 Application of Unit Costs to Intervention Activities

We want to calculate the cost-effectiveness of adding the intervention activities described in this study (Directing, Exempting, Calling-In, and Scrapping) to the I/M program. To clearly calculate the incremental costs and benefits of these intervention activities, we need to define the base case I/M program. The I/M program currently operates with an activity that directs HEP and gross polluter vehicles to test-only stations. The key goal of the current project is to estimate the costs and benefits of using RSD over other methods as part of the intervention activities. This study did not estimate the costs and benefits of the existing Directing activity. Therefore, we will define the base case I/M program to be used for the evaluation as not having the current Directing activity. Such an assumption leads to proper accounting for both costs and benefits of the Directing activity and allows us to compare the various models or approaches on equal footing.

The primary purpose of the base case I/M scenario is to have a defined level from which to compare the models developed under this project. So, we define the base case I/M program as the current I/M program but without any intervention activities for Directing, Exempting, Calling-In, or Scrapping. The base case does include exempting the newest six model years since this is an eligibility policy rather than an activity that intervenes in the Normal I/M Process.

A previous subsection estimated the cost of different items that would be used when supplementing the base case I/M program with intervention activities. However, not every intervention activity will use every one of these items. In some cases, items that are required for a particular type of intervention activity are already being paid for in the normal process of the base case I/M program scenario. In this subsection, we consider each intervention activity and each cost item so that the costs for each intervention activity can be calculated. Table 5-8 shows where different cost items are applied.

Table 5-8. Cost Changes Relative to the Normal I/M Process Caused by Intervention Activities

Cost Item	Unit Cost	Intervention Activity			
		Calling-In No-Sticker	Directing	Exempting	Scrapping
Central Office	No unit cost	Calculated as a function of the scope of the intervention activities.			
RSD Measurement	$0.50 to $1.00[a]	Cost per valid RSD measurement, matched to registration records			
Notice	$3.00	+$3/notice	None	None	+$3/notice
Certificate	$8.25	None	None	None	-$8.25/targeted vehicles that fail
Inspection	$50	+$50/targeted vehicle	None	-$50/targeted vehicle	+$50/targeted vehicle
Repair	$194	+70% * $194 per targeted vehicle that would have failed in the Normal I/M Process	+20% * $194 per targeted vehicle that would have failed in the Normal I/M Process	+45% * $194 per targeted vehicle that would have failed in the Normal I/M Process	-75% * $194 per targeted vehicle that would have failed in the Normal I/M Process

[a] Depends on RSD program design. See Figure 5-1.

Central Office –The Central Office cost is a function of many factors including the strategies selected, the penetration for each strategy, whether RSD is used or not, the fleet coverage of the RSD measurement program, and the vehicle ranking method that is used. These program features determine the amount of staff, equipment, supplies, and contract support needed to run the program. A description of the costs is provided in Section 5.2.

RSD Measurements – The cost of RSD measurements is proportional to the number of valid, matched RSD values that are obtained. Because RSD values can be used to rank vehicles for Directing, Exempting, Calling-In, or Scrapping, adding additional intervention activities does not cause the cost of RSD measurements in a geographical area to increase. However, the RSD data collection unit cost is a function of RSD coverage as described in Section 5.1.

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 notice costs for Directing and Exempting. On the other hand, Calling-In and Scrapping are off-cycle activities in 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.

Certificates – The incremental costs for certificates vary for the different intervention activities. 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 No-Sticker, 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 passed 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 failed 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 required certifications is a credit.

Inspections – For incremental inspections beyond the base case scenario, the situation is different for the different intervention activities. 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[8]. 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 vehicles that would be exempted 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.

[8] We are assuming that the average costs for repairs resulting from failures at average-performing and high-performing stations are the same.

Repairs – 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 is multiplied by the repair cost adjustment factor from Table 5-6 for the corresponding strategy and multiplied by the number of targeted vehicles that would have failed if they remained in the Normal I/M Process.

5.7 Biennial Incremental Costs for Full-Fleet Ranking Methods

In the previous two subsections, the unit costs for RSD and non-RSD items and the conditions under which they should be applied were presented. In this section, those cost items are combined with the biennial estimates of targeted vehicles and failing vehicles to arrive at the total biennial incremental cost and the cost components for each of the four intervention activities and for each of the six full-fleet ranking methods. Table 5-9 shows the results of these calculations. The table is broken down into the eight cost items: central office, RSD measurement, notices, certificates, inspections, repairs, vehicle purchases, and model update and maintenance. For each of these items, the table indicates the total cost for each intervention activity as a function of the six full-fleet ranking methods that are used in the study. The table also indicates, where applicable, the unit cost and the incremental cost for each cost item in $/2years.

In Table 5-9, positive costs represent expenditures and negative costs represent credits. For example, the cost for central office, RSD measurement, notices, vehicle purchases, and model update and maintenance are all expenditures. The cost for certificates during Scrapping is a credit since fewer certificates will need to be issued when vehicles are scrapped. For inspections in the Exempting activity, we see credits. This arises because of the large number of exempted vehicles that are exempted from receiving an inspection. Credits also occur for repairs that are not performed for scrapped vehicles.

Table 5-9. Biennial Incremental Costs for Full-Fleet Ranking Methods

Cost Item	Full -Fleet Ranking Method Description	Intervention Activity			
		Calling-In No-Sticker	Directing	Exempting	Scrapping
Central Office					
Incremental Cost ($/2years)	**Model Year**	$6,884,584			
	Vehicle Description	$6,884,584			
	VID History	$6,884,584			
	RSD + Nothing	$4,745,749			
	RSD + VID History	$7,178,438			
	VID/RSD + VID History	$7,178,438			
RSD Measurements					
Valid, DMV-Matched RSDs per year for a 5 AQMD any-VSP RSD coverage of:	50%	25,975,057			
Unit Cost ($/ valid, DMV-matched RSD measurement)		$1.00			
Incremental Cost ($/2years)	**Model Year**	$0			
	Vehicle Description	$0			
	VID History	$0			
	RSD + Nothing	$51,950,113			
	RSD + VID History	$51,950,113			
	VID/RSD + VID History	$51,950,113			
Notice					
Unit Cost ($/ notice mailed)		$3	$0	$0	$3
Incremental Cost ($/2years)	**Model Year**	$2,008,210	$0	$0	$249,018
	Vehicle Description	$2,008,210	$0	$0	$192,788
	VID History	$2,008,210	$0	$0	$176,723
	RSD + Nothing	$608,008	$0	$0	$114,306
	RSD + VID History	$2,008,210	$0	$0	$172,706
	VID/RSD + VID History	$2,008,210	$0	$0	$168,690
Certificate					
Unit Cost ($/ targeted vehicle that fails)		$0	$0	$0	($8.25)
Incremental Cost ($/2years)	**Model Year**	$0	$0	$0	($216,004)
	Vehicle Description	$0	$0	$0	($195,610)
	VID History	$0	$0	$0	($189,220)
	RSD + Nothing	$0	$0	$0	($143,450)
	RSD + VID History	$0	$0	$0	($193,788)
	VID/RSD + VID History	$0	$0	$0	($189,918)

Table 5-9. (continued)

Cost Item	Full -Fleet Ranking Method Description	Intervention Activity			
		Calling-In No-Sticker	Directing	Exempting	Scrapping
Inspection					
Unit Cost ($/ targeted vehicle)		$50	$0	($50)	$50
Incremental Cost ($/2years)	**Model Year**	$33,470,173	$0	($83,006,028)	$4,150,301
	Vehicle Description	$33,470,173	$0	($83,006,028)	$3,213,137
	VID History	$33,470,173	$0	($83,006,028)	$2,945,375
	RSD + Nothing	$10,133,471	$0	($25,131,008)	$1,905,093
	RSD + VID History	$33,470,173	$0	($83,006,028)	$2,878,435
	VID/RSD + VID History	$33,470,173	$0	($83,006,028)	$2,811,494
Repair					
Adjustment Factor (Extra Cost of Strategy beyond NIM and relative to the Unit Repair Cost)		**0.70**	**0.20**	**0.45**	**-0.75**
Unit Cost ($/repair)		$194	$194	$194	$194
Incremental Cost ($/2years)	**Model Year**	$26,644,611	$24,392,479	$2,430,309	($3,809,524)
	Vehicle Description	$31,466,136	$25,956,630	$1,434,738	($3,449,857)
	VID History	$30,152,846	$22,325,603	$5,095,806	($3,337,149)
	RSD + Nothing	$11,982,574	$7,999,007	$617,325	($2,529,944)
	RSD + VID History	$33,006,307	$23,565,283	$4,170,318	($3,417,708)
	VID/RSD + VID History	$32,022,403	$23,421,095	$4,434,299	($3,349,467)
Vehicle Purchases					
Incremental Cost ($/2years)	**Model Year**	$0	$0	$0	$15,642,628
	Vehicle Description	$0	$0	$0	$15,624,309
	VID History	$0	$0	$0	$15,672,716
	RSD + Nothing	$0	$0	$0	$15,707,016
	RSD + VID History	$0	$0	$0	$15,934,887
	VID/RSD + VID History	$0	$0	$0	$15,982,198
Model Update & Maintenance					
Unit Cost ($/year)		$200,000			
Incremental Cost ($/2years)	**Model Year**	$0			
	Vehicle Description	$400,000			
	VID History	$400,000			
	RSD + Nothing	$400,000			
	RSD + VID History	$400,000			
	VID/RSD + VID History	$400,000			

6.0 Cost-Effectiveness Results

This final section combines the benefits and costs calculated in previous sections. The overall results are presented in a single table that displays the benefits, the costs, and the cost-effectiveness for any package of special strategies for the six different full-fleet vehicle ranking methods.

All of the calculations in the analysis assume 100% participation of the vehicles that are targeted. We know that in the real world 100% participation may not be achieved. The actual participation rates will depend on human behavior and on policy decisions and the systems put in place to manage the strategies. If the actual participation is far from 100%, the estimated benefits, costs, and cost-effectiveness of these calculations will not represent what the I/M program will experience. In general, we expect that participation for Exempting will be high and Directing will be near 100%. However, for Calling-In and Scrapping, where owners must come in for a special off-cycle ASM test, we expect lower participation rates. Owner response to a request for owners to bring vehicles in for an off-cycle call-in or scrappage ASM test is likely to depend on how strong the request is and if it is backed up by enforcement or not. In addition, for Scrapping, owners must decide if they will sell their vehicles to the state before they can be considered participants. An owner’s decision is likely to depend on the size of the offer relative to their perceived value of the vehicle.

The participation rates will affect benefits. Clearly, if participation is 0%, no benefits will be realized. Lower participation can also reduce costs. However, if RSD is needed to select vehicles for special strategies, the full cost of RSD data collection is incurred even if participation is 0%. If we consider Calling-In, lower participation would reduce costs for inspections and repairs, but lower participation would not reduce costs for RSD data collection and notices, and it would likely increase central office costs substantially as the staff attempts to get owners to bring their vehicles in for a call-in ASM test. If we consider Scrapping, lower participation at bringing vehicles in for the scrappage ASM test would reduce costs for inspections, but lower participation would not reduce costs for RSD data collection and notices. If Scrapping candidates came in and received a failing ASM test but did not accept the state’s purchase offer, only the vehicle purchase cost would be reduced.

The cost-effectiveness calculations could easily be modified to demonstrate the influence of lower than 100% participation on the results, but we have not done this in this study. Nevertheless, we can see from the discussion in the previous paragraph that lower participation decreases benefits while decreasing only some of the costs. Thus, lower participation will cause the special strategies to be less cost-effective than presented in the tables of this section. This will be especially the case for Calling-In and Scrapping, where there is significant risk of lower participation. In addition, any vehicle ranking method that requires RSD measurements will be substantially less cost-effective than presented below since a full RSD data collection program is required and since a full RSD data collection program makes up a major part of the special strategy program costs.

In the two subsections below, we demonstrate the overall cost-effectiveness of supplementing the base case I/M program with two different special strategy packages.

6.1 Performance of the Four-Strategy Package

The final summary of costs and benefits for the package of four strategies is presented in Table 6-1. The benefit values were taken from Table 4-7. The cost values were taken from Table 5-9. The columns represent each of the six full-fleet ranking methods used to evaluate the enhancements to the base case I/M program. The first three results columns are for full-fleet ranking methods that do not use RSD. The second three columns are for full-fleet ranking methods that use RSD. However, note that headings of the RSD ranking method columns remind us that this large RSD data collection program provides usable-VSP RSD data on only 30.28% of the statewide I/M fleet, as discussed in Section 3.2. The final column presents the incremental benefit of the RSD technology, which was calculated as the values in the sixth column (VID/RSD + VID History) minus the third column (VID History).

Costs – The top part of the table represents the various costs described in Section 5. All four intervention activities (Calling-In, Directing, Exempting, and Scrapping) are presented in the table. The costs for each aspect of the activity are presented.

The costs for the three different non-RSD ranking methods (in the first three columns) are quite similar to each other. Each of these strategies can cover virtually 100% of the statewide I/M fleet – even those vehicles that are outside of the 5 largest AQMDs. For each of the three non-RSD methods the costs are dominated by a large savings of $83 million associated with the exemption of 20% of the fleet for one biennial inspection. In addition, large expenditures are made for Calling-In inspections, Calling-In repairs, Directing repairs, and Scrapping vehicle purchases. In total, the non-RSD ranking methods have biennial costs from $29 million to $34 million.

Table 6-1. Cost-Effectiveness Summary for Calling-In, Directing, Exempting, Scrapping

	Full-Fleet Ranking Method						
	Model Year [a]	Vehicle Description [b]	VID History [c]	RSD [f] 30.28% of statewide I/M fleet	RSD [f] 30.28% of statewide I/M fleet	VID/RSD [d] 30.28% of statewide I/M fleet	Incremental Benefit of VID/RSD + VID History over VID History
	100% of statewide I/M fleet	100% of statewide I/M fleet	100% of statewide I/M fleet	Nothing 69.72% of statewide I/M fleet	VID History [c] 69.72% of statewide I/M fleet	VID History [c] 69.72% of statewide I/M fleet	
	without RSD			with RSD			
Cost Items ($/2years) [A]							
Central Office							
5% Calling-In No-Sticker; 40% Directing; 20% Exempting; Scrapping	$6,884,584	$6,884,584	$6,884,584	$4,745,749	$7,178,438	$7,178,438	$293,854
RSD Measurements							
5% Calling-In No-Sticker; 40% Directing; 20% Exempting; Scrapping	$0	$0	$0	$51,950,113	$51,950,113	$51,950,113	$51,950,113
Notice							
5% Calling-In No-Sticker	$2,008,210	$2,008,210	$2,008,210	$608,008	$2,008,210	$2,008,210	$0
40% Directing	$0	$0	$0	$0	$0	$0	$0
20% Exempting	$0	$0	$0	$0	$0	$0	$0
Scrapping	$249,018	$192,788	$176,723	$114,306	$172,706	$164,673	($12,049)
Inspection							
5% Calling-In No-Sticker	$33,470,173	$33,470,173	$33,470,173	$10,133,471	$33,470,173	$33,470,173	$0
40% Directing	$0	$0	$0	$0	$0	$0	$0
20% Exempting	($83,006,028)	($83,006,028)	($83,006,028)	($25,131,008)	($83,006,028)	($83,006,028)	$0
Scrapping	$4,150,301	$3,213,137	$2,945,375	$1,905,093	$2,878,435	$2,744,554	($200,821)
Certificate							
5% Calling-In No-Sticker	$0	$0	$0	$0	$0	$0	$0
40% Directing	$0	$0	$0	$0	$0	$0	$0
20% Exempting	$0	$0	$0	$0	$0	$0	$0
Scrapping	($216,004)	($195,610)	($189,220)	($143,450)	($193,788)	($189,918)	($698)
Repair							
5% Calling-In No-Sticker	$26,644,611	$31,466,136	$30,152,846	$11,982,574	$33,006,307	$32,022,403	$1,869,558
40% Directing	$24,392,479	$25,956,630	$22,325,603	$7,999,007	$23,565,283	$23,421,095	$1,095,492
20% Exempting	$2,430,309	$1,434,738	$5,095,806	$617,325	$4,170,318	$4,434,299	($661,507)
Scrapping	($3,809,524)	($3,449,857)	($3,337,149)	($2,529,944)	($3,417,708)	($3,349,467)	($12,318)
Vehicle Purchase							
Fleet Sample Penetration (%)	**0.620**	**0.480**	**0.440**	**0.940**	**0.430**	**0.410**	
Scrapping	$15,642,628	$15,624,309	$15,672,716	$15,707,016	$15,934,887	$15,982,198	$309,482
Model Update & Maintenance							
5% Calling-In No-Sticker; 40% Directing; 20% Exempting; Scrapping	$0	$400,000	$400,000	$400,000	$400,000	$400,000	$0
Total Costs ($/2years) [A]	$28,840,910	$33,999,348	$32,599,772	$78,358,444	$88,117,479	$87,230,874	$54,631,106
ΔFTP (HC+NX tons/2years) out of 605088 total tons/2years							
5% Calling-In No-Sticker	(1,819)	(1,855)	(4,595)	(994)	(4,198)	(4,825)	(230)
40% Directing	(3,876)	(3,897)	(4,339)	(1,303)	(4,328)	(4,489)	(150)
20% Exempting	3,241	3,942	2,358	944	2,588	2,098	(260)
Scrapping	(3,997)	(3,533)	(3,478)	(2,566)	(3,658)	(3,612)	(135)
Total ΔFTP (HC+NX tons/2years) [B]	(6,451)	(5,343)	(10,053)	(3,920)	(9,597)	(10,828)	**(775)**
Cost Effectiveness ($/ton HC+NX) [C]	(4,471)	(6,363)	(3,243)	(19,990)	(9,182)	(8,056)	**(70,526)**
ΔFMD (miles/2years) out of 30624179635 total FMD/2years							
5% Calling-In No-Sticker	(255,391,460)	(306,632,874)	(972,447,180)	(129,859,872)	(807,887,733)	(1,012,914,979)	(40,467,799)
40% Directing	(486,496,190)	(538,672,116)	(594,758,300)	(172,236,354)	(586,924,891)	(616,084,457)	(21,326,157)
20% Exempting	200,602,866	133,453,029	143,777,037	48,037,384	148,284,306	106,007,297	(37,769,740)
Scrapping	(179,679,066)	(186,801,268)	(190,210,114)	(158,294,190)	(197,262,001)	(200,080,890)	(9,870,776)
Total ΔFMD (miles/2years) [D]	(720,963,850)	(898,653,230)	(1,613,638,558)	(412,353,033)	(1,443,790,320)	(1,723,073,029)	(109,434,472)

Table 6-1 (Continued)

	Full-Fleet Ranking Method						
	Model Year [a] 100% of statewide I/M fleet	Vehicle Description [b] 100% of statewide I/M fleet	VID History [c] 100% of statewide I/M fleet	RSD [f] 30.28% of statewide I/M fleet Nothing 69.72% of statewide I/M fleet	RSD [f] 30.28% of statewide I/M fleet VID History [c] 69.72% of statewide I/M fleet	VID/RSD [d] 30.28% of statewide I/M fleet VID History [c] 69.72% of statewide I/M fleet	Incremental Benefit of VID/RSD + VID History over VID History
	without RSD			with RSD			
Total Number of Targeted Vehicles							
5% Calling-In No-Sticker	669,403	669,403	669,403	202,669	669,403	669,403	0
40% Directing	5,355,228	5,355,228	5,355,228	1,621,355	5,355,228	5,355,228	0
20% Exempting	2,677,614	2,677,614	2,677,614	810,678	2,677,614	2,677,614	0
Scrapping	83,006	64,263	58,908	38,102	57,569	54,891	(4,016)
Targeted Vehicles That Would Fail an ASM at the Decision Point							
5% Calling-In No-Sticker	196,205	231,709	222,039	88,237	243,051	235,806	13,767
40% Directing [E]	125,734	133,797	115,080	41,232	121,471	120,727	5,647
20% Exempting	27,839	16,435	58,371	7,071	47,770	50,794	(7,577)
Scrapping	26,182	23,710	22,936	17,388	23,489	23,020	85
Fraction of Targeted Vehicles That Would Fail an ASM at the Decision Point							
5% Calling-In No-Sticker	0.293	0.346	0.332	0.435	0.363	0.352	
40% Directing [E]	0.023	0.025	0.021	0.025	0.023	0.023	
20% Exempting	0.010	0.006	0.022	0.009	0.018	0.019	
Scrapping	0.315	0.369	0.389	0.456	0.408	0.419	
Average Value of Vehicles Targeted for Scrapping	$597	$659	$683	$903	$678	$694	

Footnotes

[A] Negative Costs means saving money, Positive Costs means spending money.
[B] Negative ΔFTP means emissions decrease, Positive ΔFTP means emissions increase.
[C] Interpret cost effectiveness value in terms of Total Costs and Total ΔFTP.
[D] Negative ΔFMD means decrease in total Failed Miles Driven, Positive ΔFMD means increase in total Failed Miles Driven.
[E] The number of directed vehicles that would fail an ASM at the Decision Point shown in the table is the number of vehicles that would fail at high-performing stations incremental to the number that would have failed at average-performing stations.

Basic Ranking Method	Strategy: Calling-In No-Sticker, Directing, Exempting	Strategy: Scrapping
[a] Model Year	= FprobDP by A	= FprobDP/$ by A
[b] Vehicle Description	= FprobDP by B	= FprobDP/$ by B
[c] VID History	= ΔFMD by C	= ΔFTP CO/$ by C
[d] VID/RSD	= ΔFMD by D	= ΔFTP CO/$ by D
[f] RSD	= FprobDP by F	= FprobDP/$ by F

The first RSD ranking method (in the fourth column), which uses only RSD measurements can cover only 30% of the statewide I/M fleet. With this method, the remaining 70% of the fleet cannot participate in special strategies. The costs for this method are dominated by the $52 million spent for collecting RSD measurements in the five major AQMDs in the state. As a consequence of the 30% statewide I/M fleet coverage, non-RSD costs are relatively low in comparison since a relatively low number of vehicles can participate in the strategies. In total, the RSD-alone ranking method has biennial costs of about $78 million.

The second and third RSD ranking methods (in the fifth and sixth columns) supplement the RSD-containing ranking methods, which can cover only 30% of the statewide I/M fleet, with the VID History method so that the entire statewide I/M fleet can be covered with some ranking method. For each of these two "hybrid" methods, the costs are dominated by a large savings of $83 million associated with the exemption of 20% of the fleet for one biennial inspection. In addition, large expenditures are made for Calling-In inspections, Calling-In repairs, Directing repairs, and Scrapping vehicle purchases. However, these two methods also have $52 million in RSD data collection costs that the non-RSD ranking methods (in the first three columns) do not have. In total, the two hybrid RSD ranking methods have biennial costs of about $88 million.

Benefits – The total benefits from the four strategies are based on the basic ranking methods described in Reference 1 and on the selected penetration rates. The benefits are scaled to the California fleet using EMFAC projections described in Section 4.

The total emissions benefits of 10,828 tons/2years are largest for the best RSD full-fleet ranking method (VID/RSD + VID History), while the best non-RSD full-fleet ranking method (VID History) 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 775 tons/2years, which is about 0.13% of the I/M fleet biennial emissions inventory, but those incremental benefits come at a significantly higher cost – $54,631,106 more.

For the non-RSD ranking methods (in the first three columns) the VID History method has the highest benefits, and the Vehicle Description method, which is most similar to the current HEP, has the lowest benefits. Except for its Calling-In performance, the Model Year method[9] has a benefit performance that is nearly as high as that of the VID History method.

[9] The Model Year method does not simply select vehicles based on their model years. For Directing, Exempting, and Calling-In, vehicles are ranked by the ASM Fprob that is associated with the model year. For Scrapping, vehicles are ranked by the ASM Fprob that is associated with the model year divided by the value of the vehicle. See the modeling report [1].

Of the two hybrid RSD ranking methods (in the fifth and sixth columns), the VID/RSD + VID History method (sixth column) has slightly better benefits performance than the RSD + VID History method (fifth column). The improved performance is made at virtually the same cost by using VID information to help the RSD measurements on the 30% of the I/M fleet that RSD covers.

Of all of the ranking methods, the RSD-alone method (fourth column) has the poorest performance. At 3,920 tons/2years, the RSD-alone method reduces emissions by about three-fourths as much as the next worst method, the Vehicle Description method, which is similar to the current HEP. And it reduces emissions by only about 36% as much as the best method, the VID/RSD + VID History method.

Cost-Effectiveness – The cost-effectivenesses of the non-RSD ranking methods for the four strategy package at the chosen penetrations are between $3,200/ton and $6,400/ton. The VID History method has the best cost-effectiveness of all six of the ranking methods at $3,243/ton. The cost-effectivenesses of the RSD ranking methods for the four strategy package at the chosen penetrations are between $8,000/ton and $20,000/ton. The best RSD method, VID/RSD + VID History, has the best cost-effectiveness of the three RSD-containing ranking methods at $8,056/ton. On the surface this cost-effectiveness figure looks attractive until one considers how much the RSD information contributes to the cost-effectiveness. The VID/RSD + VID History method gets a benefit of only 775 tons/2years but $54 million in increased cost from the RSD measurement portion of that method. On the other hand, the VID/RSD + VID History method gets 93% (= 10,053 tons / 10,828 tons) of the benefit but only 37% (= $32,599,772 / $87,230,874) of the expense from the VID information. The bottom line for this analysis is that the incremental cost-effectiveness for RSD is $70,526/ton. This cost-effectiveness has been developed for the selected penetration rates for the four intervention activities considered.

In addition, the incremental changes in estimated failed miles driven are presented in Table 6-1. The best RSD model (VID/RSD + VID History) achieves the largest reduction in estimated failed miles driven based on the selected intervention activities, but the reduction for the best non-RSD model (VID History) is almost as large. The incremental reduction in estimated failed miles driven by the best RSD model over the best non-RSD model is only 0.4% of the failed miles driven by the I/M fleet.

Table 6-1 also shows the number of vehicles targeted, the number of targeted vehicles that would fail an ASM at the Decision Point, and the corresponding fraction of targeted vehicles that would fail at the Decision Point. For Calling-In, the fail fractions are between 29% and 44%. This is substantially higher than the overall I/M program ASM failure rate of 10.2% (see Table 4-1). This demonstrates the effectiveness of vehicle ranking. The highest fail fraction for the Calling-In ASM of 44% is provided by the RSD-alone ranking method (in the fourth column), but this level is not close to the desired fail rate of 95%. The fail fractions of Scrapping targets provide similar results. Again, the highest fail fraction of 45% for the scrappage ASM test is provided by the RSD-alone ranking method. However, Table 6-1 also shows that while the RSD-alone method provides the highest, although insufficiently high, fail fractions, the benefits of the RSD-alone method are the lowest – by far – of all of the vehicle ranking methods for Calling-In and Scrapping. This is a consequence of RSD's inability to cover a large fraction of the I/M fleet with usable-VSP RSD measurements.

In the case of Directing, the table shows the incremental counts and fraction of targeted vehicles that would be directed to high-performing stations rather than be allowed to get their regularly scheduled inspections at average-performing stations. All six of the ranking methods have an increase in fail fractions of about 2% of the targeted vehicles; however, because the RSD-alone method can target only 30% of the statewide I/M fleet, the number of vehicles that can be targeted by RSD-alone and that would fail at the high-performing stations is the lowest at 41,232. This is about one-third of the next lowest competitor. The table also shows that the number of tons of HC + NX emissions reduced by Directing with RSD-alone is far lower at 1,303 tons/2years than all other competitors.

In the case of Exempting, Table 6-1 shows the number and fraction of the vehicles targeted for Exempting that would have failed if they had not been exempted. The RSD-alone results show that only 0.9% (=7071/810678) would have failed, but the Vehicle Description method (in the second column) has a slightly better (i.e., lower) result of 0.6% (=16435/2677614). And, as for Directing, because RSD can cover only 30% of the statewide I/M fleet with usable RSD measurements, the 810,678 vehicles exempted by RSD-alone is much lower than for the other Exempting ranking methods.

The last line of Table 6-1 shows the average vehicle value of the vehicles that are targeted for Scrapping. This quantity is useful to help determine the size of the scrappage offers that might be accepted by potential scrappage vehicle owners. Obviously, owners will not be very likely to accept a state's offer that is below the value of the vehicle. For the Scrapping scenario calculated in Table 6-1, five of the ranking methods selected vehicles for Scrapping that had average values between $600 and $700. But RSD-alone selected vehicles with an average value of $903. Again, this is caused by low usable-VSP RSD coverage of the statewide I/M fleet.

This in turn caused a larger Scrapping penetration of 0.94% that was needed to spend the $16 million Scrapping vehicle purchase budget. Larger penetration means that vehicle selection had to cut deeper into the portion of the fleet that had RSD measurements. This caused vehicles with higher values to be selected.

6.2 Performance of the Three-Strategy Package

For this report, we also performed a cost, benefit, and cost-effectiveness analysis for a package of three strategies. We examined Directing, Exempting, and Scrapping at the same penetrations used in the analysis in Section 6.1. We left Calling-In out of the package because through an examination of many cost-effectiveness calculation runs, we saw that Calling-In was not cost-effective in comparison with the other three strategies. For example, for the VID History ranking method, we found the following cost-effectivenesses when each of the three emissions-reducing strategies was used alone: $15,870/ton for Calling-In, $5,943/ton for Directing, and $5,385/ton for Scrapping. In addition, we had heard from other jurisdictions that when Calling-In was attempted, few motorists responded to the call-in emissions test request.

Table 6-2 shows the results of the analysis on the three-strategy package. By comparing Figure 6-2 with Figure 6-1, we can see that leaving out Calling-In reduced central office costs, Calling-In notices, Calling-In inspections, and Calling-In repairs. This reduced the costs by about $70 million for the five non-RSD-alone ranking methods and reduced costs by about $24 million for the RSD-alone method (in the fourth column). Of course, the benefits of Calling-In were reduced to zero. The reductions in total benefits associated with dropping the Calling-In strategy were from 1,800 tons/2years to 4,800 tons/2years depending on the ranking method.

Table 6-2 shows the result of dropping the Calling-In strategy as a substantial improvement in cost-effectiveness for the package. Now, the non-RSD ranking methods show an overall savings of $37 million while at the same time reducing emissions by 3,500 tons/2years to 5,400 tons/2years. The RSD-containing ranking methods are also far less expensive and therefore more cost-effective. Nevertheless, the table shows that the incremental benefits and cost-effectiveness of adding RSD is still quite cost-ineffective at $96,914/ton.

Table 6-2. Cost-Effectiveness Summary for Directing, Exempting, Scrapping

	Full-Fleet Ranking Method						
	Model Year [a]	Vehicle Description [b]	VID History [c]	RSD [f] 30.28% of statewide I/M fleet	RSD [f] 30.28% of statewide I/M fleet	VID/RSD [d] 30.28% of statewide I/M fleet	Incremental Benefit of VID/RSD + VID History over VID History
	100% of statewide I/M fleet	100% of statewide I/M fleet	100% of statewide I/M fleet	Nothing 69.72% of statewide I/M fleet	VID History [c] 69.72% of statewide I/M fleet	VID History [c] 69.72% of statewide I/M fleet	
	without RSD			with RSD			
Cost Items ($/2years) [A]							
Central Office							
0% Calling-In No-Sticker 40% Directing 20% Exempting Scrapping	$3,060,165	$3,060,165	$3,060,165	$3,084,407	$3,354,019	$3,354,019	$293,854
RSD Measurements							
0% Calling-In No-Sticker 40% Directing 20% Exempting Scrapping	$0	$0	$0	$51,950,113	$51,950,113	$51,950,113	$51,950,113
Notice							
0% Calling-In No-Sticker	$0	$0	$0	$0	$0	$0	$0
40% Directing	$0	$0	$0	$0	$0	$0	$0
20% Exempting	$0	$0	$0	$0	$0	$0	$0
Scrapping	$249,018	$192,788	$176,723	$114,306	$172,706	$164,673	($12,049)
Inspection							
0% Calling-In No-Sticker	$0	$0	$0	$0	$0	$0	$0
40% Directing	$0	$0	$0	$0	$0	$0	$0
20% Exempting	($83,006,028)	($83,006,028)	($83,006,028)	($25,131,008)	($83,006,028)	($83,006,028)	$0
Scrapping	$4,150,301	$3,213,137	$2,945,375	$1,905,093	$2,878,435	$2,744,554	($200,821)
Certificate							
0% Calling-In No-Sticker	$0	$0	$0	$0	$0	$0	$0
40% Directing	$0	$0	$0	$0	$0	$0	$0
20% Exempting	$0	$0	$0	$0	$0	$0	$0
Scrapping	($216,004)	($195,610)	($189,220)	($143,450)	($193,788)	($189,918)	($698)
Repair							
0% Calling-In No-Sticker	$0	$0	$0	$0	$0	$0	$0
40% Directing	$24,392,479	$25,956,630	$22,325,603	$7,999,007	$23,565,283	$23,421,095	$1,095,492
20% Exempting	$2,430,309	$1,434,738	$5,095,806	$617,325	$4,170,318	$4,434,299	($661,507)
Scrapping	($3,809,524)	($3,449,857)	($3,337,149)	($2,529,944)	($3,417,708)	($3,349,467)	($12,318)
Vehicle Purchase							
Fleet Sample Penetration (%)	**0.620**	**0.480**	**0.440**	**0.940**	**0.430**	**0.410**	
Scrapping	$15,642,628	$15,624,309	$15,672,716	$15,707,016	$15,934,887	$15,982,198	$309,482
Model Update & Maintenance							
0% Calling-In No-Sticker 40% Directing 20% Exempting Scrapping	$0	$400,000	$400,000	$400,000	$400,000	$400,000	$0
Total Costs ($/2years) [A]	($37,106,502)	($36,769,589)	($36,855,875)	$53,973,048	$15,808,371	$15,905,670	$52,761,548
ΔFTP (HC+NX tons/2years) out of 605088 total tons/2years							
0% Calling-In No-Sticker	0	0	0	0	0	0	0
40% Directing	(3,876)	(3,897)	(4,339)	(1,303)	(4,328)	(4,489)	(150)
20% Exempting	3,241	3,942	2,358	944	2,588	2,098	(260)
Scrapping	(3,997)	(3,533)	(3,478)	(2,566)	(3,658)	(3,612)	(135)
Total ΔFTP (HC+NX tons/2years) [B]	(4,632)	(3,488)	(5,459)	(2,926)	(5,399)	(6,003)	**(544)**
Cost Effectiveness ($/ton HC+NX) [C]	8,011	10,541	6,752	(18,448)	(2,928)	(2,650)	**(96,914)**
ΔFMD (miles/2years) out of 30624179635 total FMD/2years							
0% Calling-In No-Sticker	0	0	0	0	0	0	0
40% Directing	(486,496,190)	(538,672,116)	(594,758,300)	(172,236,354)	(586,924,891)	(616,084,457)	(21,326,157)
20% Exempting	200,602,866	133,453,029	143,777,037	48,037,384	148,284,306	106,007,297	(37,769,740)
Scrapping	(179,679,066)	(186,801,268)	(190,210,114)	(158,294,190)	(197,262,001)	(200,080,890)	(9,870,776)
Total ΔFMD (miles/2years) [D]	(465,572,391)	(592,020,355)	(641,191,378)	(282,493,161)	(635,902,586)	(710,158,051)	(68,966,673)

Table 6-2 (Continued)

	Full-Fleet Ranking Method						
	Model Year [a]	Vehicle Description [b]	VID History [c]	RSD [f] 30.28% of statewide I/M fleet	RSD [f] 30.28% of statewide I/M fleet	VID/RSD [d] 30.28% of statewide I/M fleet	Incremental Benefit of VID/RSD + VID History over VID History
	100% of statewide I/M fleet	100% of statewide I/M fleet	100% of statewide I/M fleet	Nothing 69.72% of statewide I/M fleet	VID History [c] 69.72% of statewide I/M fleet	VID History [c] 69.72% of statewide I/M fleet	
	without RSD			with RSD			
Total Number of Targeted Vehicles							
0% Calling-In No-Sticker	0	0	0	0	0	0	0
40% Directing	5,355,228	5,355,228	5,355,228	1,621,355	5,355,228	5,355,228	0
20% Exempting	2,677,614	2,677,614	2,677,614	810,678	2,677,614	2,677,614	0
Scrapping	83,006	64,263	58,908	38,102	57,569	54,891	(4,016)
Targeted Vehicles That Would Fail an ASM at the Decision Point							
0% Calling-In No-Sticker	0	0	0	0	0	0	0
40% Directing [E]	125,734	133,797	115,080	41,232	121,471	120,727	5,647
20% Exempting	27,839	16,435	58,371	7,071	47,770	50,794	(7,577)
Scrapping	26,182	23,710	22,936	17,388	23,489	23,020	85
Fraction of Targeted Vehicles That Would Fail an ASM at the Decision Point							
0% Calling-In No-Sticker	N/A	N/A	N/A	N/A	N/A	N/A	
40% Directing [E]	0.023	0.025	0.021	0.025	0.023	0.023	
20% Exempting	0.010	0.006	0.022	0.009	0.018	0.019	
Scrapping	0.315	0.369	0.389	0.456	0.408	0.419	
Average Value of Vehicles Targeted for Scrapping	$597	$659	$683	$903	$678	$694	

Footnotes

[A] Negative Costs means saving money, Positive Costs means spending money.

[B] Negative ΔFTP means emissions decrease, Positive ΔFTP means emissions increase.

[C] Interpret cost effectiveness value in terms of Total Costs and Total ΔFTP.

[D] Negative ΔFMD means decrease in total Failed Miles Driven, Positive ΔFMD means increase in total Failed Miles Driven.

[E] The number of directed vehicles that would fail an ASM at the Decision Point shown in the table is the number of vehicles that would fail at high-performing stations incremental to the number that would have failed at average-performing stations.

Basic Ranking Method	Strategy: Calling-In No-Sticker, Directing, Exempting	Strategy: Scrapping
[a] Model Year	= FprobDP by A	= FprobDP/$ by A
[b] Vehicle Description	= FprobDP by B	= FprobDP/$ by B
[c] VID History	= ΔFMD by C	= ΔFTP CO/$ by C
[d] VID/RSD	= ΔFMD by D	= ΔFTP CO/$ by D
[f] RSD	= FprobDP by F	= FprobDP/$ by F

7.0 References

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Appendix A

Summary of Selected RSD Coverage Scenarios

Table A-1. RSD Measurement Counts for the Large RSD Program (Any-VSP RSD Coverage = 50%) (Usable-VSP RSD Coverage = 39.7%)

Area	Vehicles			RSD Measurements		
	Subject to I/M, In-range-VSP, Unique, Valid, DMV-Matched	**In-range-VSP, Unique, Valid, DMV-Matched**	**Unique, Valid, DMV-Matched**	**Valid, DMV-Matched**	**Valid**	**Raw**
	53.7% of In-range VSP, Unique, Valid, DMV-Matched	*79.5% of Unique, Valid, DMV-Matched*	*36.5% of Valid, DMV-Matched*	*83.7% of Valid*	*65.0% of Raw*	
Sacramento	176,330	328,166	412,896	1,129,965	1,350,018	2,076,951
San Diego	419,936	781,537	983,325	2,691,047	3,215,110	4,946,323
San Joaquin	439,219	817,424	1,028,477	2,814,615	3,362,743	5,173,450
South Coast	1,943,275	3,616,602	4,550,384	12,452,957	14,878,085	22,889,362
Bay Area	994,134	1,850,169	2,327,870	6,370,642	7,611,281	11,709,663
Rest of State	80,495	149,808	188,487	515,830	616,284	948,129
Total	4,053,388	7,543,705[c]	9,491,440[b]	25,975,057[a]	31,033,520	47,743,878

Proj1/Decision Model/Report/IM_Strategy_Evaluator_071119.xls

[a]Used to determine RSD data collection cost. Estimated RSD data collection cost is $1.00/valid, DMV-matched RSD reading for a total annual RSD data collection cost of $25,975,057.
[b]Used to determine the Any-VSP RSD Coverage of the (I/M + non-I/M) fleet driving in the five largest AQMDs.
[c]Used to determine the Usable-VSP RSD Coverage of the (I/M + non-I/M) fleet driving in the five largest AQMDs.

Table A-2. RSD Measurement Counts for the Medium RSD Program (Any-VSP RSD Coverage = 30%) (Usable-VSP RSD Coverage = 22.2%)

Area	Vehicles			RSD Measurements		
	Subject to I/M, In-range-VSP, Unique, Valid, DMV-Matched	**In-range-VSP, Unique, Valid, DMV-Matched**	**Unique, Valid, DMV-Matched**	**Valid, DMV-Matched**	**Valid**	**Raw**
	51.3% of In-range VSP, Unique, Valid, DMV-Matched	*73.9% of Unique, Valid, DMV-Matched*	*51.6% of Valid, DMV-Matched*	*83.7% of Valid*	*65.0% of Raw*	
Sacramento	93,854	182,976	247,738	479,679	573,093	881,682
San Diego	223,516	435,763	589,995	1,142,370	1,364,839	2,099,753
San Joaquin	233,779	455,773	617,086	1,194,826	1,427,510	2,196,170
South Coast	1,034,330	2,016,517	2,730,231	5,286,378	6,315,863	9,716,713
Bay Area	529,139	1,031,603	1,396,722	2,704,387	3,231,048	4,970,843
Rest of State	42,844	83,529	113,092	218,974	261,617	402,488
Total	2,157,461	4,206,161[c]	5,694,864[b]	11,026,614[a]	13,173,972	20,267,649

Proj1/Decision Model/Report/IM_Strategy_Evaluator_071119.xls

[a]Used to determine RSD data collection cost. Estimated RSD data collection cost is $0.69/valid, DMV-matched RSD reading for a total annual RSD data collection cost of $7,560,751.
[b]Used to determine the Any-VSP RSD Coverage of the (I/M + non-I/M) fleet driving in the five largest AQMDs.
[c]Used to determine the Usable-VSP RSD Coverage of the (I/M + non-I/M) fleet driving in the five largest AQMDs.

Table A-3. RSD Measurement Counts for the Small RSD Program (Any-VSP RSD Coverage = 10%) (Usable-VSP RSD Coverage = 6.7%)

Area	Vehicles			RSD Measurements		
	Subject to I/M, In-range-VSP, Unique, Valid, DMV-Matched	**In-range-VSP, Unique, Valid, DMV-Matched**	**Unique, Valid, DMV-Matched**	**Valid, DMV-Matched**	**Valid**	**Raw**
	48.9% of In-range VSP, Unique, Valid, DMV-Matched	*67.5% of Unique, Valid, DMV-Matched*	*73.1% of Valid, DMV-Matched*	*83.7% of Valid*	*65.0% of Raw*	
Sacramento	27,225	55,727	82,579	113,032	135,044	207,760
San Diego	64,837	132,716	196,665	269,189	321,611	494,787
San Joaquin	67,814	138,810	205,695	281,549	336,379	517,507
South Coast	300,036	614,151	910,077	1,245,685	1,488,273	2,289,651
Bay Area	153,491	314,185	465,574	637,263	761,366	1,171,332
Rest of State	12,428	25,440	37,697	51,599	61,648	94,843
Total	625,831	1,281,030[c]	1,898,288[b]	2,598,317[a]	3,104,322	4,775,880

Proj1/Decision Model/Report/IM_Strategy_Evaluator_071119.xls

[a]Used to determine RSD data collection cost. Estimated RSD data collection cost is $0.52/valid, DMV-matched RSD reading for a total annual RSD data collection cost of $1,360,993.
[b]Used to determine the Any-VSP RSD Coverage of the (I/M + non-I/M) fleet driving in the five largest AQMDs.
[c]Used to determine the Usable-VSP RSD Coverage of the (I/M + non-I/M) fleet driving in the five largest AQMDs.

Table A-4. RSD Measurement Counts for the Fleet-Characterization RSD Program (Any-VSP RSD Coverage = 15.3 %) (Usable-VSP RSD Coverage = 10.7 %)

Area	Vehicles			RSD Measurements		
	Subject to I/M, In-range-VSP, Unique, Valid, DMV-Matched	**In-range-VSP, Unique, Valid, DMV-Matched**	**Unique, Valid, DMV-Matched**	**Valid, DMV-Matched**	**Valid**	**Raw**
	Percent of In-range VSP, Unique, Valid, DMV-Matched	*Percent of Unique, Valid, DMV-Matched*	*Percent of Valid, DMV-Matched*	*Percent of Valid*	*Percent of Raw*	
Sacramento	**131,043** *53.4%*	**245,554** *63.3%*	**388,122** *38.7%*	**1,001,607**[a] *83.7%*	**1,196,663** *65.0%*	**1,841,020**
San Diego	**238,208** *51.0%*	**467,341** *86.9%*	**538,075** *53.8%*	**1,000,186**[a] *83.7%*	**1,194,965** *65.0%*	**1,838,408**
San Joaquin	**203,317** *50.9%*	**399,682** *73.2%*	**545,710** *54.5%*	**1,001,465**[a] *83.7%*	**1,196,493** *65.0%*	**1,840,759**
South Coast	**250,468** *48.7%*	**514,797** *67.7%*	**760,824** *76.0%*	**1,001,030**[a] *83.7%*	**1,195,974** *65.0%*	**1,839,960**
Bay Area	**199,830** *49.4%*	**404,643** *60.6%*	**668,099** *66.7%*	**1,001,578**[a] *83.7%*	**1,196,629** *65.0%*	**1,840,967**
Total	**1,022,865**	**2,032,017**[c]	**2,900,830**[b]	**5,005,866**[a]	**5,980,724**	**9,201,114**

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[a]Used to determine RSD data collection cost. As shown in the table below, because the Any-VSP RSD Coverage is different in the different areas for this RSD data collection program, the RSD unit cost varies by area. The table shows that with this RSD measurement program the net effective RSD unit cost would be about $0.66/valid, DMV-matched RSD reading for a total annual RSD data collection cost of $3,312,651.

Area	Any-VSP RSD Coverage Required (%)	Number of Valid, DMV-Matched RSD Readings	RSD Measurement Unit Cost ($/valid, DMV-matched RSD reading)	RSD Measurement Cost ($)
Sacramento	47.00	1,001,607	0.94	944,611
San Diego	27.36	1,000,186	0.66	655,706
San Joaquin	26.53	1,001,465	0.65	647,617
South Coast	8.36	1,001,030	0.52	517,816
Bay Area	14.35	1,001,578	0.55	546,902
Total		5,005,866		3,312,651

[b]Used to determine the Any-VSP RSD Coverage of the (I/M + non-I/M) fleet driving in the five largest AQMDs.
[c]Used to determine the Usable-VSP RSD Coverage of the (I/M + non-I/M) fleet driving in the five largest AQMDs.

Appendix B

The Rate at which RSD Measurements Produce Valid, Matched, Unique Vehicles within a Given Operating Range

This appendix discusses the evidence behind assumptions of how many of the vehicles passing an RSD measurement unit will produce a valid RSD measurement on a vehicle with a readable license plate image that is contained in the DMV registration database.

Issues involved in getting a usable RSD reading depend upon the intended use of the measurement. In the case of calling vehicles in for an off-cycle I/M inspection, the strictest of criteria must be used – those that will minimize the chance that the vehicle will be called in unfairly. Here is a list of issues that affect the usability of an RSD measurement.

1. Not all vehicles that drive past an RSD unit receive a valid measurement. For example, many vehicles that are coasting do not have enough of an exhaust plume to be measured accurately, so the RSD software rejects the measurement.

2. Not all valid measurements are accompanied by a usable license plate image. For example, sometimes glare or dirt obscures the plate image or the vehicle is from out of state or it has a temporary "paper" license plate because it was recently sold.

3. How long an RSD unit spends at each site affects how much of the fleet it has a chance to get a measurement on. If the RSD units are moved frequently, they will get measurements on more of the fleet than if they spend their time at only a few sites. Also, redundant measurements (repeated on the same vehicle) are valuable for some uses, but there is a limit to how many actually add useful information.

4. Sometimes vehicles are driven past an RSD unit in a way that does not fairly represent whether that vehicle is a high emitter or not. At some point in practically every trip a vehicle takes, it will be operated in a way that does not fairly represent the vehicle. Since vehicles are certified to their pollution standards in a very controlled situation, it is normal for even the cleanest of vehicles to emit short puffs of pollution under extreme operating conditions (e.g., a very hard acceleration). If RSD data is to be used to call in vehicles for off-cycle inspection, it must be evaluated in a way that minimizes the incidence of such unfair measurements.

Below, we describe how we have accounted for these four issues in the assumptions of the size of the required RSD programs.

What fraction of vehicles driving past an RSD unit receive a valid measurement?

We can estimate this fraction from empirical evidence. Data from the California Pilot RSD project are most applicable, but many other programs and research projects are also applicable.

During the pilot project, valid fractions ranged from almost zero to nearly 98% for freeway ramp sites, and from zero to 92% for surface street sites. These huge ranges are acceptable for a research project, but not for an actual RSD program. In actual RSD programs, sites that do not produce valid fractions of above 60% are not generally considered productive enough. The average percentage of valid readings in RSD programs ranges from 75% to 90%. We have assumed an average for California programs of 75%.

What fraction of vehicles driving past an RSD unit record a usable license plate image?

For many reasons, not all vehicles driving past an RSD unit get a usable image of their license plate recorded. For example, trailer hitches, glare from the sun, and shadows can make the plates unreadable. Also, a number of other circumstances make the plate images unusable. For example, many vehicles drive with “paper” plates from the car dealer or have plates from out of state.

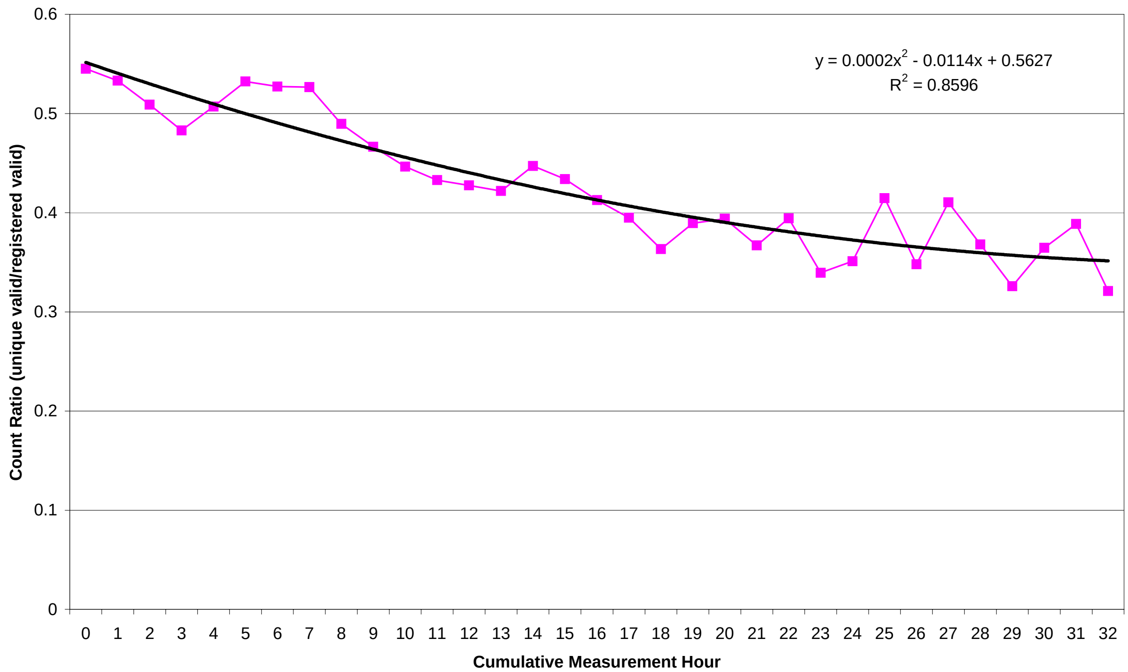
Experience from this pilot RSD program has shown that about 60% of the license plate images are useful. This is similar to experience from other RSD programs.

What fraction of vehicles driving past an RSD unit are unique (not redundant) measurements?

Usually called “fleet coverage,” this is the fraction of the fleet measured at least once by RSD. To maximize fleet coverage, RSD units should visit as many sites as possible. Vehicles tend to be driven in the same area, so if an RSD unit stays at one site too long, it will eventually be measuring mostly the same vehicles over and over. So when an RSD unit first visits a site, most of the vehicles will be getting their first RSD measurements, but after only a few days, the productivity of the site falls because the same vehicles are passing the RSD unit day after day.

The productivity curve (the percentage of vehicles receiving their first RSD measurement of the RSD Pilot Project) of a typical site in Sacramento is shown in Figure B-1. Within 8-hours of testing at one site, the productivity falls (on average) from about 55% of the vehicles receiving their first RSD measurement, to about 48%. Within 32 hours the average productivity falls to around 35%. This result is consistent with observations from other programs, where sites are changed frequently enough to keep productivity averages around 40%.

Figure B-1. The Average Unique-Vehicle Productivity of Sacramento Sites in the Pilot RSD Program



What is a "fair" driving mode range, and what fraction of vehicles driving past an RSD unit are driving in that range?

There is a range of driving modes that represent the driving conditions under which vehicles are tested to find out if they emit too much pollution. For this reason, vehicle driving conditions must be monitored while measuring emissions, so vehicles are not unfairly labeled as "high-emitters." (All vehicles can have high emissions under some driving conditions, like a high acceleration or driving up a steep hill.)

RSD takes a snap-shot 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. Site selection is a critically important part of collecting representative vehicle RSD data. The site can help limit vehicle operating conditions to a "representative" mode. Unfortunately, RSD sites that both provide ample traffic volume and representative conditions are not plentiful. Post-processing and analysis of the data are also critical. Researchers use quality assurance techniques and "filter" the speed and acceleration measurements to try to determine which vehicles were "blinking" (i.e., in an unrepresentative operating mode) at the time of the measurement.

In RSD measurements the vehicle operating range is characterized using a calculated value to estimate the load on a vehicle's engine. The value is called Vehicle Specific Power or VSP. It is typically expressed in units of kilowatts per metric ton or kW/Mg. Previous RSD studies have used various ranges of VSP, all of which approximate the range of engine loads found in the federal and California tests used to certify that new vehicles are as clean as they should be. When choosing the range of VSPs to accept for usable RSD measurements, there is a trade-off between emissions-representativeness and quantity of usable RSD measurements. In this study, we chose to use RSD measurements that have a VSP range of 5 to 25 kW/Mg.

Appendix C

Evaluation of Freeway Ramps for the Sacramento Metropolitan Area for High RSD Coverage Levels

This appendix is an abridged version of the Sierra Research report that documents the study of freeway ramps as potential RSD sites for the Sacramento metropolitan area. The work was done as part of this RSD pilot study. For the purposes of this implementation report, we have removed the extensive details included in the original: T.C. Austin, F. DiGenova, T.R. Carlson, "Fleet Coverage Limitations and Cost of Remote Sensing Devices for the Measurement of Motor Vehicle Emissions," prepared for State of California Air Resources Board, Sierra Research, Sacramento, California, November 29, 2005.

1. Summary

Based on a detailed survey conducted in the Sacramento, California metropolitan area, only about 19% of passenger cars and light-duty trucks registered in the area use freeway ramps that have operating conditions suitable for the measurement of exhaust emissions by remote sensing devices most of the time. Most vehicles use ramps that are either physically unsuitable for remote sensing (e.g., multiple lanes) or that usually have operating conditions (e.g., high congestion levels) that are unsuitable for remote sensing due to inadequate separation between passing vehicles or vehicle operating conditions that are poorly correlated with average emissions in stop-and-go driving.

An estimated 49% of the fleet can eventually be measured on freeway ramps under suitable operating conditions if monitoring is done for an extended period of time (i.e., many weeks) at all ramps that are physically suitable. This estimate is based on the fact that there is a finite, non-zero probability of measuring a vehicle under suitable operating conditions even at ramps that routinely have unsuitable vehicle operating conditions. The other half of the fleet either does not frequently use the freeway system or uses ramps that are physically incompatible with the use of remote sensing.

Given the practical problems associated with making emissions measurements on surface streets, the potential for measuring vehicle emissions with remote sensing devices is more limited than has been previously realized. A more significant factor affecting our conclusions is that the study area, like most other metropolitan areas in California, has more extensive use of multilane on-ramps with ramp metering. Such ramps are not suitable for remote sensing for two reasons. First, two separate lanes of traffic make it impractical to identify individual vehicle exhaust plumes. Second, ramp meters routinely produce vehicle operating conditions (deceleration and queues approaching the meter and hard acceleration after the meter) that are outside the range of operation that correlates with average emissions in stop-and-go driving.

Our survey of potential freeway RSD sites was conducted using an instrumented vehicle. In all, 51 survey drives were completed, covering 2,977 miles and including evaluation of 471 ramps or ramp segments. The survey found the following:

- 48% of the ramps surveyed (225 of 471) were determined to be unsuitable for remote sensing in any time period, due to multiple lanes, speed consistently outside the target range, engine load consistently outside the target range (usually due to excessive acceleration, deceleration or grade), inadequate space to position equipment, inadequate vehicle spacing, problems associated with active ramp metering, or for other reasons. 100 of the unsuitable ramps (21% of all 471 ramps) were physically unsuitable, usually because they had multiple lanes.

- 52% of the ramps surveyed (245 of 471) were determined to be suitable during at least one time period of the day. During the AM-, PM- and off-peak travel periods, respectively, 40%, 37% and 33% of the ramps were suitable for remote sensing, meaning that all suitability criteria were met for most vehicles in the respective time periods.

- 22% of the ramps (103 of 471) were found "suitable" for most vehicles in all three travel periods but only 5% of the ramps (24 of 471) were found to be "good" or "very good" ramps, meaning that almost all light-duty vehicles (rather than just "most" light-duty vehicles) would normally be expected to operate over a suitable range of speed and load in a consistent, predictable location along the ramp.

Merging of the instrumented vehicle survey results of potential freeway RSD sites with trip information derived from a regional traffic model showed that a typical deployment of remote sensing equipment, rotated between the sites identified as suitable, would result in approximately 19% of the light-duty vehicle fleet receiving a representative measurement by a remote sensing device in a relatively short period of time. Because ramps considered unsuitable would occasionally produce representative vehicle operating conditions, representative measurements could be obtained for a higher fraction of the fleet if remote sensing equipment were deployed at additional ramps. The longer the deployment, the greater the number of vehicles that could eventually be measured under representative conditions. However, because many of the ramps were physically unsuitable (regardless of congestion levels), and because a significant fraction of the fleet does not routinely use the freeway system, the upper limit for fleet coverage on freeway ramps is only about 49%.

The inability of remote sensing devices to collect representative emissions measurements for the majority of the vehicle fleet limits the extent to which remote sensing can be used to either replace or augment a conventional vehicle I/M program. This limitation does not affect the ability to use remote sensing for emissions inventory or I/M program evaluation purposes, as long as any sample bias resulting from the feasible measurement sites is addressed.

In order to provide insight into the practicality of applying remote sensing to a typical California metropolitan area having a population on the order of one million people, one scenario has been constructed and analyzed. The scenario is designed to provide maximum fleet coverage, as would be needed if remote sensing were intended to effectively identify high emitting vehicles for repair. The high cost to achieve maximum fleet coverage results largely from the extensive number of ramps at which monitoring would be required and the substantial staffing and labor costs that result.

2. Introduction

Remote sensing devices (RSDs) have been used for the measurement of emissions from vehicles in customer service since the late 1980s. During this period of time, most of the literature has addressed the feasibility of using RSDs to (1) detect vehicles with emissions-related defects, (2) identify "clean" vehicles that should be exempted from motor vehicle I/M programs, and (3) estimate average emissions from vehicles in customer service. However, there has been no definitive study of the extent to which a network of RSDs can be expected to obtain measurements from a high fraction of the vehicles within a particular geographic area under operating conditions that can be correlated with average emissions in customer service.

The limitations of RSDs for the measurement of emissions from a high fraction of the motor vehicle fleet are related to the conditions under which useful measurements can be obtained. With currently available RSD technology, limitations include the following:

1) Remote sensing measurements are reliable only across a single lane of traffic.
2) Vehicle operating conditions must generally be limited to moderate accelerations in order to achieve reasonable correlation with average emissions in stop-and-go driving.
3) Traffic congestion must be low enough to provide sufficient spacing between vehicles for RSD software to distinguish the exhaust plume of an individual vehicle from the emissions of other vehicles.

With few exceptions, blocking lanes of traffic or otherwise altering the flow of traffic to achieve conditions compatible with the use of RSDs creates intolerable traffic congestion problems at most locations requiring such alterations. As a result, there are a fairly limited number of roadways that could be suitable for the routine deployment of RSDs, including the following:

1) Collectors and minor arterials with one lane of traffic in each direction and a center median strip.

2) Single-lane freeway ramps with a curved section that limits acceleration rates or a downhill grade that limits the amount of throttle opening required to achieve an acceptable acceleration to merge with traffic.

3) Single-lane freeway on ramps with a cloverleaf design that limits acceleration rates.

4) Single-lane off ramps with a cloverleaf design and an uphill grade that routinely requires part-throttle operation at some point on the ramp to maintain speed.

5) A limited number of double lane surface streets that can be coned to a single lane without causing intolerable traffic problems.

Surface streets are generally impractical for remote sensing because there are few roadways with a single lane of travel in each direction and a median strip where remote sensing equipment can be located. In addition, such roadways typically handle a relatively low volume of traffic. Based on the detailed review of hundreds of road routes extracted from transportation models for metropolitan areas, a very small fraction of the vehicle population routinely uses roadways with median strips and a single lane of traffic traveling in each direction. The ability of RSDs to make usable emissions measurements on a high fraction of the vehicle fleet therefore depends on the extent to which motorists routinely use freeway ramps and the few surface streets meeting the above descriptions under traffic conditions that allow for measurements to be made.

3. The Driving Survey

Evaluating the Suitability of Ramps for Remote Sensing - The objective of the driving survey was to characterize all freeway ramps in the study area as to their suitability for remote sensing. Assessment of suitability was based on the following criteria, all of which would need to be met at the same location and time on a ramp in order for the ramp to be considered suitable for remote sensing:

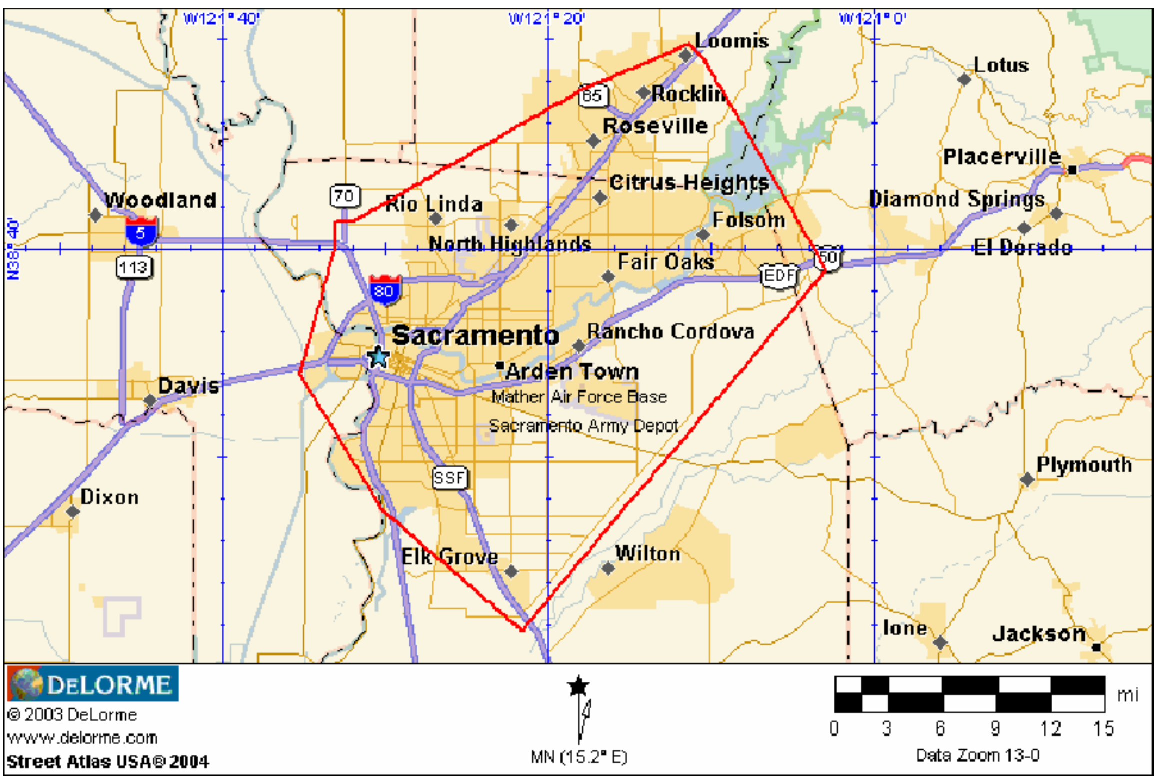
- Single lane section of ramp with adequate space for safe positioning of a remote sensing van (approximately 10'x 25') on one side and adequate space for a set back retro-reflective mirror on the opposite side (if either space was more limited but still feasible for a smaller system, the site was considered to be marginal for space but still possibly suitable for an automated remote sensing system).
- Speed for most vehicles in the range from 15 to 50 mph.
- "Low" to "moderate" engine load for most vehicles.

- All requirements (above) able to be met simultaneously at a reasonably predictable location on the ramp.

To assess suitability, each freeway ramp in the Sacramento region was driven during the AM (6:00-9:00), PM (3:00-6:00), and off-peak periods (usually 9:00 am to 3:00 pm). Driving in all three time periods was usually necessary because the type of driving that occurs on a ramp can be influenced by the other traffic on the ramp and by the traffic on the freeway, both of which can vary by time of day. The two drivers of the survey car, both experienced Sacramento drivers, were instructed to try to emulate typical driving of ramps by other drivers.

Temporal and Spatial Scope of the Study - The survey was conducted from February 11 to April 12, 2004, in an area that could be described as the greater Sacramento Metropolitan Area. A map showing the boundaries and major freeways is provided in Figure 3-1. Included in the study were all known freeway ramps, including freeway-to-freeway transition ramps.

Figure 3-1
Boundaries of the Ramp Survey Study Area



Engine Load - Remote sensing site selection needs to ensure to the extent practicable that vehicles will be under light to moderate load when their exhaust plumes are being sampled by RSD. Thus, to quickly assess the suitability of a large number of potential remote sensing sites, the current survey required a means (1) to assess relative vehicle power "on the fly" for the survey vehicle, and (2) to determine the range of power for the survey vehicle and most of the other vehicles and drivers that it mimicked that would reasonably ensure normal closed loop operation.

These two objectives were met by measuring manifold air pressure, or MAP, as a surrogate for power and, prior to the survey, by operating the survey vehicle on a chassis dynamometer, using suitable test cycles to record the reasonable range of MAP values over which the survey vehicle and, by inference, most modern vehicles, could reasonably be assured to be operating within closed loop control.

It should be noted that the representative operating range used in this study is significantly narrower than the operating range that has been used to define representative remote sensing measurements in other studies. In Virginia, for example, ESP used a VSP range of 3-22 kW/tonne to define representative measurements. The upper limit was apparently established based on the maximum VSP that occurs on the Federal Test Procedure and the IM240. While an upper limit for VSP based on the maximum VSP that occurs on the FTP and IM240 may seem reasonable in concept, our previous studies indicate that emissions at this VSP level do not correlate well with overall average emissions in stop-and-go driving. We have found that the HC and NOx emissions rates of vehicles driving steady-state loaded-mode traces for speeds of 15 to 50 mph are best correlated ($r^2 > 0.7$) with FTP emissions when the VSP of the traces are between 4 and 14 kW/tonne.

3.3 Procedures

In performing the ramp assessments, the drive team categorized ramps as suitable, marginal (or indeterminate), or unsuitable for remote sensing according to the aforementioned criteria. As time permitted, the team also took note of the reasons for disqualifying a ramp (e.g., high speed, low MAP, no space). Lastly, the team noted any ramp drives that were unusually good for remote sensing in that, over a relatively long portion of the ramp, both speed and MAP were well within the target ranges for a suitable drive.

Qualifications/Limitations of the Survey - It is recognized that most ramps that were judged to be either "suitable" or "unsuitable" for remote sensing based on one or more drives in each time period by the survey team could, by a deliberate effort, be driven in such an overtly aggressive or conservative manner as to yield the opposite result. Furthermore, even absent such intent, it is recognized that some drivers are much more or less aggressive than the norm, and if their driving were followed or mimicked by the survey team, it could result in drives giving an opposite assessment to that for the norm. Therefore, the assessment of suitability that was performed for the survey was based not only on how the survey car drove in its attempt to emulate typical driving that was observed but also on how most typical cars were observed or expected to drive the same ramp under conditions prevailing at the ramp for that time period.

Despite performing repeat drives in many cases and applying on-site judgments about suitability of ramps, some drives unavoidably resulted in an assessment that suitability of a ramp was indeterminate, i.e., not clearly suitable or unsuitable most of the time, or that it was marginally suitable due, for example, to space, or a speed or power constraint that was marginally exceeded or not exceeded.

Finally, it should be noted that for the variety of reasons discussed earlier, repeat assessments of the same ramp in the same time period sometimes resulted in conflicting results, or in the assessment that a ramp was marginal. To reconcile all of these results for the purposes of this report, ramps were deemed suitable if 50% or more of the determined drives (i.e., excluding drives that were indeterminate or marginal) were found to be suitable. With respect to marginal ramps, the most conservative assessment would consider all of them to be unsuitable and the most optimistic assumption would consider all of them to be suitable. For the purpose of providing an unbiased overview of the data in the next section, we assume that ramps that were either marginal or, in a small number of cases, inadvertently omitted from the survey in one or two time periods, were equally likely to be suitable or unsuitable.

3.4 Survey Results

In all, 51 survey drives were completed, covering 2,977 miles and including evaluation of 471 ramps or ramp segments. There were 236 on-ramps, 211 off-ramps, and 24 freeway-to-freeway transition ramps. Almost all ramps were driven in all three different time periods (AM, PM, and off-peak), thus allowing independent assessments for each period. More than 1900 ramp assessments were made. Survey results were later merged with data from the travel model. Regarding suitability of ramps for remote sensing, the survey found the following:

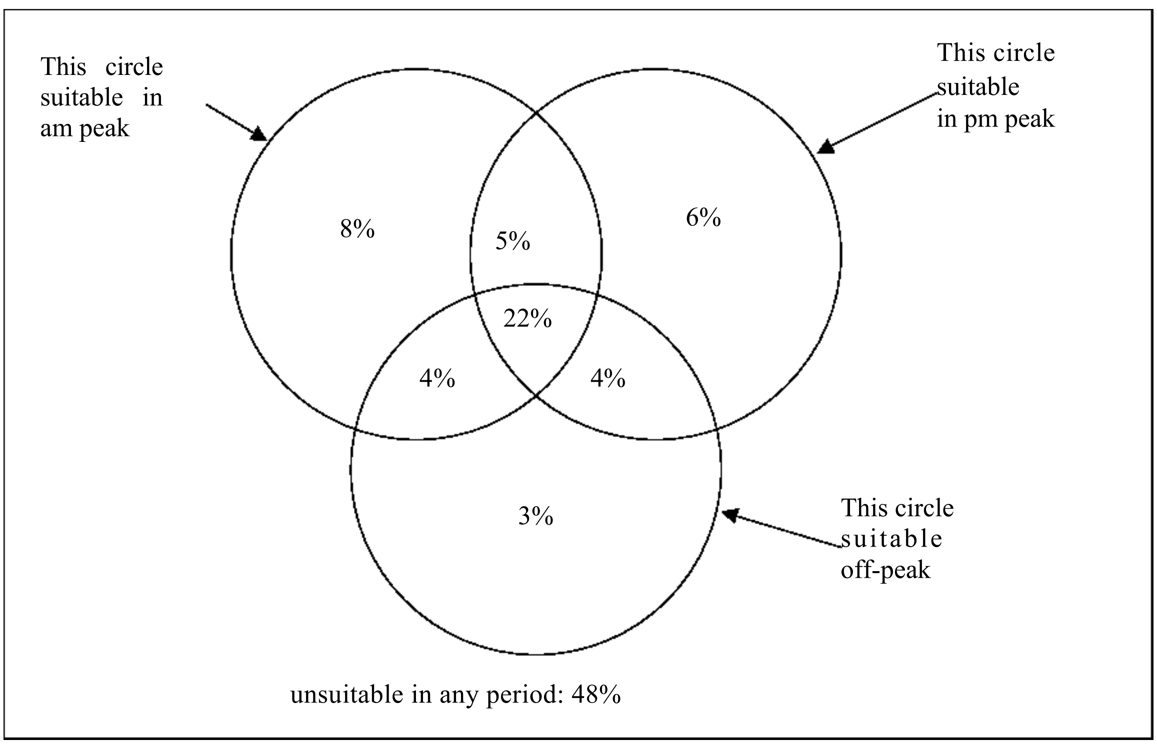
- 225 of the 471 ramps surveyed (48%) were determined to be probably unsuitable for remote sensing in any time period, due to multiple lanes, speed outside the target range, engine load outside the target range (usually due to excessive acceleration, deceleration or grade), inadequate space to position equipment, problems associated with active ramp metering, or for other reasons. 100 of the unsuitable ramps (21% of all 471 ramps) were physically unsuitable, usually because they had multiple lanes.

- During the AM-, PM- and off-peak travel periods, respectively, 40%, 37% and 33% of the ramps were suitable for remote sensing, meaning that all suitability criteria were met for most vehicles in the respective time periods.

- 103 ramps (22%) were found "suitable" for most vehicles in all three travel periods but only 24 of those ramps (5% of the total number of ramps) were found to be "good" or "very good" ramps, meaning that all suitability criteria were met in all three time periods and additionally that almost all light-duty vehicles (rather than just most light-duty vehicles) would normally be expected to operate over a suitable range of speed and load at a consistent, predictable location along the ramp.

Figure 3-4 summarizes the survey results in the form of a Venn diagram having three circles, one for each driving period. The numbers within each circle and within each area of overlap refer to the corresponding percentage of the total 471 ramps that were found suitable for remote sensing. For example, 22% of ramps (the area of overlap of all three figures) were suitable in all three periods, and 5% of ramps (area of overlap of the upper left and right circles) were found suitable in both the AM and PM peak periods but not in the off-peak period (lower circle). The area outside the circles represents the 48% of ramps that were not suitable in any period(s).

Figure 3-4
Percent of Ramps Suitable for Remote Sensing by Traffic Period
(n = 471 ramps)



4. Analysis of Fleet Fraction

Estimating the fraction of vehicles frequently using ramps compatible with RSDs requires three steps: (1) determining which ramps in a metropolitan area have physical geometry that is RSD compatible; (2) determining the periods of the day when the traffic congestion at ramps with compatible geometry is suitable for RSD measurement; and (3) determining what fraction of the vehicles registered in the area routinely use the compatible ramps during periods of the day when the level of traffic congestion yields suitable vehicle operation. The ramp field survey discussed in the preceding section addressed the first two steps. The third step, determining the fraction of vehicles routinely using the compatible ramps under acceptable traffic conditions, is the most difficult. The brute-force approach to performing this step would involve recording license plate numbers at each of the suitable ramps during the suitable periods for an extended period of time and comparing the vehicles identified to all of the vehicles known to be registered in the area. To avoid the cost and potential errors associated with that approach, an alternative method has been developed.

4.1 Travel Model-Based Methodology

All major metropolitan areas use transportation planning models to assist in the management of traffic flow through changes in the roadway network. These models provide reasonably accurate representations of travel using the results of comprehensive surveys used to construct trip origin and trip destination tables. The models calculate the path for each trip that minimizes travel time. Traffic volumes on individual roadway links demonstrate close agreement with measured volumes once the model has been calibrated. Manual review of the paths selected by the model consistently indicate that they are logical (e.g., trips from residential areas to other locations consistently take a route that minimizes travel time, usually involving freeway travel when long distances are involved).

Basic Approach - The approach used to estimate the fraction of the vehicle population that can be detected using RSDs involved making several special runs of the SACMET transportation model for the Sacramento Metropolitan Area. These special runs consisted of modifying the normal “loaded network” and “trip table” output files produced by the model to produce breakdowns of vehicle volumes by individual trip purpose. The trip purpose categories employed in the SACMET model are as follows:

- Home-based work;
- Home-based shopping;

- Home-based school;
- Home-based other;
- Work-based;
- Other;
- Transit; and
- Commercial.

The SACMET model produced separate files for each of four daily time periods:

6) AM peak (6:00-9:00 am);
7) Midday (9:00 am-3:00 pm),
8) PM peak (3:00-6:00 pm) and
9) Evening (6:00 pm-6:00 am).

Freeway, ramp, and arterial street links could be readily identified. To better estimate unique vehicle trips, the travel model analysis focused on home-based trips (home-work, home-school, home-shopping or home-other). The basic approach thus consisted of using AM and PM peak loaded network outputs for home-based trips from a SACMET model run for calendar year 2000 to calculate the number of vehicles in the study area that regularly used at least one freeway ramp within the study area. This was accomplished by first summing all the AM peak and PM peak ramp link volumes for home-based trips within the study area. After identifying the study area ramps and eliminating serial duplicates, totals of 385,726 AM peak and 366,247 PM peak ramp trips were found.

Estimation of Ramp Vehicles from Ramp Trips – The next step in the analysis consisted of converting the summed ramp trip volumes above into an estimate of unique vehicles. In general, when combining AM and PM peak ramp trips, each vehicle was assumed to cross two freeway ramps (an on ramp and an off ramp) per trip when the entire trip occurred within the study area. (These types of trips are called internal trips.) For trips that began or ended outside the study area (called internal-external trips), only one ramp was assumed per vehicle trip. The internal and internal-external trip fractions were found to be 94.1% and 5.9%, respectively. (External-external trips, though contained in the trip tables, were excluded from this analysis since by definition they travel through the study area and thus do not use freeway on- or off-ramps.)

Assuming two ramp trips per vehicle for internal trips and one for internal-external trips, an average trips-per-vehicle factor of 1.94 was calculated (2×94.1% + 1 ×5.9% = 1.94). This factor was then divided into the AM and PM peak ramp trip volumes to estimate the number of home-based vehicles using any ramp in the each peak period. The resulting totals of 198,687 and 188,653 vehicles in the AM peak and PM peak periods, respectively, were estimated to use any ramp in the study area from analysis of the link-based travel model outputs.

Determination of Study Area Vehicle Population - In order to determine the fraction of the vehicle fleet that regularly crossed any freeway ramp, the next step in the analysis consisted of determining the population of vehicles in the study area. Vehicle population was estimated using county-level vehicle population outputs for calendar year 2000 from ARB's EMFAC2002 model.

To account for the fact that the surveyed study area includes portions of most of these counties, city and county-level U.S. Census data were used to calculate the fraction of vehicle in these counties that regularly traveled in the study area. The total study area vehicle population was calculated to be 907,368. The adjusted non-commercial vehicle population for the study area was calculated as 862,000.

Instrumented Vehicle-Based Adjustments – Ramp vehicle estimates developed from the SACMET travel model had to be further adjusted to account for several factors that could not be accounted for using the travel model outputs:

- Day-to-Day Variability
- Vehicle Trip Overlap Between AM and PM Peak
- Non-Overlapping Off-Peak Ramp Use

Adjustment factors for each of these three elements were developed from analysis of a special instrumented vehicle (IV) study[5] sponsored by the U.S. Environmental Protection Agency in 1992. The locations of the trips in this IV study were not recorded. Thus, in order to estimate which of the IV trips included travel on freeways and ramps, logic was developed and applied to the IV data that estimated freeway/ramp trips as those that reached speeds of at least 55 mph for at least 30 consecutive seconds. (Trips that did not meet these criteria were assumed to be non-freeway/ramp trips.) This logic was developed from an analysis of chase car driving studies[6,7] performed for the California Department of Transportation in 2000. A series of additional SAS programs were then written and applied to the IV trip data to develop adjustment factors for day-to-day driving variability, AM and PM peak overlap, and off-peak ramp use.

Based on this analysis, it can be stated that 67% of the Sacramento study area vehicle fleet will make at least one ramp trip over any one-week period.

Calculation of Suitable Ramp Fraction – Up to this point, the analysis examined the vehicle fleet fraction using any freeway ramp within the study area, regardless of RSD suitability. These baseline results were then merged with the results obtained from the ramp field survey to determine the fleet fraction that could be detected during a short period of time on RSD-suitable ramps. The time required would be somewhat greater than one-week because all vehicles are not always in the acceptable operating range at the "suitable" ramps.

The SACMET travel model, which contained traffic volumes on each modeling link by time period, was tied using GIS to each freeway ramp in the field survey. This enabled the connection of the traffic volumes and RSD suitability determinations for each ramp by time period (e.g., AM peak, PM peak, etc.). Non-duplicate home-based ramp volumes were then summed (1) across all ramp links, and (2) across RSD-suitable ramp links for each time period. The "suitable volume" percentage, which is the ratio of (2) to (1), ranges from 27.3% to 28.1% across the time periods. Since the suitable volume percentages are clustered in a tight range across the time periods, a single value of 28% was assumed to apply across the entire day. This value was then simply applied to the vehicle fleet fraction expected to be seen across all ramps (of 67%) to calculate the fraction of the vehicle fleet expected to captured on RSD suitable ramps (within a short period of time).

Based on the above described analysis, if RSD sensors were deployed on all suitable ramps in the Sacramento study area for a short period of time, only 19% (=67% × 28%) of the vehicle fleet would be expected to be captured.

Because some ramps considered "unsuitable" would produce representative measurements for some vehicles, representative measurements could be obtained for a higher fraction of the fleet if remote sensing equipment were deployed at additional ramps. The longer the deployment, the greater the number of vehicles that could eventually be measured under representative conditions. However, because many of the ramps were physically unsuitable (regardless of congestion levels), and because a significant fraction of the fleet does not routinely use the freeway system, the upper limit for fleet coverage on freeway ramps is obviously less than 100% even ignoring the fact that many ramps have a very low fraction of vehicle operation in the acceptable range of engine load. To determine the upper limit irrespective of operating range, the analysis described above for the "suitable" ramps was repeated for all ramps that were not excluded for "physical" reasons (only). The excluded ramps were primarily those having multiple lanes, which also tend to be at the most heavily traveled interchanges. Excluding only those ramps, the 73% of the vehicles using the freeway system would be captured. Accounting for vehicles that do not routinely use the freeway, the capture rate drops to 49% (=67% × 73%).

4.2 Comparison of Travel Model and IV-Based Ramp-Use Fractions

The validity of the travel-model-based approach to calculating the vehicle fleet fraction that regularly traveled on freeway ramps was also examined by simply performing an analysis of vehicle ramp use based exclusively on the instrumented vehicle database. After accounting for the higher apparent ramp frequency in the instrumented vehicle data due to driving in rural areas, there is good agreement between the travel model and instrumented-vehicle-based estimates of vehicle fleet ramp use fractions.

4.3 Effects of Deployment Duration on Captured Fleet Fraction

The preceding analysis estimated the fraction of vehicle using all ramps and RSD-suitable ramps in the Sacramento study area during a one-week period. Vehicle fractions using any freeway ramps and RSD-suitable ramps in one week were found to be 67% and 19%, respectively. The extent to which an increasing fraction of the fleet will use freeway ramps over a longer period of time cannot be reliably estimated from the available data. However, anecdotal evidence suggests that the longest period most drivers deviate from their normal driving patterns (e.g., due to vacations) is approximately two weeks. Therefore, it would probably not be efficient to deploy RSDs at "suitable" sites for much than about one month because the same vehicles will simply continue to be seen over and over again, with little new vehicle capture occurring after the two weeks. This finding suggests that the most cost-effective RSD deployment strategy would consist of deploying monitors at suitable sites in an urban area for a about one month per site and rotating the monitors from site to site over a one-year period. In Sacramento, where roughly 260 ramps were identified as suitable (in any time period), this would entail deploying 22 monitors rotated between sites once per month to most efficiently cover the Sacramento ramp network in a one-year period. As indicated in the earlier analysis, however, this deployment strategy would capture only about 20% of all light-duty vehicles in the area. To capture a higher fraction of the fleet, less suitable ramps need to be used and the time RSDs would need to be deployed would be much longer because the probability of measuring vehicles under appropriate operating conditions would be much lower.

4.4 Comparison with Fleet Coverage Results Reported in Other Recent Studies

In addition to differences in the range of vehicle operating conditions accepted, there are other differences between regions that can affect fleet coverage. For example, it would be inappropriate to compare freeway ramp coverage from the Missouri study with that expected in Sacramento without accounting for the fact that many higher volume freeway ramps in Sacramento are metered during rush hours (and therefore, unsuitable for remote sensing), whereas St. Louis does not use freeway ramp metering[17]. Coupled with the fact that the vast majority of off-ramps are unsuitable, this means a much larger fraction of the fleet in Sacramento is expected to be inaccessible to remote sensing than in cities like St. Louis. This and several other key factors[18] which distinguish freeway travel in the two areas in 2003 (most recent year of data) are summarized in Table 4-5.

Table 4-5
Comparison of Selected Mobility-Related Factors for Sacramento and St. Louis

	Sacramento area	St. Louis area
Population density in 2003 (persons/sq. mile)	3,849	1,812
Daily vehicle miles of freeway travel	13,705,000	26,145,000
Freeway lane miles	710	1,785
Ramp Metering	used on busiest ramps	not used
Fraction of freeway traffic that drives on sections of freeway that have meters[19]	92%	none
Fraction of the miles of freeway that have metered ramps	87%	none

5. A Remote Sensing Scenario for Vehicle Surveillance Purposes

The use of remote sensing for vehicle surveillance will require developing a large number of ramp sites in order to maximize coverage of the vehicle fleet. As discussed earlier, this study has found that only 67% of the vehicle fleet in the Sacramento metropolitan area can be expected to use the freeway system during the course of a seven-day period, thus limiting the potential for measuring emissions by remote sensing installation on a freeway ramp. The remaining 33% of the vehicle fleet do not use freeway ramps on a frequent basis.

This fundamental limitation to fleet coverage is further complicated by the fact that only 52% of the freeway ramps surveyed were found to be probably suitable for remote sensing measurements during at least one time period of the day, while 48% were found probably unsuitable in all time periods due to a variety of factors. Accounting for the fact that suitable ramps tend to have lower traffic volumes, and considering the distribution of travel during peak and off-peak periods, the analysis concluded that only 28% of freeway traffic could be expected to use one or more of the suitable ramps within a short period of time (a few days to few weeks). This fraction translates to only 19% of the vehicle fleet in the Sacramento metropolitan area.

Thus, it will not be sufficient for vehicle surveillance to cover 50% of the fleet to conduct remote sensing measurement at suitable ramps only. Instead, it will be necessary to expand fleet coverage by deploying remote sensing at all ramps except those found to be physically unsuitable (meaning that measurements cannot be taken, most commonly because the ramp consists of multiple lanes). With this expansion, it was estimated that as much as 49% of the vehicle fleet in the Sacramento metropolitan area could be captured.

Obtaining valid, representative emissions measurements at the additional sites will be difficult because the (non-physical) factors that make the additional ramps unsuitable for remote sensing—most commonly that a large proportion of passing vehicles operate outside of the valid speed/acceleration range—mean that the probability of obtaining a representative measurement will be low. Therefore, it will be necessary to operate remote sensing equipment for extended periods at these sites.

Productivity for Vehicle Emissions Measurement – The productivity of prototypical ramp sites for vehicle emissions measurement depends on a range of factors. Productivity may be expressed as the number of valid emission measurements on individual vehicles that can be obtained during a given period of time. In general, the productivity depends on the following factors:

- The gross number of vehicles passing the monitoring equipment each day.
- The probability of obtaining a valid emission measurement (including a reliable license plate image, etc.) per vehicle pass
- The distribution of trip types and their repeatability on successive days, which determine the number of unique vehicles present in the traffic flow during the observation period.

Given these factors and the number of days that measurements are taken at each site, the number of valid emission measurements on individual vehicles per site can be calculated. Table 5-1 summarizes the some of the factors affecting productivity estimates used in this analysis.

Table 5-1
Ramp Characteristics Affecting Productivity of Sites for Remote Sensing Measurements in Sacramento Metropolitan Area

	Suitable Ramps	Unsuitable Ramps[a]
Total Number	246	126
Average Daily Traffic Volume	2,957	4,162
Measurement Method	Mobile Crews in RS vans	Unmanned Equipment
Daily observation period/site	24 hours	24 hours
Predominant Trip Type	Daily Commute	Daily Commute
Probability of Valid, Representative Measurement per vehicle pass	25%	5%
Expected number of valid, Representative and unique measurements per site-yr	2,661	3,726

[a] Ramps at which measurements could be taken, but were found unsuitable due to congestion or vehicle operating characteristics outside the representative range of speed and acceleration.

The suitable ramps are generally lower-capacity single-lane ramps. This characteristic leads to an average daily traffic volume that is less, on average, than the freeway system overall or the unsuitable ramps. Measurements at suitable ramps would be taken by remote-sensing equipped mobile vans, each operated round-the-clock by three crews. (Each crew works 8 hours per day.) Measurements at the selected unsuitable ramps would be taken 24 hours per day, 7 days per week by unmanned equipment.

While fewer vehicles will be observed each day at the suitable ramps compared to the unsuitable ramps, the probability of obtaining valid measurements is substantially greater. For this analysis, we estimate that the probability of a valid, representative measurement on each vehicle pass is:

- 25% at suitable ramps, and
- 5% at unsuitable ramps.

The 25% estimate for suitable ramps is based on the observation that more than 50% of the vehicles were estimated to be in the acceptable operating range, combined with an estimate that 50% of the time there will be problems obtaining a valid license plate reading (due to obscuring traffic, missing or dirty plates, errors in the DMV database, etc.) or valid remote sensing reading (wet pavement, water plume, too windy, traffic spaced too closely, etc.) The 5% estimate for unsuitable ramps is based on the assumption that vehicles will be in the acceptable operating range 10% of the time with 50% valid readings. The percentage of vehicles in the acceptable operating range is based on the best judgment of staff involved in the ramp surveys.

The repeat measurements of the same vehicles on successive days offers the possibility to increase the overall expected number of valid and unique vehicle measurements each day. If the circumstances determining whether a measurement is valid are assumed to be independent from one day to the next, then the total probability of obtaining a valid measurement on a given vehicle is:

- 90% after 8 measurements at suitable ramps, where the probability of valid, representative measurement is 25% on each pass; and
- 90% after 44 days at unsuitable ramps, where the probability of valid, representative measurement is 5% on each pass.

Considering all of the characteristics, the manned sites (suitable ramps) will yield an average of 2,661 valid measurements on unique vehicles, while the unmanned sites (unsuitable ramps) will each yield 3,726 valid measurements on unique vehicles (a higher number due to the higher traffic volume at those sites and the much longer monitoring period, as discussed below).

Further details about the scenario for deploying remote sensing for vehicle surveillance are shown in Table 5-2. Mobile units would be rotated among the 246 “probably suitable” ramps, staying on average 8 days at each location, while 126 “probably unsuitable” ramps would be developed as unmanned sites and each kept in operation for 44 calendar days per year. We also note that although it is a common practice to operate RS vans using two daytime crew shifts[20], such a 16-hour sampling day could miss about 20 percent of the traffic and is inconsistent with the goal of obtaining maximum coverage. To avoid this significant loss of coverage, and to maximize efficient use of the capital investment in RS equipment, RS vans are assumed to operate around the clock, using three 8-hour crew shifts.

The primary physical resources required to implement this scenario include the installation of speed sensing systems at unmanned sites, remote sensing measurement equipment to be rotated among manned and unmanned sites, and vans and field crews to serve as mobile units and to move, setup/teardown and service unmanned sites. Considering the need for spare equipment and backup personnel, this scenario will require:

- Developing 126 ramps as unmanned measurement sites with the requisite speed sensors and partially below-ground bunkers (for safety and security),
- Procuring a total of 27 remote sensing units, of which 8 would be operated in vans and rotated among the 246 suitable sites, 16 would be deployed unmanned and rotated among the prepared permanent sites, and 3 would be spares,
- Procuring and converting for use 15 vans, and
- Hiring 57 field personnel to staff a total 27 2-person field crews and 3 1-person field crews.

Table 5-2
Scenario and Resource Requirements for Deploying Remote Sensing in the Sacramento Metropolitan Area for Vehicle Surveillance Purposes

	'Probably Suitable' Ramps	**'Probably Unsuitable' Ramps[a]**	**Total**
Total Number	246	126	372
Measurement Method	Mobile Crews in RS vans	Unmanned Equipment	
Coverage period (days per site)	8	44	
Probability of valid measurement during coverage period	90%	90%	
Expected number of valid and unique measurements per site-yr	2,661	3,726	
Coverage of fleet using freeways	28%	45%	73%
Coverage of area wide fleet	19%	30%	49%
Physical Resources Required			
Unmanned sites developed	0	126	126
Remote sensing units[b]	9	18	27
Vans and field crews	24[c]	6	30

[a] Ramps at which measurements can be taken, but found unsuitable due to congestion and vehicle operating characteristics outside the valid range of speed and accelerations.
[b] Based on number of sites operating simultaneously plus allowances for spare equipment and backup personnel.
[c] Assumes three 8-hour crews per day

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18. "Performance Measure Summary for Sacramento" and "Performance Measure Summary for St. Louis", available at http:/mobility.tamu.edu/ums/congestion_data/tables.

19. Personal communication with Dr. David Schrank, Texas Transportation Institute, July 2005.

20. Personal communication with ESP, July 2005.