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**A Study of
Emissions Deterioration,
Post-I/M Tampering, and
Cost/Effectiveness of the
Smog Check Program**

**Final Report
ARB Contract No. A6-220-64**

prepared for:

California Air Resources Board

June 7, 1990

prepared by:

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EMISSIONS DETERIORATION, POST-I/M TAMPERING, AND
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EMISSIONS DETERIORATION, POST-I/M TAMPERING, AND
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A Study of
EMISSIONS DETERIORATION, POST-I/M TAMPERING, AND
COST/EFFECTIVENESS OF THE SMOG CHECK PROGRAM

SUMMARY

Under Contract No. A6-220-64, Sierra Research performed a variety of tasks for ARB and the California I/M Review Committee, most of which were related to the state's motor vehicle inspection and maintenance (I/M) program, called "Smog Check". The major tasks covered:

- Evaluation of the Emissions Deterioration and Post-Inspection Tampering Associated With the Smog Check Program;
- An Analysis of Smog Check Program Cost/Effectiveness;
- Routine Technical Support to the California I/M Review Committee;
- Technical Support to ARB and the I/M Review Committee Regarding the Development of Improved Test Analyzer Systems for the Smog Check Program; and
- Technology Assessment and Standards Development Support to the ARB Mobile Source Division.

Highlights of the work performed under each task of the contract are presented below.

Evaluation of Emissions Deterioration and Post-I/M Tampering

During 1985 and 1986, about 800 vehicles expected to fail the Smog Check program were recruited by ARB from the general public. After baseline tests at the ARB lab, these "undercover" vehicles were taken to randomly selected Smog Check stations by ARB employees posing as ordinary vehicle owners in need of a Certificate of Inspection. Those vehicles that received repairs were brought back to the ARB laboratory for testing to determine the emissions changes associated with the Smog Check program. An analysis of the test results published in 1987 indicated that there were significant emission reductions recorded for the average of the vehicles that received repairs.

* "Evaluation of the California Smog Check Program - Technical Appendix," Sierra Research, Inc., April 1987.

Following the second test at ARB, the vehicles were returned to their owners. After a period of time in customer service, ARB "recaptured" some of the vehicles and ran additional laboratory tests. Some of the vehicles were recaptured on two separate occasions.

Sierra's analysis of the available test data indicated that the average emission level of the undercover cars has increased over time. For 1975 and later models, the increase in emissions per unit of mileage accumulation is about the same as would have been expected in the absence of the Smog Check program. For pre-1975 models, hydrocarbon and carbon monoxide emissions appear to deteriorate more rapidly after Smog Check repairs.

Figures 1, 2, and 3 show the trend in emissions vs. mileage for the 1975-1979 model recaptured undercover cars compared to the average emissions for all 1975-1979 model vehicles. The straight lines showing the estimates of emissions from all 1975-1979 model vehicles were produced by a preliminary version of the "I/M Model" that Sierra is developing for ARB under another contract. The "no-I/M" forecast produced by the I/M Model is based on Sierra's analysis of data from "average vehicles" that have not received I/M repairs.

Figure 1

Undercover Car HC Emission Trends Compared to Average Non-I/M Vehicle (1975-79 Models)

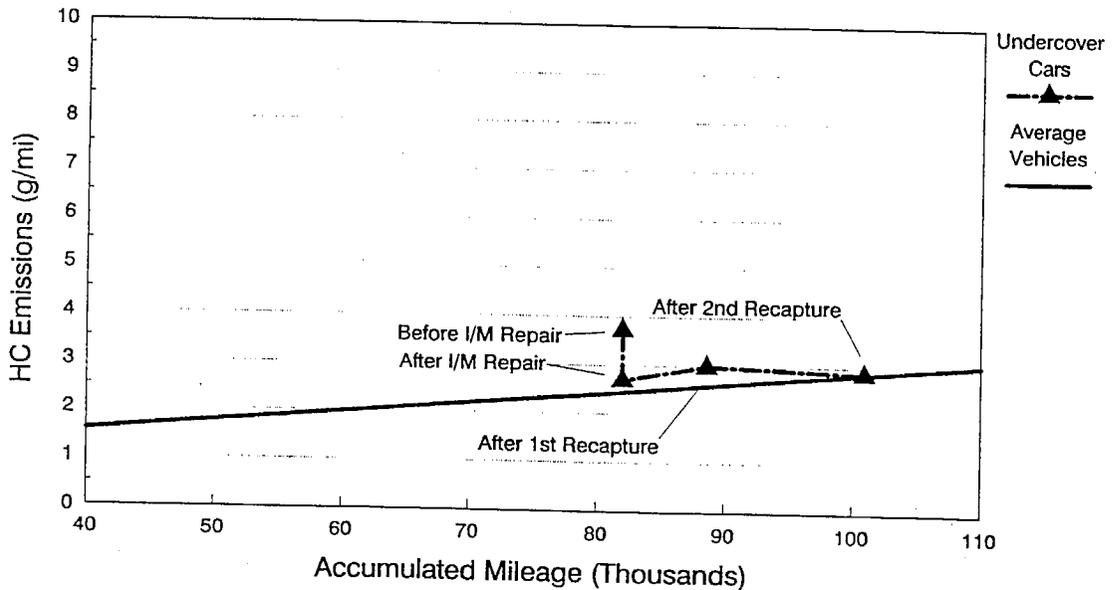


Figure 2

Undercover Car CO Emission Trends Compared to Average Non-I/M Vehicle (1975-79 Models)

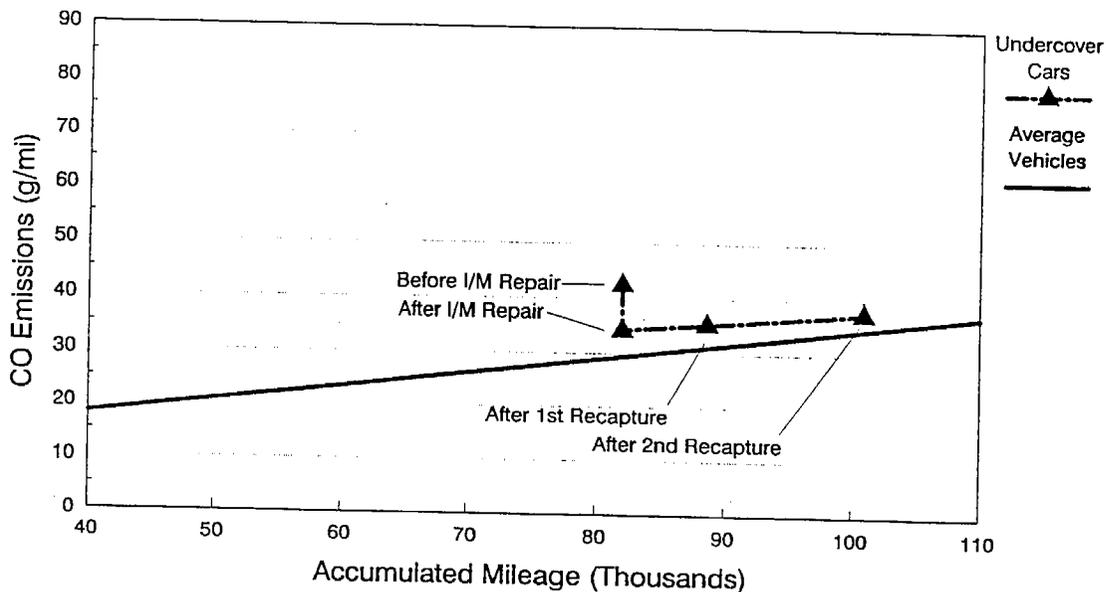
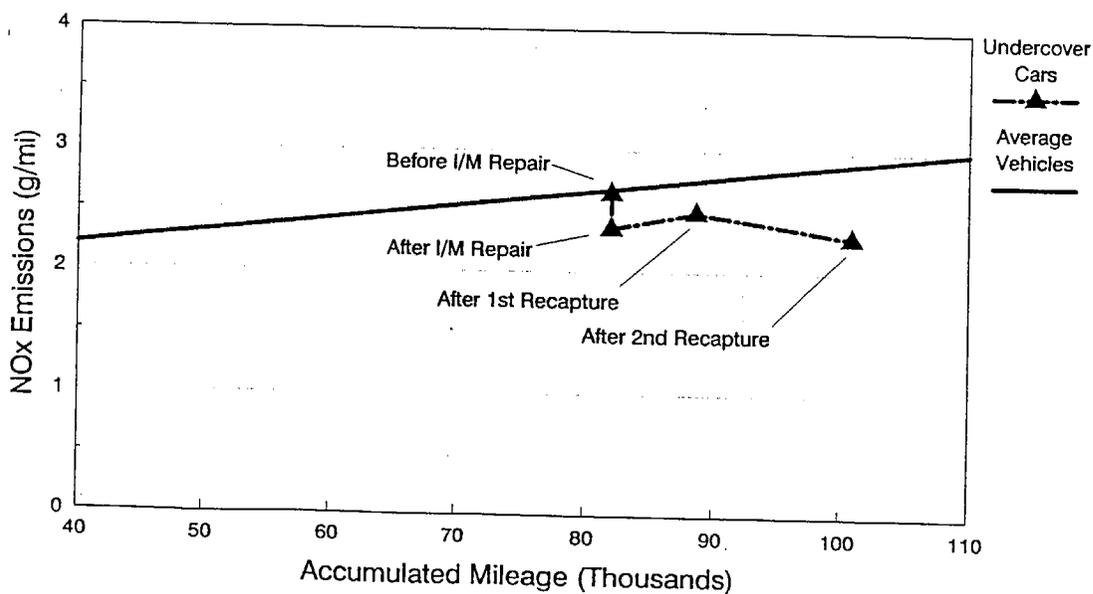


Figure 3

Undercover Car NOx Emission Trends Compared to Average Non-I/M Vehicle (1975-79 Models)



Data for undercover cars are shown by the dashed lines. The lowest mileage points on each graph show the immediate effect of Smog Check station repairs on emissions. The next two points show how emissions changed as mileage was accumulated. As the figures show, emissions of all three pollutants were initially reduced by Smog Check repairs. For hydrocarbons (HC) and carbon monoxide (CO), the before-repair emissions of the vehicles that failed the Smog Check were significantly higher than the estimated emissions for all 1975-1979 models. After-repair emissions of the failed vehicles were much closer to the average emissions estimated for all 1975-1979 model year vehicles on the road. The change in emissions as mileage was accumulated on the repaired vehicles tended to follow the characteristic deterioration of the average of all cars. For oxides of nitrogen (NOx) emissions, the before-repair emissions of the failed vehicles were slightly lower than the average car. This is not surprising because defects that cause high HC or CO emissions often tend to reduce NOx.

Figures 4, 5, and 6 show similar trends for 1980 and later model vehicles. As with the case of the 1975-1979 models, the before-repair emissions of the failed cars are higher than average for HC and CO and slightly lower than average for NOx. I/M repair results in reduced emissions of all three pollutants. HC and CO values come close to the average of all vehicles. When returned to customer service, the change in emissions as mileage is accumulated appears to be similar to the average of all vehicles that are not subject to I/M.

Figure 4

Undercover Car HC Emission Trends Compared to Average Non-I/M Vehicle (1980 and Later Models)

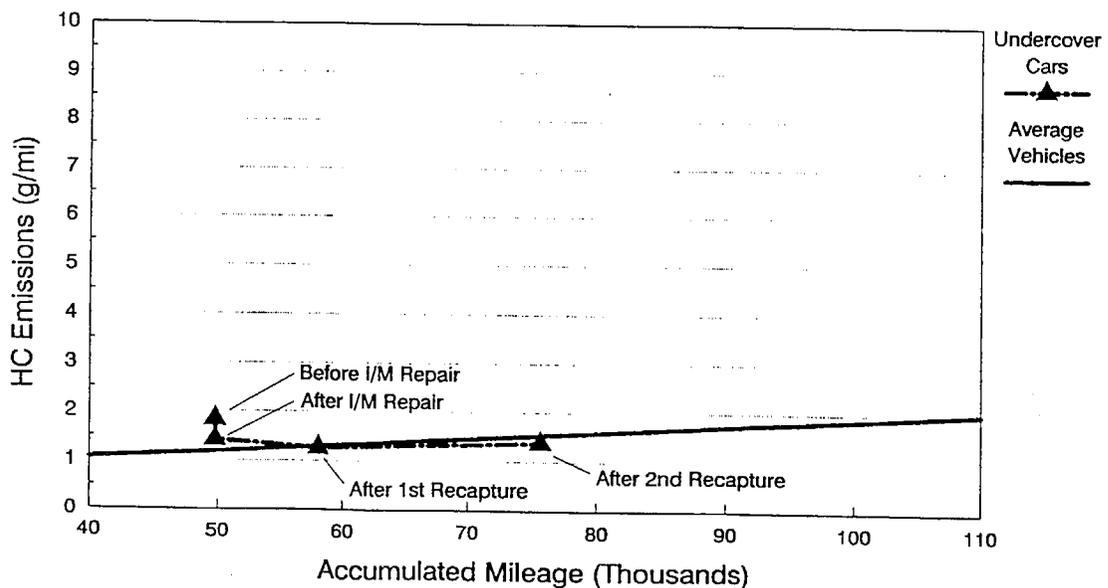


Figure 5
**Undercover Car CO Emission Trends
 Compared to Average Non-I/M Vehicle
 (1980 and Later Models)**

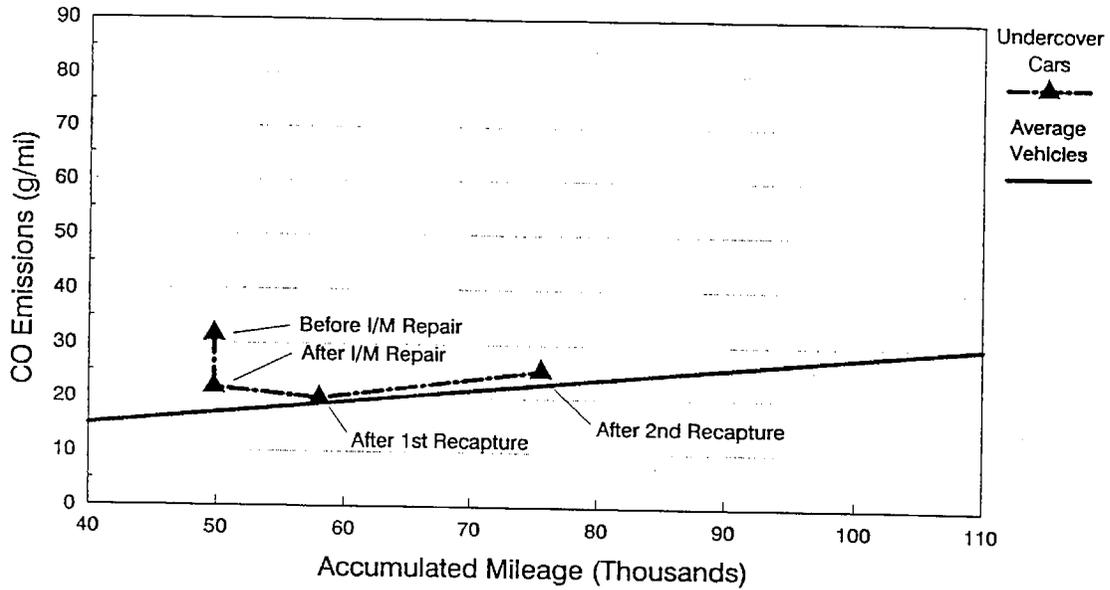
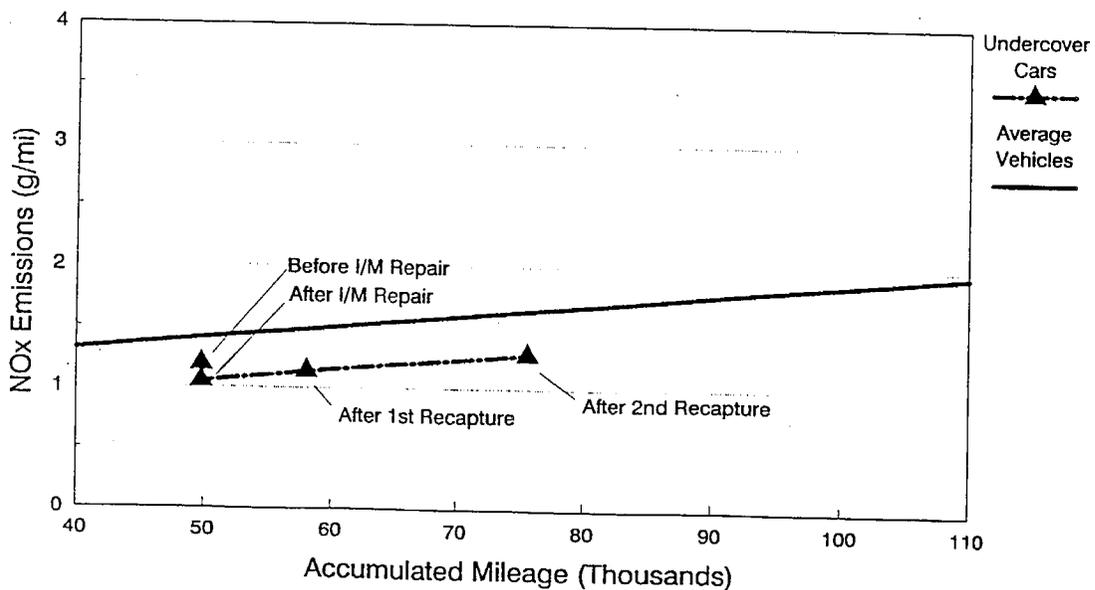


Figure 6
**Undercover Car NOx Emission Trends
 Compared to Average Non-I/M Vehicle
 (1980 and Later Models)**



Figures 7, 8, and 9 illustrate the difference in the performance of pre-1975 models. As in the case of the 1975 and later models, the before-repair HC and CO emissions of the vehicles that failed the Smog Check were significantly higher than the estimated average emissions for all vehicles of the same model year range. As with the newer models, after-repair emissions of the failed vehicles were much closer to the average emissions of all vehicles of the same model year range. However, the increase in emissions as mileage was accumulated on the repaired vehicles was much higher than for the pre-1975 model year fleet on the whole. The pre-1975 models also show a different trend for NOx emissions. Before-repair emissions start out slightly higher than the average vehicle and continued NOx reductions occur when the vehicle is returned to customer service.

Sierra believes that the higher deterioration rates observed for pre-1975 models are associated with the inherently less durable ignition systems and readily adjustable carburetors used on these vehicles. For example, most pre-1975 models have recommended spark plug change intervals of 6,000 miles. In contrast, most late model vehicles can run 30,000 miles between spark plug changes. Vehicles that fail Smog Check tend to be those which are not properly maintained. A continued

Figure 7

Undercover Car HC Emission Trends Compared to Average Non-I/M Vehicle (Pre-1975 Models)

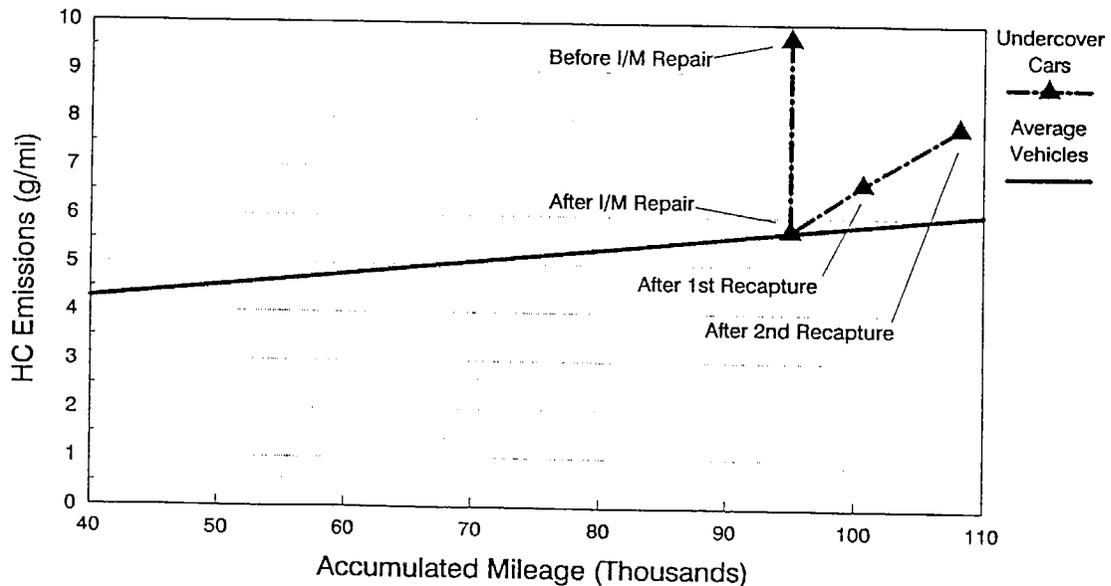


Figure 8
**Undercover Car CO Emission Trends
 Compared to Average Non-I/M Vehicle
 (Pre-1975 Models)**

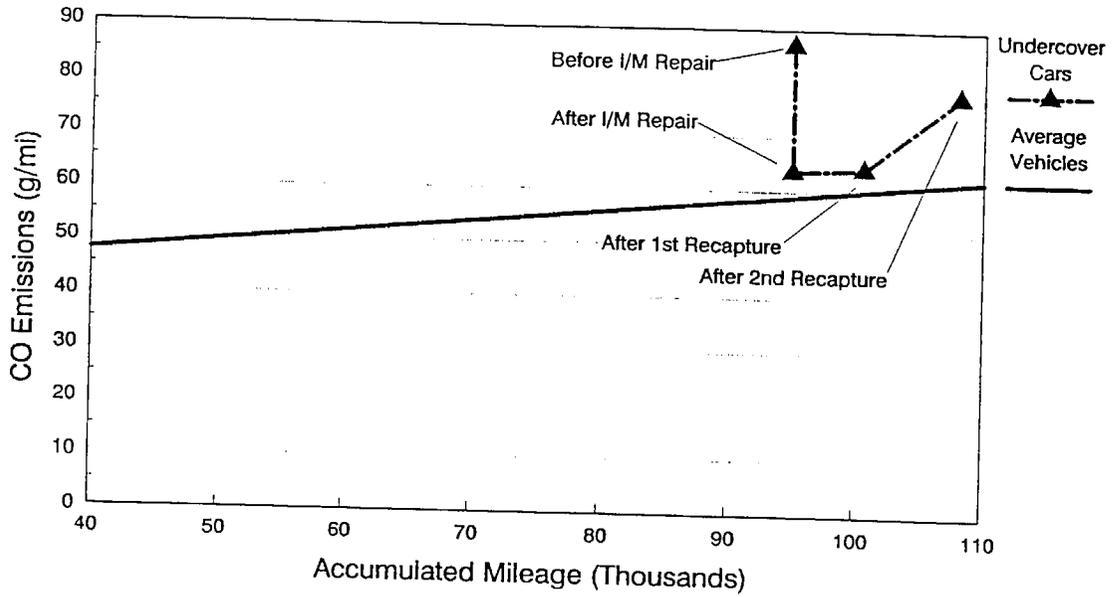
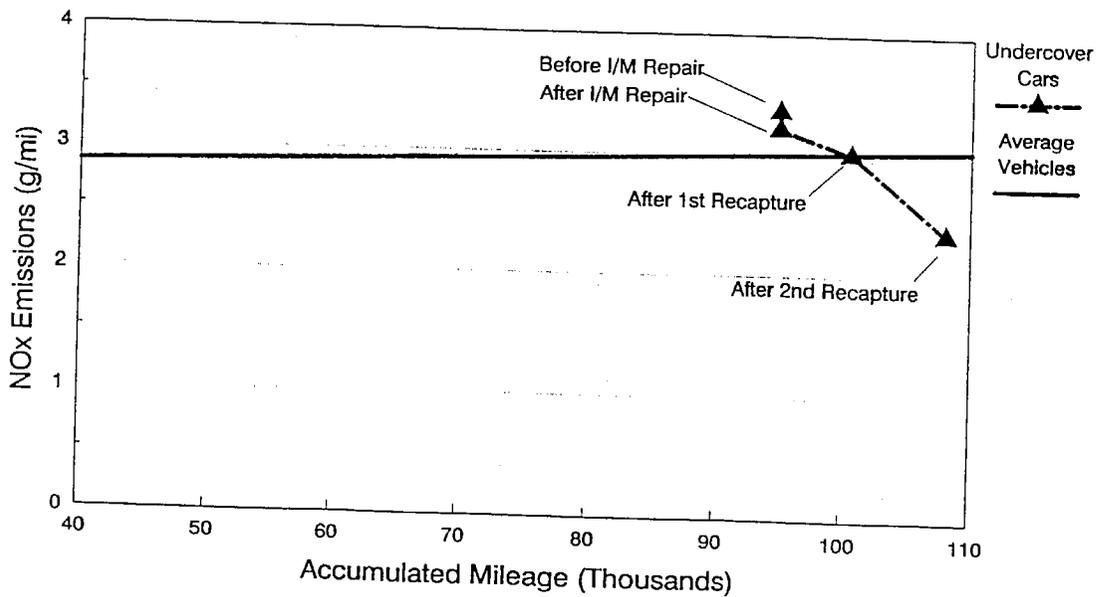


Figure 9
**Undercover Car NOx Emission Trends
 Compared to Average Non-I/M Vehicle
 (Pre-1975 Models)**



lack of attention to maintenance after Smog Check repairs would be expected to lead to rapid deterioration in emissions control.

Based on the analysis of emissions changes, it was apparent that I/M repairs seem to hold up fairly well, at least for 1975 and later model cars. This finding was consistent with the results of a separate analysis of "repeat tampering." Based on Sierra's analysis of inspection results on the recaptured undercover vehicles and on vehicles inspected under the Random Roadside inspection program, the rate of repeat tampering is about 20%. In other words, only one out of five vehicles with tampering corrected under the Smog Check program shows evidence of the same type of tampering when it is subsequently inspected after accumulating mileage in customer service.

Cost/Effectiveness of the Smog Check Program

Based on the above-referenced 1987 study, the exhaust emission reductions achieved during the first two years of the Smog Check program were estimated to be 12.3% for HC, 9.8% for CO, and, in areas with functional checks, 3.9% for NOx. Using data on the average cost of the inspection and repairs during 1986, Sierra has calculated the cost-effectiveness of the program for HC + NOx to be \$1.35/pound. This is a very favorable ratio of cost to emission reductions compared to other emission control measures. Some of the other hydrocarbon and NOx controls proposed by ARB and local air pollution control districts cost over \$5/pound.

Since the completion of the 1987 report, Sierra Research has been asked to estimate the effect of numerous changes to the Smog Check program that were considered during the 1988 session of the California Legislature. All of the program enhancements contained in the final version of Senate Bill 1997 were considered. Increased program enforcement by the Bureau of Automotive Repair (BAR) and program enhancements mandated by SB 1997 are projected to increase the emission reductions from vehicles subject to the California Smog Check program by more than a factor of two. Although higher inspection fees and repair costs will be incurred, the percentage increase in costs is projected to be less than the percentage increase in benefits. As a result there will be a favorable impact on the "cost-effectiveness" of the Smog Check program.

Based on Sierra's analysis, the level of hydrocarbon (HC) and carbon monoxide (CO) emission reductions achieved under the Smog Check program will increase from 12.3% HC and 9.8% CO reported in 1987 to about 25-30% in the early 1990s. Oxides of nitrogen (NOx) emission reductions are projected to increase from 3.9% (in those areas with functional inspections) to about 10-15%.

With the program enhancements contained in SB 1997, the cost-effectiveness ratio of the Smog Check program during 1986 would have improved from \$1.35 per pound of hydrocarbons and NOx to \$1.17 per pound. However, the average emissions of the motor vehicle fleet are decreasing over time as newer vehicles, designed to meet more

stringent emission standards, replace older, less well-controlled cars and trucks. Because of this drop in average emission levels, the absolute gram/mile benefits of an enhanced Smog Check program do not increase by as much as the percent reduction benefits. As a result, the cost/effectiveness of the program under SB 1997 will eventually become less than the baseline program was in 1986. During the 1990s, when HC and NOx levels are reduced to an average of about 1.0 g/mi, the cost effectiveness of the program is projected to be about \$2.30 per pound of HC + NOx. This is still very competitive with other hydrocarbon and NOx control measures.

With additional program features, it will be possible to improve the effectiveness of the Smog Check program over the minimum performance targets of SB 1997. Through advanced diagnostic testing or loaded-mode testing, the percentage reduction in emissions from vehicles subject to the program could be in the range of 50% for HC and CO and 20% for NOx. Even with the additional cost of loaded-mode testing equipment (which may not be required), the cost/effectiveness of the program in the 1990s could improve to about \$1.60 per pound of HC plus NOx.

It should be noted that there is significant uncertainty associated with the forecasts of future Smog Check program cost/effectiveness made by Sierra. The key element of uncertainty is the future performance of advanced-technology vehicles in customer service. If such vehicles perform much better than vehicles produced during the early 1980s, the benefits of I/M may not be as great as projected.

Another significant uncertainty is future mechanic performance. Under this task, Sierra made assumptions about the expected performance of mechanics based on very limited survey data indicating that about 75% of Smog Check mechanics are capable of performing proper visual and functional checks. Despite evidence that only 30% of current mechanics understand closed-loop fuel metering systems, Sierra assumed that upgraded mechanic qualification requirements would result in 75% of failed vehicles being properly repaired. Real data on the performance of mechanics under BAR's expanded enforcement program and with greater qualification requirements are needed to evaluate the accuracy of the projections.

Finally, a more sophisticated approach to I/M modeling is desirable. Under this task, Sierra manually addressed the benefits of various program changes in isolation. A computer-based I/M model currently under development by Sierra should provide a superior means of estimating the benefits of alternative I/M programs in the future.

I/M Review Committee Support

A variety of support services were performed for the California I/M Review Committee during the course of the contract. Subtasks completed by Sierra included:

- editing of the Review Committee's omnibus I/M bill, originally drafted by Sierra under a previous contract;
- development of a series of "fact sheets" for use by the I/M Review Committee during the consideration of its omnibus I/M bill during the 1988 Legislative session;
- performance of a comprehensive evaluation of the Bureau of Automotive Repair Smog Check enforcement program;
- development of an implementation plan for a roadside emissions inspection program for heavy-duty trucks;
- preparation of a presentation and paper for I/M Review Committee Chairman Sommerville commenting on EPA's methodology for auditing and evaluating I/M programs; and
- preparation of the I/M Review Committee's 1989 report to the California Legislature.

The support provided by Sierra related to the Committee's I/M legislation (SB 1997) contributed to the enactment of the bill (Presley, Ch. 1544, Statutes of 1988) with relatively minor changes from its original form. Program enhancements required by the bill are currently being implemented. Sierra's evaluation of the BAR enforcement program identified several changes that BAR agreed would enhance the effectiveness of Smog Check program. The heavy-duty roadside emissions inspection program implementation plan prepared by Sierra is also being implemented at the present time. That program is expected to lead to reductions in the number of smoking trucks on California roadways.

Test Analyzer System Development Support

The Test Analyzer System (TAS) used in Smog Check stations is key to the effectiveness of California's decentralized I/M program. Introduced in 1984, the first version of the TAS provided computerized selection of standards, computer-controlled pass/fail decisions, computerized checking for exhaust system leaks, and automatic data recording for subsequent analysis. While this was a big improvement over the previously used analyzers, the 1984 version of the TAS provides very little in the way of diagnostic capability and very limited data storage capability. Greatly expanded capabilities were designed into a new "BAR'90" TAS specification developed by Sierra under a previous ARB contract.

Under this contract, Sierra provided additional support to ARB and BAR related to the completion of the BAR'90 detailed specifications. In addition to serving as a technical resource during BAR workshops, Sierra developed a detailed specification for a "Vehicle Information Data File" that will eventually be maintained within each BAR'90 analyzer. The vehicle information data file is designed to maximize

the effectiveness of the Smog Check program by reducing the frequency of improper vehicle descriptions, ensuring that all of the components subject to visual and functional inspections have been accurately identified, allowing manufacturer specifications for maximum idle speed to be used instead of some universally applicable upper limit, allowing model-specific exhaust dilution limits to be used, allowing model-specific emission standards to be used in the future, allowing recall campaign requirements to be identified at the Smog Check station and allowing Smog Check mechanics to confirm recall completion, and providing model-specific diagnostic tips to Smog Check mechanics.

Technology Assessment and Standards Development

Under a previous ARB contract, Sierra had principal responsibility for the preparation of a Technical Support Document entitled, "Proposed Test Procedure and Emission Standard Revisions for Medium- and Light-Heavy-Duty Trucks". Under this contract, Sierra assisted ARB staff with revisions to the TSD.

A major new effort completed under this contract was the preparation of a draft of a report to the Legislature (in response to Senate Concurrent Resolution 100) entitled "Progress Report on Reducing Public Exposure to Diesel Engine Emissions". That report summarizes ARB's past efforts in controlling Diesel emissions and outlines the Board's plan for further controls. The report also describes related programs being conducted by the California Energy Commission and the South Coast Air Quality Management District.

###

Section 2

INTRODUCTION

Under Contract No. A6-220-64, Sierra Research performed a variety of tasks for ARB and the California I/M Review Committee, most of which were related to the state's motor vehicle inspection and maintenance (I/M) program, called "Smog Check". The initial contract was executed on June 4, 1987 and consisted of three tasks:

- Task 1 - Evaluate Emissions Deterioration and Post-Inspection Tampering Associated With the Smog Check Program
- Task 2 - Smog Check Program Cost/Effectiveness Analysis
- Task 3 - I/M Review Committee Support

The budget for the contract was increased by 30% to cover three additional and related tasks that were added to the contract on August 29, 1988. Those tasks were:

- Task 4 - Smog Check Program Test Analyzer System Development Support
- Task 5 - Additional I/M Review Committee Support
- Task 6 - Technology Assessment and Standards Development

During the course of the contract, some of the services provided by Sierra consisted of technical consultation to ARB and the I/M Review Committee during a variety of private and public meetings. Examples of meetings in which Sierra participated include:

- routine public meetings of the I/M Review Committee;
- meetings involving the I/M Review Committee Chairman, ARB staff, and Senator Presley and his staff;
- meetings involving the I/M Review Committee Chairman, ARB staff, and the Automotive Service Councils of California;
- meetings involving the I/M Review Committee Chairman, ARB staff, and the California Highway Patrol;
- workshops between manufacturers of Test Analyzer Systems and the Bureau of Automotive Repair; and
- workshops involving ARB staff and automobile manufacturers.

The documents and reports produced by Sierra during the course of the contract included:

- a report entitled, "Evaluation of Bureau of Automotive Repair Smog Check Enforcement Program;"
- a series of "fact sheets" on the provisions of Senate Bill 1997;
- a report entitled, "Implementation Plan for a Roadside Emissions Inspection Program for Heavy-Duty Trucks;"
- a paper entitled, "Critique of EPA's Methods for Evaluating I/M Programs;"
- a report to the California Legislature entitled, "Evaluation of the California Smog Check Program, Second Report to the Legislature;" and
- a report to the California Legislature entitled, "Progress Report on Reducing Public Exposure to Diesel Engine Emissions."

All of the above-listed reports were reviewed by ARB staff and/or the I/M Review Committee and published in final form during the course of the contract. Copies of the above-listed documents are included in the Appendices A through F.

In addition to these reports, Sierra prepared two draft reports in response to Tasks 1 and 2:

- "Evaluation of Emissions Deterioration and Post-I/M Tampering in the California Smog Check Program;" and
- "Evaluation of the Cost/Effectiveness of the California Smog Check Program"

The final versions of these reports, incorporating ARB staff comments on the drafts, are contained in sections 3 and 4 of this report. Section 5 summarizes the work performed in support of the I/M Review Committee under Tasks 3 and 5. Section 6 summarizes the work performed under Task 4. Section 7 summarizes the work performed under Task 6.

###

Section 3

EVALUATION OF EMISSIONS DETERIORATION AND POST-I/M TAMPERING IN THE CALIFORNIA SMOG CHECK PROGRAM

The basic objective under Task 1 of the contract was to quantify the deterioration in emissions control that occurs following I/M repairs. The analysis required was designed to provide additional information on the deterioration of I/M benefits which occurs after I/M repairs. In support of the effort, ARB recaptured the "undercover" vehicles previously tested in the "I/M Evaluation Program" to obtain additional information on how their emissions are changing over time. Sierra's role was to analyze the new data and refine the estimates of post-I/M deterioration that were used in the I/M Review Committee's 1987 report to the Legislature. Post-I/M tampering was a specific element of the post-I/M deterioration phenomenon that was addressed.

As outlined below, the Task 1 analysis was divided into two parts: Recaptured Vehicle Analysis and Random Roadside and TAS Data Analysis.

Task 1a. Recaptured Vehicle Analysis

During 1985 and 1986, ARB procured and tested a large sample of about 800 vehicles which, based on screening tests, were expected to fail an inspection at a Smog Check Station. After baseline FTP tests at the ARB lab, the vehicles were taken to randomly selected Smog Check Stations by ARB employees posing as ordinary vehicle owners in need of a Certificate of Inspection. Many of the vehicles did not fail the Smog Check test, primarily due to improper visual and functional inspections by Smog Check Mechanics. About 500 vehicles which did fail were repaired at the Smog Check Station and returned to the ARB laboratory for another FTP test. These vehicles were designated as the "F-sample".

Following the second FTP test at ARB, the F-sample vehicles were returned to their owners. After a period of time in customer service, ARB recruited the vehicles again and ran additional FTP tests on those vehicles which could be recaptured. The recaptured vehicles were referred to as the "F-prime" (F') sample. Approximately 300 of the F-sample vehicles were recaptured and tested in time to be included in the analysis which was incorporated in the I/M Review Committee's report to the Legislature dated April, 1987.

There were significant limitations with the "after repair deterioration" data available for incorporation in the April 1987 report to the Legislature, particularly with respect to pre-1975 models. Only 73 pre-'75 models were recaptured and the indicated deterioration rates were highly variable. In addition, only 5,068

miles were accumulated on the average pre-'75 model since the Smog Check. For '75-'79 models, 115 vehicles were recaptured and for post-'79 models, 102 vehicles were recaptured. The average mileages accumulated since the Smog Check were 6,768 and 8,272 for the '75-'79s and the post-79s, respectively.

ARB has now recaptured the F' vehicles for further evaluation. Under Task 1, Sierra was required to analyze the data from these additional tests in conjunction with the data already available on the same vehicles.

The basic thrust of Sierra's analysis was to determine how emission changes were related to mileage accumulation since the initial Smog Check. To facilitate an understanding of the probable reasons for the observed emission changes, Sierra also reviewed the diagnostic information available on each retested vehicle and compared it to the previously recorded diagnostic inspection results. During this analysis, Sierra attempted to relate the observed emission changes to the type of repair performed on the vehicle at its last Smog Check. Sierra also determined whether any post-I/M repeat tampering occurred.

Because of the consistency observed between the recaptured vehicles and the deterioration assumptions built into the new I/M Model, the model was used to estimate the benefits of the baseline Smog Check program and the enhanced program being implemented under SB 1997.

Task 1b. Random Roadside and TAS Data Analysis

Task 1 of the scope of work also required Sierra to use Random Roadside, TAS data, and "other available sources" to estimate post-I/M tampering. As mentioned above, Sierra used the recaptured F-Sample vehicles as one of the "other" sources of information regarding post-I/M tampering.

Sierra also obtained TAS data for vehicles that were tested in the Random Roadside program. The analysis of the TAS and Random Roadside data accounted for the fact that most Smog Check mechanics do not properly identify tampering. As a result, a vehicle found tampered at the roadside may have also been tampered at the time of its last Smog Check even though no tampering was reported. To avoid this error of commission problem, Sierra computed the repeat tampering rate for vehicles that were identified as tampered during the previous Smog Check. Since only 70 such vehicles could be identified, District-to-District differences in post-I/M tampering could not be evaluated.

RECAPTURED VEHICLE ANALYSIS

Several analyses were conducted on undercover vehicles which had been recaptured and retested at a later time. Of the 855 undercover vehicles, the available database consisted of 291 vehicles which had been recaptured once and 142 vehicles which were recaptured and retested a second time. The time interval between initial and

recapture testing ranged from 3 months to 13 months for the first recapture and from 19 months to 32 months for the second recapture.

Regression Analysis

Linear regressions of FTP emissions vs. change in mileage since the vehicles first entered the undercover program were determined. The data consisted of 2 or 3 data points per vehicle corresponding to emissions (and mileage) after initial repair, and after subsequent recapture (once or twice). The sample was sub-divided by model year range (pre-75, 75-79 and post-79 models). However, the regression analysis was aborted after it was found the data contained too much scatter. Coefficients of determination (r^2) were typically below 0.1 (indicating virtually no correlation). The corresponding emission changes showed no significant correlation with the observed mileage increments. Inspection of the scatter plots indicated that non-linear regressions would suffer from this same problem.

Average Emission Changes

Table 1 shows the average emissions for all vehicles that were recaptured by the time the I/M Review Committee's 1987 report to the Legislature was published. As the table shows, there was some increase in emissions occurring for all three pollutants by the time an average of 6,869 miles had been accumulated in customer service after I/M. Table 2 shows the same basic information for all of the vehicles that have now been recaptured twice. By comparing Tables 1 and 2, it can be seen that only 134 vehicles were recaptured twice, compared to 290 that were recaptured only once. It is also apparent that the average odometer reading since the Smog Check has increased by over 20,000 miles.

Figure 10 shows how the vehicles recaptured a second time compare to those recaptured once by the time the 1987 report to the Legislature was published. As the figure shows, the initial emission reduction associated with the Smog Check and the change in emissions from before Smog Check to the time of the first recapture were similar.

Tables 3 and 4 show average emission changes for vehicles that had tampering identified by the Smog Check station and for vehicles where no tampering was identified. The data shown are only for vehicles that were recaptured twice. The overall results listed in these tables and from Table 2 are summarized in Figures 11, 12, and 13.

As shown in Figure 11, the immediate hydrocarbon emission reduction of 31.7% dropped to 26.4% after the first recapture and 21.7% after the second recapture. From Table 2 it can be seen that the first recapture occurred at an average of 7,091 miles after the Smog Check. The second recapture occurred 20,984 miles after the Smog Check. Since some deterioration in emissions would be expected with

Table 1

Changes in Emissions by Model Year Group
for All Vehicles Recaptured at Least Once
From 1987 Report to Legislature

	<u>Pre-1975</u>	<u>75-79</u>	<u>Post-1979</u>	<u>All</u>
<u>HC Emissions (g/mi)</u>				
before I/M	10.29	4.61	2.08	5.15
after repair	5.97	3.03	1.37	3.19
deteriorated	7.66	3.59	1.34	3.82
% Emission Changes				
initial	-42.0%	-34.3%	-34.1%	-38.1%
deteriorated	-25.6%	-22.1%	-35.6%	-25.8%
.....				
<u>CO Emissions (g/mi)</u>				
before I/M	72.01	48.29	34.41	49.38
after repair	63.04	39.18	21.83	39.08
deteriorated	65.83	40.36	21.59	40.17
% Emission Changes				
initial	-12.5%	-18.9%	-36.6%	-20.9%
deteriorated	- 8.6%	-16.4%	-37.3%	-18.7%
.....				
<u>NOx Emissions (g/mi)</u>				
before I/M	3.33	2.77	1.22	2.36
after repair	3.07	2.39	1.15	2.12
deteriorated	2.83	2.50	1.26	2.15
% Emission Changes				
initial	- 7.8%	-13.7%	- 5.7%	-10.2%
deteriorated	-15.0%	- 9.8%	+ 3.3%	- 8.9%
.....				
Mean Mileages				
baseline	103,359	86,228	50,875	78,106
deteriorated	108,427	92,996	59,147	84,975
Δ Mileage	5,068	6,768	8,272	6,869
Sample Size	73	115	102	290

Table 2

Changes in Emissions by Model Year Group
for All Vehicles Recaptured Twice

	<u>Pre-1975</u>	<u>75-79</u>	<u>Post-1979</u>	<u>All</u>
<u>HC Emissions (g/mi):</u>				
before I/M	9.69	3.73	1.83	3.82
after repair	5.71	2.70	1.42	2.61
after recapture 1	6.67	2.99	1.26	2.81
after recapture 2	7.86	2.86	1.38	2.99
* Emission Changes:				
initial	-41.1%	-27.6%	-22.4%	-31.7%
after recapture 1	-31.2%	-19.8%	-31.2%	-26.4%
after recapture 2	-18.9%	-23.3%	-24.6%	-21.7%
.....				
<u>CO Emissions (g/mi):</u>				
before I/M	87.13	42.41	31.55	44.63
after repair	63.62	34.22	21.75	33.33
after recapture 1	64.07	35.25	19.86	32.99
after recapture 2	77.71	37.40	25.17	38.33
* Emission Changes:				
initial	-27.0%	-19.3%	-31.1%	-25.3%
after recapture 1	-26.5%	-16.9%	-37.1%	-26.1%
after recapture 2	-10.8%	-11.8%	-20.2%	-14.1%
.....				
<u>NOx Emissions (g/mi):</u>				
before I/M	3.37	2.65	1.19	2.12
after repair	3.22	2.36	1.05	1.92
after recapture 1	3.01	2.49	1.14	1.98
after recapture 2	2.35	2.29	1.28	1.85
* Emission Changes:				
initial	- 4.5%	-10.9%	-11.8%	- 9.4%
after recapture 1	-10.7%	- 6.0%	- 4.2%	- 6.6%
after recapture 2	-30.3%	-13.6%	- 7.6%	-12.7%
.....				
<u>Mean Mileages:</u>				
baseline	95,010	82,036	49,848	69,897
after recapture 1	100,623	88,579	57,968	76,989
after recapture 2	108,079	100,852	75,635	90,882
.....				
Δ Mileage (Base-R1)	5,613	6,543	8,120	7,091
Δ Mileage (Base-R2)	13,069	18,816	25,787	20,984
.....				
Sample Size	21	54	59	134

Note: Average time to 1st recapture was 9.3 months
Average time to 2nd recapture was 28.6 months

Table 3
Changes in Emissions by Model Year Group
For Vehicles With Identified Tampering
(Immediate and Deteriorated After Recapture)

	<u>Pre-1975</u>	<u>75-79</u>	<u>Post-1979</u>	<u>All</u>
<u>HC Emissions (g/mi)</u>				
before I/M	8.23	2.33	1.25	3.49
after repair	3.71	1.97	0.84	2.08
after recapture 1	6.46	2.50	0.88	3.03
after recapture 2	9.95	2.40	0.99	3.89
* Emission Changes				
initial	-54.9%	-15.5%	-32.8%	-40.4%
after recapture 1	-21.5%	+ 7.3%	-29.6%	-13.2%
after recapture 2	+20.9%	+ 3.0%	-20.8%	+11.5%
.....				
<u>CO Emissions (g/mi)</u>				
before I/M	110.76	24.33	16.56	43.72
after repair	66.14	23.68	10.60	30.56
after recapture 1	69.58	24.08	10.68	31.62
after recapture 2	78.98	23.21	10.34	33.48
* Emission Changes				
initial	-40.3%	- 2.7%	-36.0%	-30.1%
after recapture 1	-37.2%	- 1.0%	-35.5%	-27.7%
after recapture 2	-28.7%	- 4.6%	-37.6%	-23.4%
.....				
<u>NOx Emissions (g/mi)</u>				
before I/M	2.93	2.14	1.73	2.72
after repair	2.90	1.52	1.06	2.08
after recapture 1	2.51	1.47	1.03	2.18
after recapture 2	2.33	1.96	1.26	1.85
* Emission Changes				
initial	- 1.0%	-29.0%	-38.7%	-23.5%
after recapture 1	-14.3%	-31.3%	-40.5%	-19.9%
after recapture 2	-20.5%	- 8.4%	-27.2%	-32.0%
.....				
<u>Mean Mileages</u>				
baseline	102,145	82,779	39,172	75,161
after recapture 1	110,106	89,279	46,228	82,186
after recapture 2	115,141	101,964	60,045	93,281
Δ Mileage (Base-R1)	7,962	6,500	7,056	7,024
Δ Mileage (Base-R2)	12,996	19,185	20,873	18,119
.....				
Sample Size	7	13	8	28

Note: Average time to 1st recapture was 9.1 months
Average time to 2nd recapture was 28.0 months

Table 4
 Changes in Emissions by Model Year Group
 For Vehicles With No Tampering Identified
 (Immediate and Deteriorated After Recapture)

	<u>Pre-1975</u>	<u>75-79</u>	<u>Post-1979</u>	<u>All</u>
<u>HC Emissions (g/mi)</u>				
before I/M	10.41	4.17	1.92	3.91
after repair	6.71	2.93	1.51	2.75
after recapture 1	6.78	3.15	1.32	2.75
after recapture 2	6.81	3.00	1.45	2.76
* Emission Changes				
initial	-35.5%	-29.7%	-21.4%	-29.7%
after recapture 1	-34.9%	-24.5%	-31.3%	-29.7%
after recapture 2	-34.6%	-28.1%	-24.5%	-29.4%
.....				
<u>CO Emissions (g/mi)</u>				
before I/M	75.31	48.14	33.90	44.88
after repair	62.35	37.56	23.50	34.07
after recapture 1	61.32	38.79	21.31	33.35
after recapture 2	77.08	41.90	27.50	39.62
* Emission Changes				
initial	-17.2%	-22.0%	-30.7%	-24.1%
after recapture 1	-18.6%	-19.4%	-37.1%	-25.7%
after recapture 2	+ 2.4%	-13.0%	-18.9%	-11.7%
.....				
<u>NOx Emissions (g/mi)</u>				
before I/M	3.58	2.47	1.10	1.96
after repair	3.37	2.93	1.05	1.87
after recapture 1	3.26	2.41	1.16	1.92
after recapture 2	2.36	2.40	1.28	1.85
* Emission Changes				
initial	- 5.9%	+18.6%	- 4.5%	- 4.6%
after recapture 1	- 8.9%	- 2.4%	+ 5.5%	- 2.0%
after recapture 2	-34.1%	- 2.8%	+16.4%	- 5.6%
.....				
<u>Mean Mileages</u>				
baseline	91,442	81,801	51,523	68,507
after recapture 1	95,881	98,357	59,809	75,616
after recapture 2	104,548	100,500	78,080	90,247
.....				
Δ Mileage (Base-R1)	4,439	6,556	8,286	7,109
Δ Mileage (Base-R2)	13,105	18,698	26,557	21,741
.....				
Sample Size	14	41	51	106

Note: Average time to 1st recapture was 9.4 months
 Average time to 2nd recapture was 28.9 months

Figure 10

**Comparison of Emission Changes
After Initial Repair and First Recapture
for Vehicles Recaptured Once and Twice**

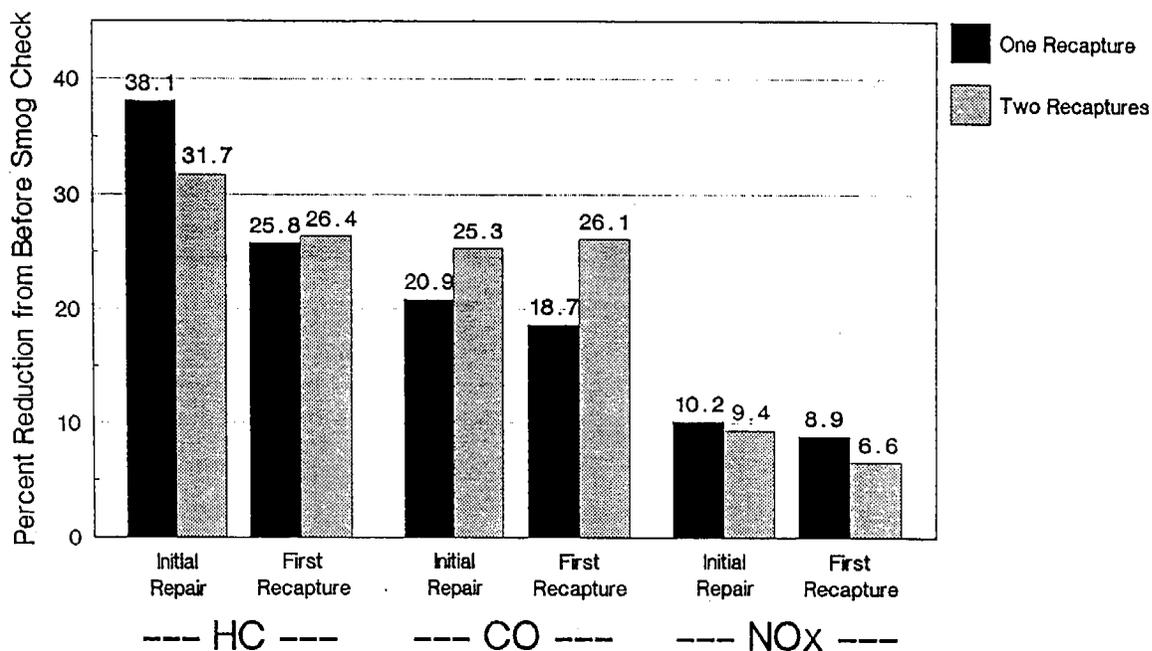


Figure 11

**Reduction in Emissions
for All Recaptured Vehicles
(Immediate and Deteriorated)**

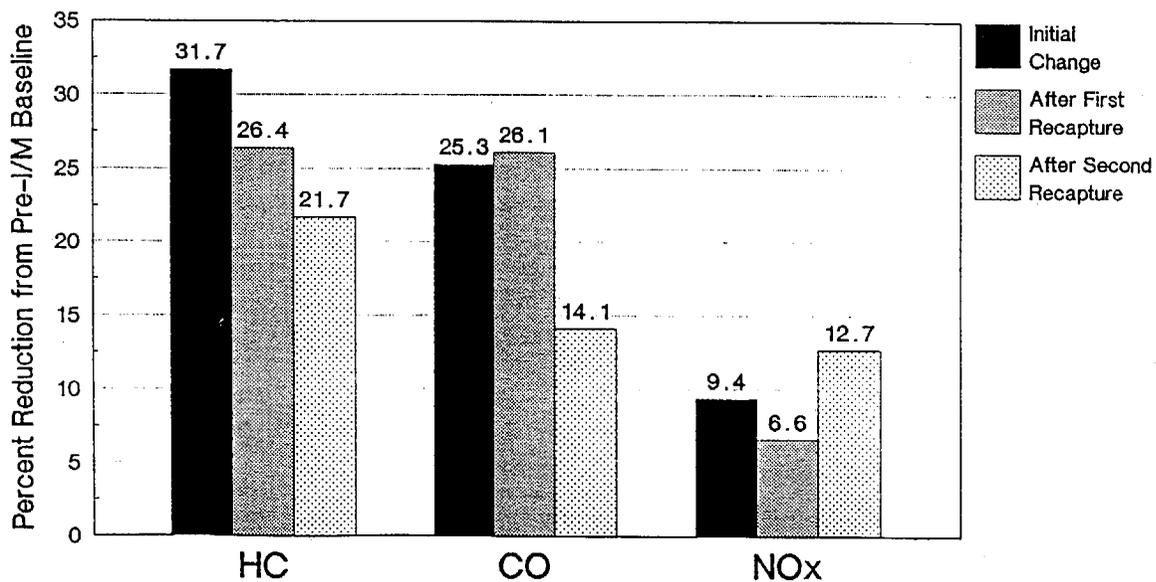


Figure 12

Reduction in Emissions for Vehicles With Corrected Tampering (Immediate and Deteriorated)

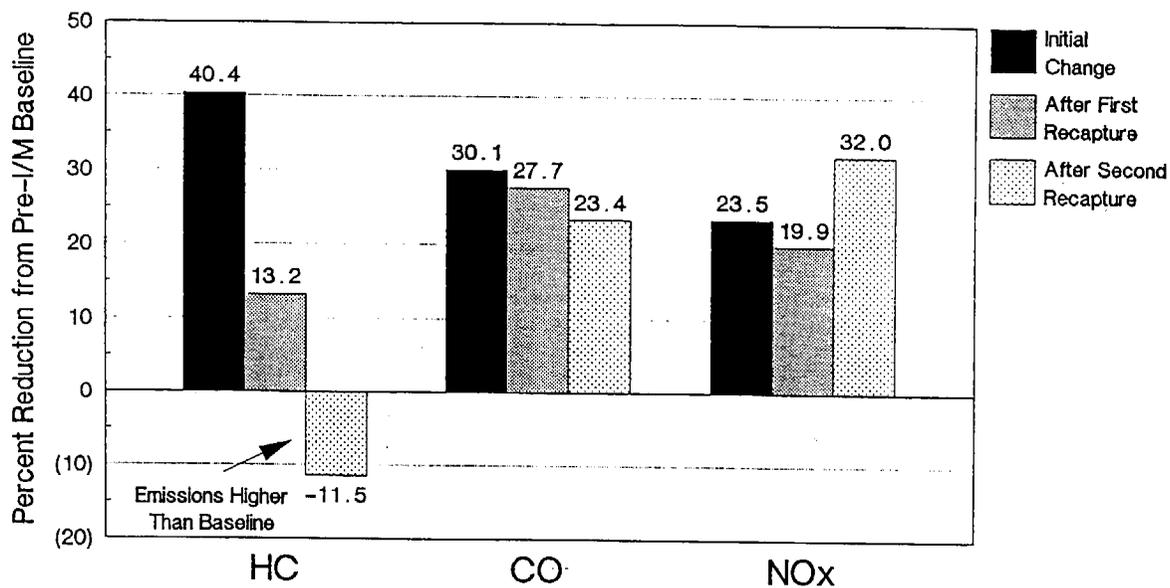
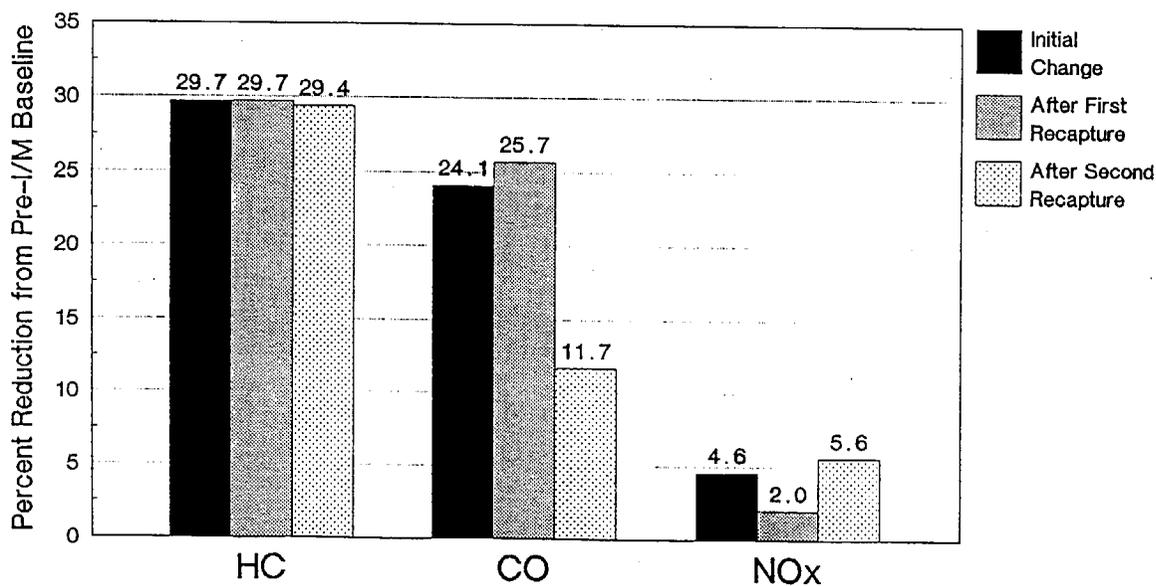


Figure 13

Reduction in Emissions for Vehicles Without Tampering Detected (Immediate and Deteriorated)



increasing mileage, it appears that more than two-thirds of the initial HC emission reductions were maintained for an extended period of time. (The amount of deterioration that would have been expected in the absence of I/M is addressed later.)

Figure 11 also shows that the immediate carbon monoxide emission reduction of 25.3% increased slightly to 26.1% after the first recapture and then decreased to 14.1% after the second recapture. NOx emission trends after recapture were more erratic. The immediate decrease of 9.4% dropped to 6.6% after the first recapture and then rose to 12.7% after the second recapture.

Figure 12 shows the same trends for vehicles that had tampering corrected at the Smog Check station. These vehicles represented 21% of the sample. The initial emission reductions were greater for these vehicles. However, HC emission reductions had decreased substantially by the first recapture and had been eliminated by the second recapture. CO reductions held up quite well. NOx emission reduction trends upon recapture were erratic.

Figure 13 indicates that the immediate HC and CO emission reductions observed for non-tampered vehicles (79% of the sample) were similar to the average for all of the vehicles, and they held up very well upon the first recapture. HC emission reductions also held up upon the second recapture. NOx emission changes were not significant.

Repair and Deterioration Plots

Figures 14 through 22 compare undercover car repair and deterioration to the "No-I/M" emission factors that Sierra recently developed for the new I/M model being developed for ARB under a separate contract. I/M Model deterioration shown in the figures is based on model year-specific emission factors which were weighted together by the model year fractions for each model year range of the recaptured undercover vehicles (the 134 element sample in Tables 2, 3, and 4). It should be noted that undercover vehicles are I/M fail vehicles, I/M model deterioration is for the fleet.

The emissions of vehicles that had tampering corrected during the Smog Check repair are shown by the dashed lines. The emissions of vehicles that did not have any correction of tampering are represented by the dotted lines. All vehicles combined are shown by "chain dashed" lines (a combination of dots and dashes). The lowest mileage points for each line show the immediate effect of Smog Check station repairs on emissions. The next two points show how emissions changed as mileage was accumulated.

Figure 14

Undercover Car HC Emission Trends Compared to Average Non-I/M Vehicle (1980 and Later Models)

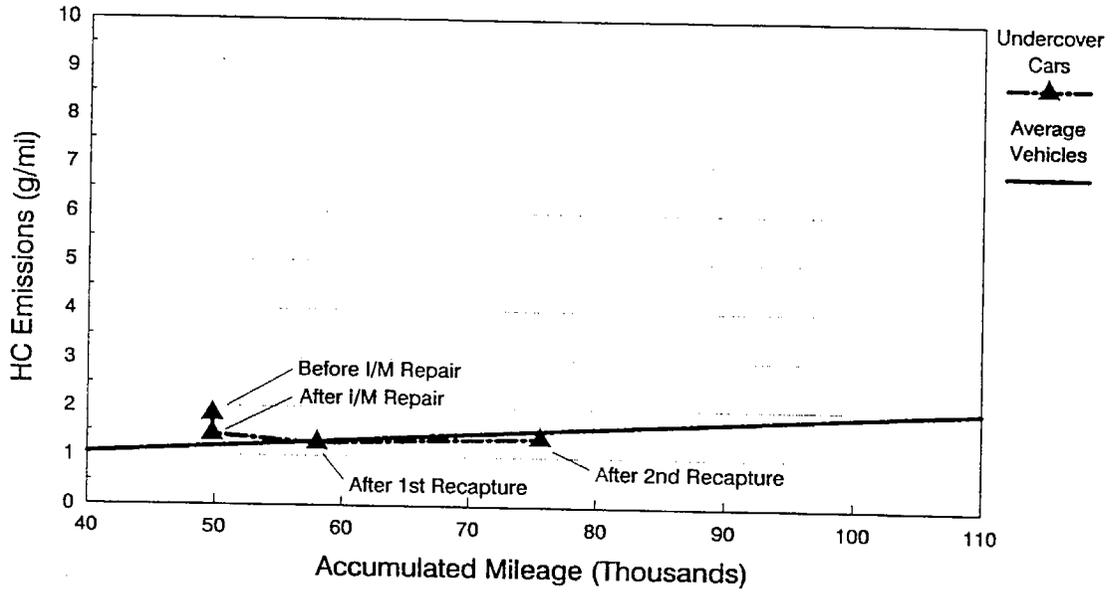


Figure 15

Undercover Car CO Emission Trends Compared to Average Non-I/M Vehicle (1980 and Later Models)

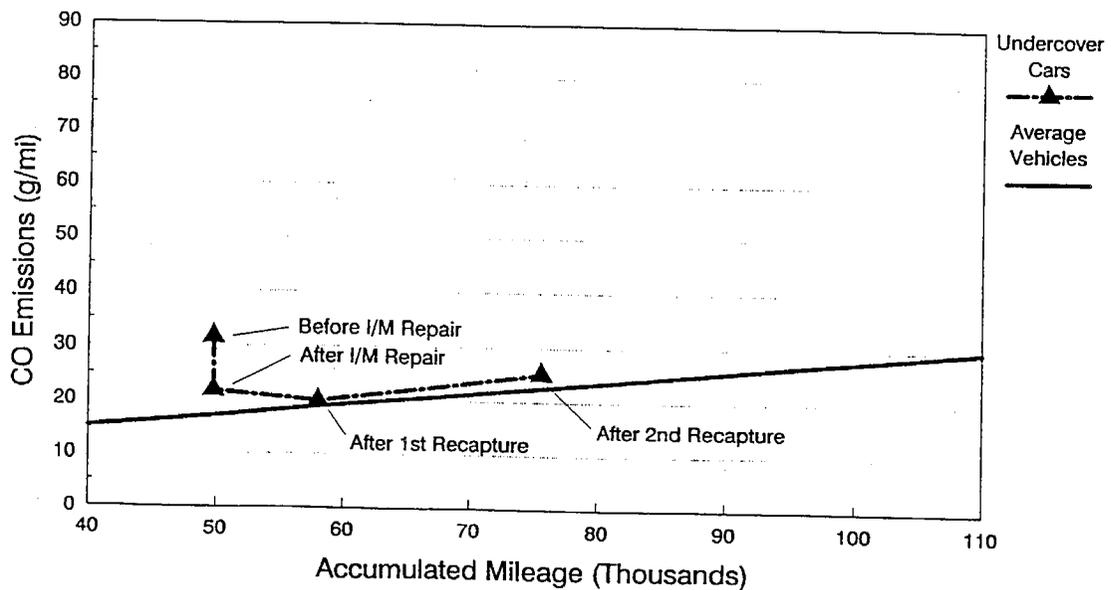


Figure 16
**Undercover Car NOx Emission Trends
 Compared to Average Non-I/M Vehicle
 (1980 and Later Models)**

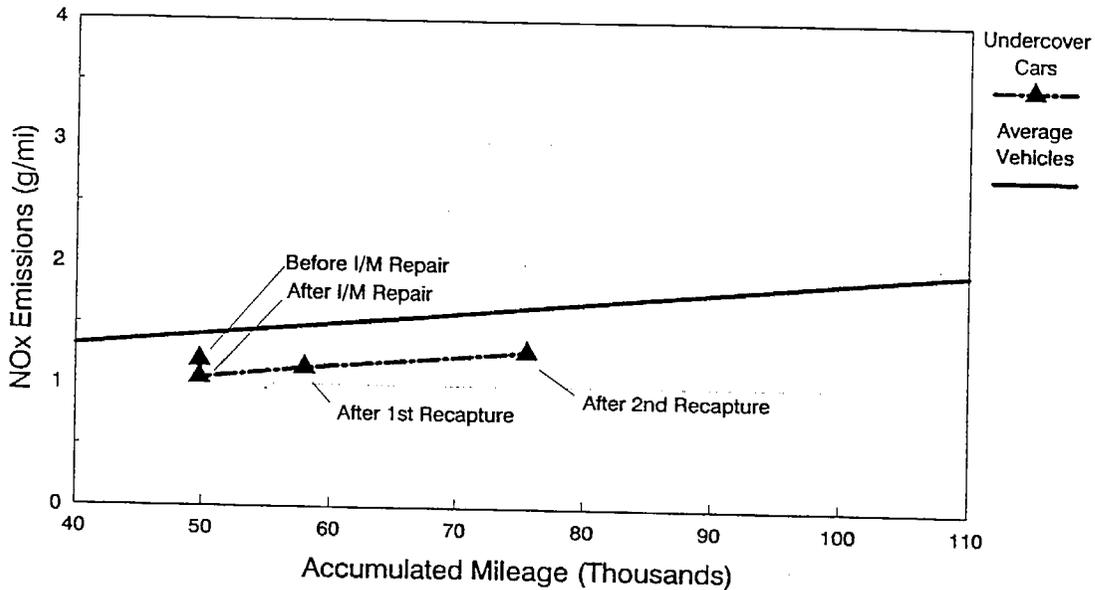


Figure 17
**Undercover Car HC Emission Trends
 Compared to Average Non-I/M Vehicle
 (Pre-1975 Models)**

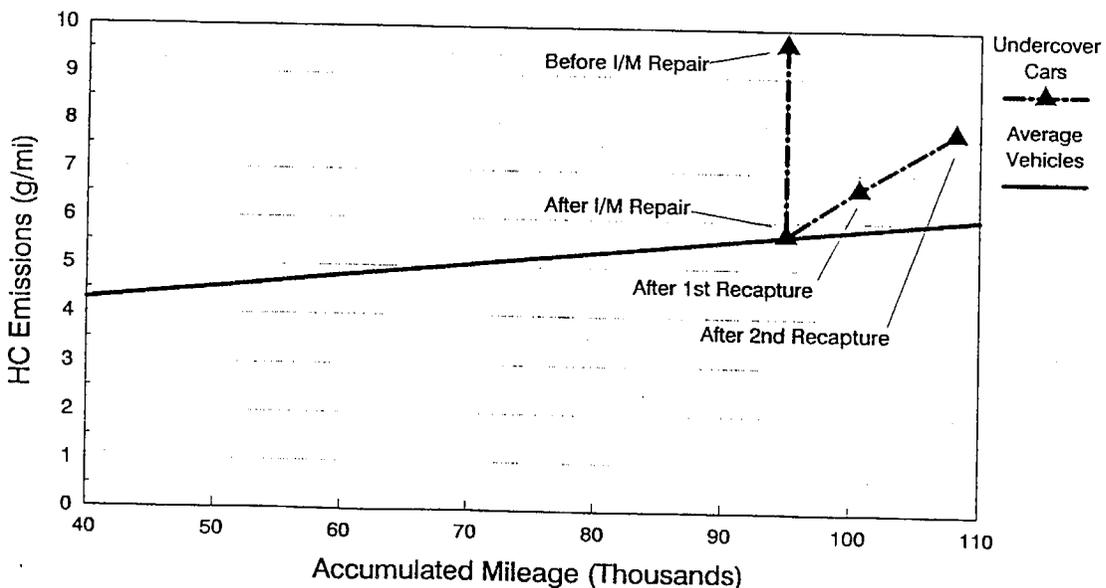


Figure 18

Undercover Car CO Emission Trends Compared to Average Non-I/M Vehicle (Pre-1975 Models)

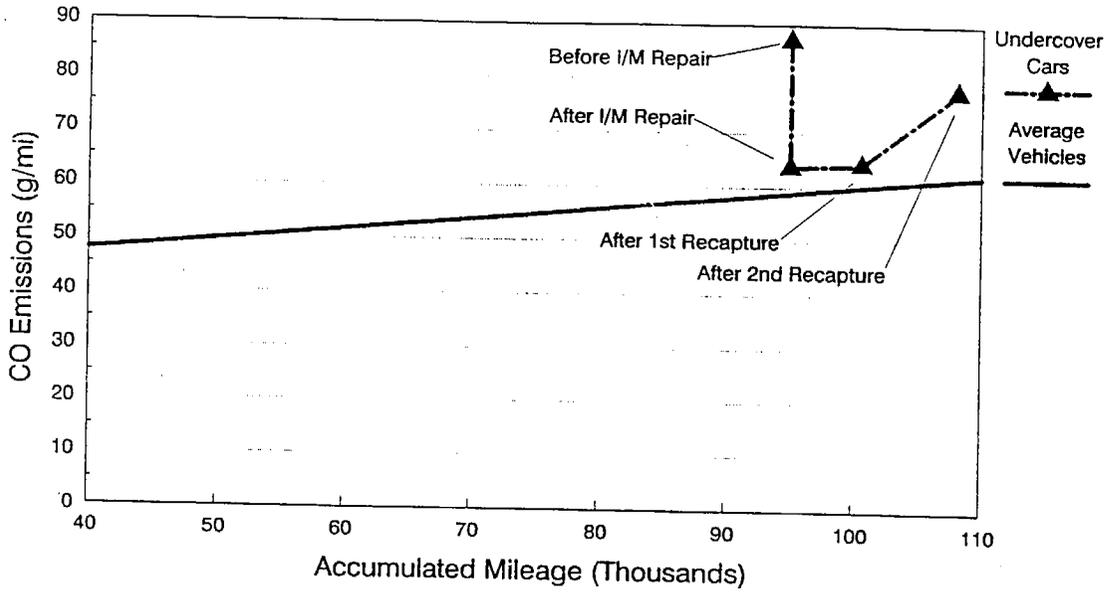


Figure 19

Undercover Car NOx Emission Trends Compared to Average Non-I/M Vehicle (Pre-1975 Models)

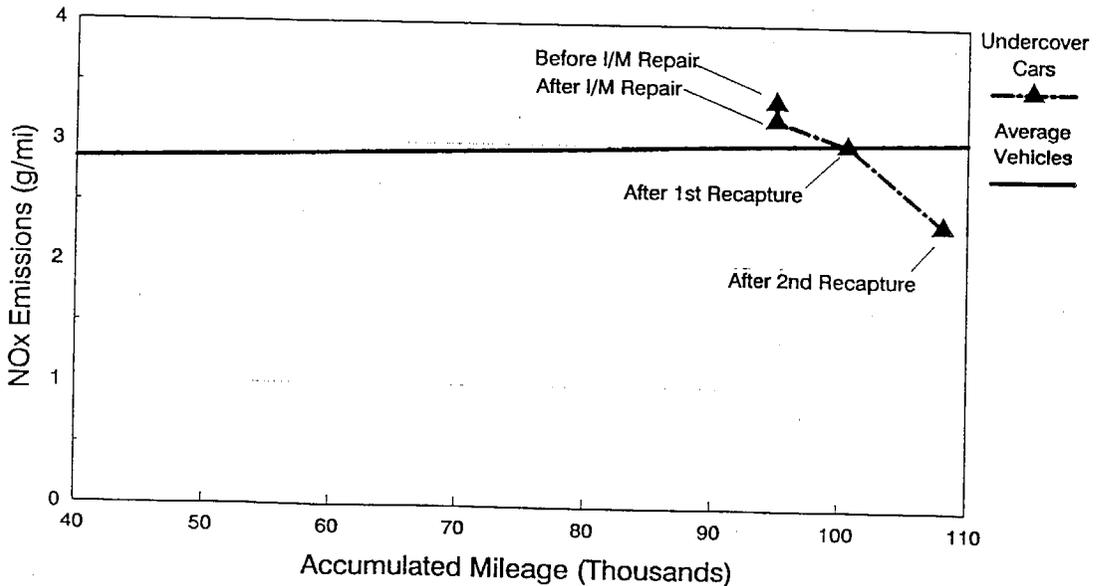


Figure 20

Undercover Car HC Emission Trends Compared to Average Non-I/M Vehicle (1975-79 Models)

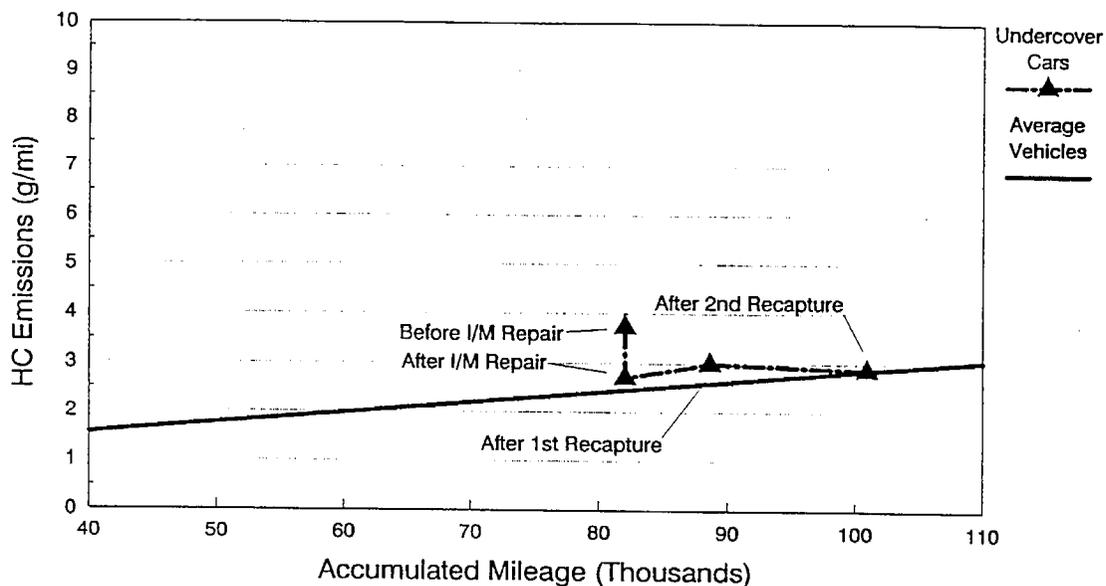


Figure 21

Undercover Car CO Emission Trends Compared to Average Non-I/M Vehicle (1975-79 Models)

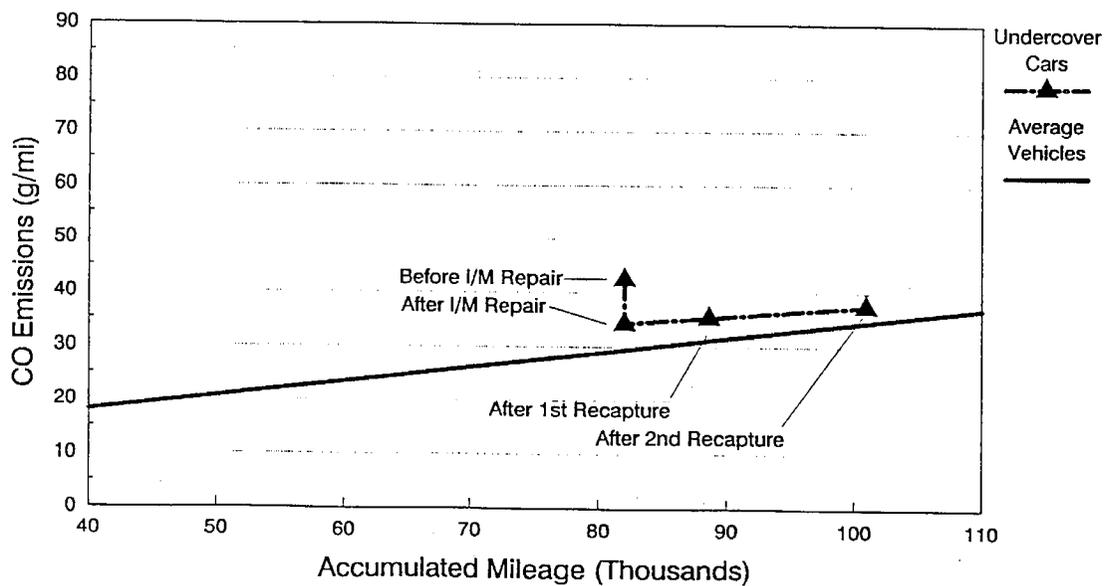
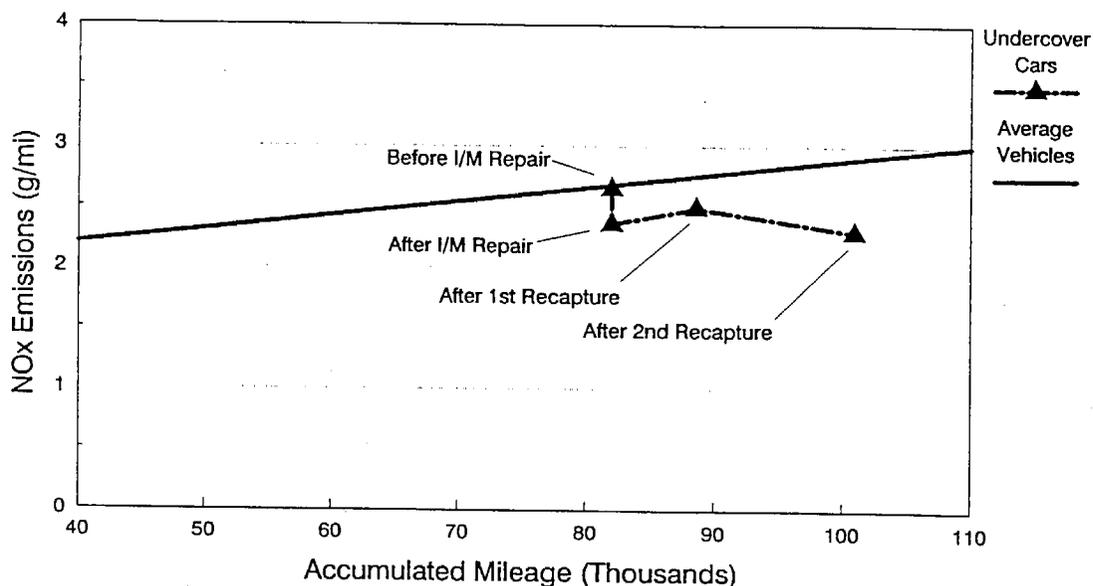


Figure 22

Undercover Car NOx Emission Trends Compared to Average Non-I/M Vehicle (1975-79 Models)



As can be seen from the figures, the following relationships are apparent:

HC and CO Trends

- ⊙ Hydrocarbon and carbon monoxide emissions for the recaptured vehicles before I/M are higher than the no-I/M fleet average (as would be expected for failed vehicles).
- ⊙ As a result of I/M repairs, HC and CO emissions immediately drop to about the level of the no-I/M fleet average. (With higher quality repairs and/or a higher repair cost ceiling, a greater reduction in emissions would be expected.)
- ⊙ Following I/M repairs, the HC and CO emissions of the recaptured vehicles increase. For 1975 and later models, the rate of deterioration is very similar to the rate of deterioration for the no-I/M fleet. For 1974 and older models, the deterioration rate is higher.

- There was usually no significant difference in the rate of emissions deterioration for vehicles that had tampering corrected and those which did not (except for the HC deterioration on pre-'75 tampered vehicles).

NOx Trends

- NOx emissions for the recaptured vehicles before I/M are about the same as the no-I/M fleet average (as might be expected for a program where vehicles are not failed based on NOx emission measurements and where the visual and functional inspection is often not performed correctly).
- As a result of I/M repairs, NOx emissions drop slightly.
- Following I/M repairs, there is no significant change in NOx emissions for 1975 and later model vehicles. This lack of deterioration is very similar to the NOx vs. mileage characteristics for the no-I/M fleet. For 1974 and older models, NOx emissions decrease significantly as mileage is accumulated.

Repair Effectiveness

Sierra also attempted to relate the post-I/M deterioration with the type of repair that was performed at the Smog Check station. The attempt at this analysis involved the use of the diagnostic comments field in the test record for each undercover car. However, this effort was only marginally successful. The main problem was lack of information on what happened to the vehicle at the Smog Check station. On about 54% of the vehicles, there was little or no indication of what happened (or didn't happen) at the Smog Check station. For example, sometimes there was no diagnostic comment at all for the after-repair test at ARB. On other occasions, the comment might indicate "possible carburetor adjustment" but the before-repair comment would say nothing other than "idle HC high." In these circumstances, Sierra did not believe it was possible to clearly identify what was wrong with the vehicle initially and what type of repair it received.

For about 27% of the vehicles, the diagnostic comments indicated that repairs were attempted that did not address the problem(s) identified in the before-repair diagnosis. For example, the before-repair diagnostic comments might indicate "vacuum line leaking" and the after-repair comments might indicate "possible carburetor adjustment."

Based on the diagnostic comments, about 7% of the vehicles appeared to receive no repair. In these cases some defect might have been identified during the before-repair inspection by ARB and the after-repair comment might say "defect still exists."

The remaining 12% of the vehicles appeared to have received repair of a specific, defective component. After deleting five unique problems that were identified and corrected, there were only 28 vehicles left to analyze. The results for these vehicle were segregated into five major repair categories: misfire correction, air/fuel adjustment, vacuum leak correction, oxygen sensor replacement, and air injection repair.) Table 5 summarizes the results.

As the table shows, each of the five specifically identified types of repairs was highly effective in reducing hydrocarbon emissions. Except for air/fuel mixture adjustment, the benefits of these repairs seemed to be holding up well at the first recapture. Except for the repair of vacuum leaks, each of the five repairs was also effective in reducing CO emissions. (CO benefits would not be expected for the repair of vacuum leaks because the enleanment caused by the leak would tend to reduce CO levels.) As in the case of HC, the benefits of the repairs on CO seem to hold up well at the first recapture.

The effects of the five different repair actions on NOx emissions were mixed. Oxygen sensor repair tended to increase NOx, indicating that most of the oxygen sensor failures were of the fail-rich type. As expected, the correction of vacuum leaks reduced NOx emissions. The NOx reduction observed for idle air/fuel mixture adjustment is inexplicable. The increase in NOx associated with misfire correction is also curious, but may be the result of leaner operation under high load conditions (by avoiding power enrichment that may have been required under misfiring conditions).

The emissions reductions for the five specifically identified repair actions are generally larger than those shown for average F-sample vehicle (see Table 1); however, it is clear that many vehicles for which the repair action could not be identified also experienced emission reductions as a result of repairs at the Smog Check station.

POST-I/M TAMPERING ANALYSIS

One approach that Sierra used to determine the extent to which repeat tampering occurs was to obtain Test Analyzer System records for vehicles that had been tested in the Random Roadside program. However, it was recognized that the analysis of the TAS and Random Roadside data accounted for the fact that most Smog Check mechanics do not properly identify tampering. As a result, a vehicle found tampered at the roadside may have also been tampered at the time of its last Smog Check even though no tampering was reported. To avoid this "error of commission" problem, Sierra decided to compute the repeat tampering rate for vehicles that were identified as tampered during the previous Smog Check.

Table 5

Emissions Changes Due to Specific Repair Actions

<u>Type of Repair</u>	<u>Sample Size</u>	<u>Pollutant</u>	----- Grams/Mile ----- (Percent Change from Baseline)		
			<u>Baseline</u>	<u>After- Repair</u>	<u>After 1st Recapture</u>
Oxygen Sensor	6	HC	3.09	0.93 (-69.9%)	1.19 (-61.5%)
		CO	79.78	17.69 (-77.8%)	19.48 (-75.6%)
		NOx	0.53	0.68 (+28.3%)	0.66 (+24.5%)
Vacuum Leak	11	HC	7.71	4.37 (-43.3%)	4.72 (-38.8%)
		CO	50.72	53.13 (+4.7%)	48.49 (-4.4%)
		NOx	2.71	2.45 (-9.6%)	2.54 (-6.3%)
Misfire Correction	2	HC	14.26	4.35 (-69.5%)	3.21 (-77.5%)
		CO	46.44	37.19 (-19.9%)	40.17 (-13.5%)
		NOx	3.70	4.16 (+12.4%)	3.48 (+5.9%)
A/F Mixture	7	HC	5.98	3.54 (-40.8%)	5.39 (-9.9%)
		CO	32.57	25.02 (-23.2%)	47.18 (+44.9%)
		NOx	1.98	1.77 (-10.6%)	1.28 (-35.4%)
Air Injection	2	HC	4.11	0.88 (-78.6%)	1.21 (-70.6%)
		CO	112.17	21.73 (-80.6%)	26.98 (-75.9%)
		NOx	2.74	2.85 (+4.0%)	2.69 (-1.8%)

At Sierra's request, the Bureau of Automotive Repair searched the entire TAS data base for the state in an attempt to locate Smog Check station records for the several thousand vehicles that were captured during the Random Roadside Inspections performed during 1985 and 1986. Only 70 vehicles could be identified that had previously failed the underhood inspection at a Smog Check station.

Table 6 shows repeat tampering percentages by component for 1985 and 1986 random roadside vehicles which had failed a prior TAS underhood inspection. The table also shows repeat tampering percentages for the last recapture of the 290 undercover cars that were recaptured at least once by ARB. Considering the small sample size, the results are reasonably consistent. Repeat tampering rates for individual components range all the way from 0 to 67%; however, where the sample size is the largest, the repeat tampering rate is close to 20%. The sample size-weighted average repeat tampering rate that can be computed from Table 6 is 24.4%.

Table 6
Repeat Tampering Percentages by Component
For Random Roadside and Recaptured Undercover Vehicles

	Repeat Failure Rate and Sample Size by Type of Device								
	<u>AIR</u>	<u>CAT</u>	<u>SPARK</u>	<u>EVAP</u>	<u>EGR</u>	<u>FILL</u>	<u>O2S</u>	<u>PCV</u>	<u>TAC</u>
Random Roadside Vehicles	20.0	25.0	33.3	44.4	56.0	66.7	0.0	57.1	34.5
Sample Size	10	4	6	9	6	3	0	7	29
.....									
Recaptured Undercover Cars	21.1	0.0	28.6	0.0	21.5	50.0	0.0	13.3	16.1
Sample Size	19	2	14	8	135	2	1	15	31

Legend: AIR = air injection
 CAT = catalytic converter
 SPARK = spark advance controls
 EVAP = evaporative emissions controls
 EGR = exhaust gas recirculation
 FILL = fillpipe lead restrictor
 O2S = exhaust oxygen sensor
 PCV = positive crankcase ventilation system
 TAC = thermostatic air cleaner

In addition*to the 70 identified vehicles that previously failed an underhood inspection, BAR was able to locate TAS test records for 1,006 vehicles captured in the Random Roadside Inspection program that did not fail an underhood inspection. These vehicles were combined with the 70 underhood failures for an analysis of changes in idle CO emissions from Smog Check-to-Random Roadside. For vehicles with adjustable carburetors (most pre-'80 models), this type of analysis might be expected to shed some light on post-I/M tampering related to significant changes in carburetor adjustment. (Sierra did not investigate changes in idle HC emissions because CO concentrations are a much better indicator of idle air/fuel ratio.) As shown in Table 7, 26.9% of the pre-'80 vehicles captured in the Random Roadside program had idle CO emissions that were more than 1.0% higher than measured during the last Smog Check test on the vehicle. 14.2% of the vehicles had idle CO emissions that were more than 1.0% lower. Since some deterioration in CO emissions performance would be expected with increasing mileage accumulation, and if at least as many significant CO increases are assumed to be unrelated to "tampering" as the number of significant CO emission reductions that occur, the maximum rate of post-I/M tampering with idle air/fuel ratio adjustments appears to be less than 12.7%, based on this analytical technique.

Table 7

Changes in Idle CO Concentration
Between Smog Check Test and Random Roadside Inspection

	Sample Size	>1.0% Lower	≤1.0% Change	>1.0% Higher
Pre-'75 Models	278	21.9%	45.0%	33.1%
1975-1979 Models	384	8.6%	69.0%	22.4%
Pre-'80 Models	662	14.2%	58.9%	26.9%
Post-'79 Models	414	1.7%	92.0%	6.3%

ESTIMATION OF SMOG CHECK PROGRAM BENEFITS

As shown above, when the recaptured vehicle data are compared to the average of the entire motor vehicle fleet with no I/M program, there are substantial similarities. The initial "post-I/M" emission levels and the rate of deterioration for the failed and recaptured vehicles are very similar to the average emissions and rate of deterioration for the entire motor vehicle fleet. This indicates that vehicles that fail I/M and are then repaired, subsequently perform much like non-I/M vehicles with the same average emission levels. This is precisely the deterioration algorithm Sierra used in the new I/M model; i.e., future

deterioration characteristics are estimated to be a function of current emissions level, regardless of prior vehicle history. The one category where the recaptured vehicle data are inconsistent with the assumptions built into the model is for 1974 and earlier model year vehicles. Based on a very limited sample of recaptured vehicle data (21 vehicles), it appears that the post-I/M deterioration rate is significantly higher for repaired vehicles.

Table 8 shows how the emission benefits for the Smog Check program computed from the new I/M model compare to the manually calculated benefits used in the 1987 report to the Legislature from the California I/M Review Committee. Except for NOx emissions, the benefits predicted by the I/M model correspond reasonably well with the benefits calculated manually. The correlation between the predictions is not surprising given the fact that similar deterioration assumptions were used in Sierra's manual calculation of benefits. Had Sierra assumed the post-I/M deterioration for pre-1975 models to be as large as observed for the recaptured vehicles, our manual calculation of the benefits of the program would have been about 1% lower for HC and CO.

Table 8

Comparison of Predicted Benefits: Baseline Program

	--- Pollutant ---		
	<u>HC</u>	<u>CO</u>	<u>NOx</u>
I/M Model	10.6%	11.8%	0.0%
Manual Calculation	12.3	9.8	3.9

The discrepancy in NOx emissions benefits is a result of the I/M modeling approach in which each pollutant was analyzed separately. As explained in Sierra's report on the development of the I/M model, the lack of NOx benefits predicted is due to the inability of the idle test to detect NOx emission failures and the low degree of mechanic accuracy in identifying the NOx-related component defects through the visual/functional check. During the earlier analysis of the I/M Evaluation Program data, it was determined that 20% of the excess NOx emissions are identified "by accident" because some vehicles with high HC and CO emissions also have high NOx emissions. Because each pollutant was modeled separately, the "accidental" detection and correction of excess emissions of pollutants other than the one for which the analysis was being conducted is not addressed in the I/M model.

It should be noted that the benefit estimates manually calculated for the 1987 report to the Legislature were computed for one complete I/M cycle (about mid-1986). However, the deterioration characteristics of repaired vehicles appear to be such that benefits become compounded over time. Using the new I/M model, the Smog Check program benefits in 1988 are increased to about 16% for hydrocarbons and 18% for carbon monoxide. Reductions from the program are projected to peak around 1990, with approximately a 17% reduction in HC and a 18% reduction in CO, and then level off about 2012 with reductions of 17% HC and 11% CO. However, substantial changes to the program are anticipated to occur in the near future. Under Senate Bill 1997, repair cost ceilings are being increased and several measures are being incorporated to increase mechanic performance. The model predicts that two-tier mechanic licensing requirements, increased cost limit for repairs and computerized emission test analyzers will increase the benefits of the program to approximately 27% HC, 26% CO and 4% NOx by 1995 and 28% HC, 22% CO and 4% NOx by 2010.

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Section 4

EVALUATION OF THE COST/EFFECTIVENESS OF THE CALIFORNIA SMOG CHECK PROGRAM

The basic objective of Task 2 of the contract was to quantify the costs and emission reductions associated with enhancements to the Smog Check program and to compare the ratio of total program costs and total program emission reductions of an enhanced program to the baseline program.

Background

Because California's air pollution problems result from the combined effect of thousands of different sources of air pollution, there are very few emissions control measures that could be expected to have a substantial effect on air pollution levels. So many sources contribute a small amount to the problem that without many individual control measures it will not be possible to achieve and maintain the ambient air quality standards. When a large portion of the air pollution problem is the result of many different sources, it is necessary to pursue control measures that individually have a small effect, but collectively have a significant impact.

In a situation where emissions control must be achieved from a large number of diverse sources, it is unreasonable to expect that a requirement for some fixed percentage of emissions control would be reasonable. For some types of sources, it may be possible to almost completely eliminate emissions through the application of relatively inexpensive emissions controls. The use of Stage II vapor recovery systems at gasoline stations is one such example. Greater than 95% control of gasoline vapors is being achieved with such systems. For other sources, it is extremely difficult to achieve such high levels of control. For example, there is no practical system for achieving 90% reductions of the NOx emissions from Diesel-powered trucks. A uniform requirement for 95% reductions in emissions would be fine for gasoline stations, but it would not be technologically feasible for heavy-duty trucks. By reducing the degree of emissions control to the amount that could be achieved by all sources, enormous amounts of available pollution control would be foregone.

To deal with the differences in emissions control feasibility, air pollution control officials generally try to determine how much control is technologically and economically feasible. Using this approach, the ratio of control cost and emission reductions has become a standard measure of performance for an air pollution control program.

Previous Estimates of Program Effectiveness - In an April 1987 report to the Legislature*, the emission reductions for vehicles subject to the Smog Check program were estimated at 12.3% for HC, 9.8% for CO, and (in areas with functional inspections) 3.9% for NOx. Those estimates were based on the results of tests conducted on about 800 vehicles recruited from customer service that were taken to Smog Check stations after receiving baseline tests at the ARB laboratory in El Monte. ARB employees posed as ordinary citizens needing a "Smog Certificate" to complete the registration renewal process. When returned from the Smog Check station, the vehicles were again tested by ARB using the full Federal Test Procedure (FTP).

Although the ratio of cost and effectiveness was not computed in the April 1987 report, the data needed to compute the cost-effectiveness ratio was available.

Program Enhancements - The its 1987 report to the Legislature, the I/M Review Committee identified several deficiencies in the Smog Check program and made a series of recommendations for how program benefits might be increased. Some of those recommendations required statutory changes. The recommendations for which increased emission reductions could be calculated included:

1. Beginning with the 1990 model year, the 5-year/50,000 mile comprehensive emissions warranty would be replaced with a 3-year/50,000 mile "full coverage" warranty and a 10-year/100,000 mile warranty with a \$300 "deductible".

Many emissions control-related components on new, computer-controlled vehicles are very expensive to replace and when they fail, emissions can increase tenfold. Although failure rates for expensive systems like electronic control units and catalysts are not expected to be high, the emissions impact is so dramatic that failure in only a few percent of the vehicle population can cause the average emissions of the population to double. The I/M Review Committee's report projected that the repair cost ceiling under the Smog Check program would have to be increased to approximately \$1,000 to ensure the repair of such components. Alternatively, the Committee proposed that those vehicles experiencing high repair costs could be repaired under an extended warranty, with a \$300 deductible, that would increase the cost of new cars by a small amount. The Review Committee and ARB agreed to cut back the "full coverage" warranty from 5 years to 3 years in order to obtain service industry support for this significant new warranty coverage for the failure of expensive components.

* "Evaluation of the California Smog Check Program - Technical Appendix," Sierra Research, Inc., April 1987.

2. The class of vehicles subject to the program would be changed from those 20 years old or less to all 1966 and later models.

The Review Committee's study showed that the emissions from vehicles more than 20 years old are so high that their inclusion in the program is important even though their numbers are relatively small. In addition, the Committee's study showed that these vehicles can achieve very large emission reductions at relatively low cost. 1966 was selected as the cutoff point because this is the first model year when exhaust emission control devices were required.

3. A "Multiple Tier" system of mechanic qualification was recommended in order to establish more rigorous qualification criteria for mechanics who work on the most complicated emission control systems.

The I/M Review Committee's study showed that more than half of all mechanics participating in the program lack the skills necessary to effectively test and repair computer-controlled vehicles. However, most mechanics are capable of doing a good job on vehicles equipped with more conventional technology. In order to maximize both the opportunity for participation in the program and the effectiveness of the program, the Review Committee concluded that more than one class of mechanics is needed.

4. Only BAR or a Referee facility would be able to issue waivers.

The Review Committee was convinced that the ability of I/M stations to issue waivers has significantly reduced the emission reduction benefits achievable under the program. The Committee's study showed that many vehicles receiving waivers could have been better repaired, even under the \$50 repair cost ceiling. When the repair cost ceilings are revised upwards, there will seldom be a need for any vehicle to receive a waiver, and there is no need for I/M stations to continue to be able to issue them.

5. The repair cost ceiling would be increased from \$50 to a range of \$60-\$300 depending on vehicle age.

The Committee's evaluation of the program clearly showed that the \$50 repair cost ceiling is grossly inadequate to deal with the types of defects that cause excess emissions on late model cars and trucks. For 1980 and later models, 34% of the defects causing excess emissions could not be repaired under the \$50 cost ceiling. When adjusted for inflation to \$60, the \$50 limit was projected to be adequate for pre-1972 model year vehicles. However, newer vehicles need progressively higher repair cost ceilings to cover the cost of repairing commonly occurring defects. For 1972-1974 models the Review Committee recommended that the ceiling should be \$125 to provide for more effective repair of air injection and EGR systems. For 1975-1979 models, the Review Committee concluded that more sophisticated air

injection and EGR systems require a \$175 cost ceiling. For 1980 and later models, the Committee concluded that a \$250 limit would ensure coverage of critical electronic sensors. Even under this limit, however, about 16% of the defects occurring in 1980 and later model vehicles could not be fixed. Starting with the 1990 model year, the Review Committee recommended a \$300 repair cost ceiling in conjunction with a 10-year/100,000 mile/\$300 deductible warranty, to ensure that all defects could be corrected.

6. Requirements would be added for the use of improved Test Analyzer Systems.

Although the "BAR '84" analyzers now used in I/M stations have assisted in the accurate inspection of motor vehicles, the I/M Review Committee concluded that the quality of inspections could be improved significantly through the use of analyzers capable of storing more information about various makes and models of vehicles. Enforcement of program requirements could also be improved if more information is recorded for each inspected vehicle. Supplemental diagnostic procedures could also be incorporated into a new analyzer design. Because of the continuous advances in technology, the Review Committee recommended that BAR to have the authority to require TAS system upgrades on a periodic basis.

All of the recommendations for program enhancements made by the I/M Review Committee were accepted by Senator Robert Presley and incorporated into the original version of his Senate Bill 1997. With some modifications, most of the recommended changes remained in the final version of the bill that was passed by the Legislature and signed into law by the Governor.

Work Program Summary

Cost/effectiveness analyses were not required under the previous work that Sierra performed for ARB and the Review Committee. However, most of the data necessary to perform a cost/effectiveness calculation were readily available. For example, data had already been compiled on the average cost of inspections, the failure rate for the program, and the average cost of repairs for failed vehicles. In conjunction with estimates of annual vehicle mileage accumulation and the previous estimates of program benefits, the cost/effectiveness calculation for the baseline program was relatively straightforward.

Effectiveness estimates for an improved program (short term and long term improvements) were also available from Sierra's previous work for the I/M Review Committee. However, during the course of the contract, numerous assumptions had to be changed regarding the features that would be included in an enhanced program. The program changes recommended by the Review Committee were modified during the course of the Legislature's consideration of Senate Bill 1997. In addition,

Sierra was directed to evaluate the potential effects of certain changes that were not recommended by the Review Committee, such as annual inspection frequency and the elimination of all waivers. Also, Sierra was able to improve the methodology used for estimating I/M benefits during the course of the contract.

BASELINE COST/EFFECTIVENESS

In the April 1987 report to the Legislature, the benefits of the Smog Check program were calculated based on the actual change in emissions from the "undercover" vehicles taken to Smog Check stations by ARB. Because only vehicles that were likely to fail an I/M test were included in the sample, it was necessary to compute the expected effect on the entire vehicle fleet by accounting for that portion of the vehicle fleet expected to pass the Smog Check test. A detailed description of the methodology used is contained in the previously referenced 1987 Sierra report. Based on that earlier report, the baseline fleet emissions and current Smog Check benefits were as shown in Table 9.

Table 9

Estimated Effects of the Smog Check Program
on the Exhaust Emissions of Vehicles Subject to the Program

	----- grams/mile -----		
	<u>HC</u>	<u>CO</u>	<u>NOx</u>
Baseline, before I/M	2.11	23.7	1.55
After I/M	1.85	21.4	1.49
I/M Reduction	12.3%	9.8%	3.9%

The April 1987 report contained no estimate of cost-effectiveness. Sierra has now computed the cost-effectiveness associated with the estimates in the 1987 report using the costs of the program at that time. Table 10 uses the average 1986-timeframe inspection fee (\$20), certificate cost (\$6), and repair cost (\$35) in the calculation of a cost-effectiveness value for the combined HC plus NOx and CO emissions reductions associated with the baseline Smog Check program. As indicated in the table, an average annual mileage accumulation rate of 10,000 per vehicle is assumed. In addition, cost have been rather arbitrarily divided between the three principal automotive pollutants. 50% of the cost has been assigned to HC plus NOx control and the other 50% to CO. The net result is that HC + NOx cost-effectiveness is computed to be \$1.35/pound. CO cost-effectiveness is computed to be \$0.19/pound.

Table 10

Cost/Effectiveness of 1986 Smog Check Program

Costs:

	\$20 + 2 =	\$10	(annual average inspection fee)
	+ 6 + 2 =	3	(annual avg. cost for Smog Certificate)
	+ (\$35 × 0.35) + 2 =	6	(annual avg. repair cost per vehicle)
		<hr/>	
		\$19	(total annual cost per vehicle)
	+ 2		(50% of costs assigned to HC + NOx)
		<hr/>	
		\$9.50	(annual cost for HC + NOx control)
		\$9.50	(annual cost of CO control)

Emission Reductions:

2.11 g/mi HC × 12.3% =	0.26 g/mi	(HC reduction)
1.55 g/mi NOx × 3.9% =	0.06 g/mi	(NOx reduction)
	<hr/>	
	0.32 g/mi	(HC + NOx reduction)
	× 10,000 miles/year	(annual vehicle mileage)
	<hr/>	
	7.05 pounds	of HC + NOx (annual reduction)
23.71 g/mi CO × 9.8% =	2.32 g/mi	(CO reduction)
	× 10,000 miles/year	(annual vehicle mileage)
	<hr/>	
	51.10 pounds	of CO (annual reduction)

Cost/Effectiveness:

HC + NOx Cost/Effectiveness Ratio = \$9.50 ÷ 7.05 lbs. = \$1.35/pound

CO Cost/Effectiveness Ratio = \$9.50 ÷ 51.10 lbs. = \$0.19/pound

BENEFITS OF PROGRAM ENHANCEMENTS

Estimates of the benefits of enhancements to the I/M program were included in the 1987 report to Legislature. However, the assumptions used in the 1987 report differ from the final provisions of Senate Bill 1997. In addition, Sierra has improved its benefits estimation methodology during the last two years. To clarify the evolution of the projections, a brief summary of the previous estimates of program enhancements is presented below, followed by the latest estimates.

Prior Estimates of Program Enhancements

Tampering Correction - The theoretical benefits of I/M program improvements were estimated by first calculating the impact of all tampering being eliminated. Using EEA's "malperformance model" and the tampering rates from the roadside inspection program, the elimination of all tampering was estimated to reduce emissions as shown in Table 11.

Table 11

Effect of Tampering Correction on I/M Benefits

	<u>HC</u>	<u>CO</u>	<u>NOx</u>
Baseline, before I/M	2.11	23.7	1.55
With All Tampering Fixed	1.50	18.9	1.32
Reduction from baseline	28.9%	20.3%	14.8%
Current I/M Reduction	-12.3%	-9.8%	-3.9%
Incremental reduction	16.6%	10.5%	10.9%

In the April 1987 report, Sierra stated that this "incremental reduction" was the theoretical incremental benefit from the complete elimination of tampering and more realistic estimates of potential improvements were computed based on the percent of currently uncorrected tampering that was expected to be detected and corrected under a program with short term improvements (51%) and longer term improvements (81%).

This approach to estimating the benefits of tampering correction was based on a very conservative assumption that all of the current benefits from the Smog Check program should be treated as though they were due to the correction of tampering. To the extent that non-tampering defects contributed to the current emission reductions, the incremental benefits of correcting all tampering (or some percentage of uncorrected tampering) would be higher.

Under the "short term improvements" scenario in the April 1987 report, we estimated the potential improvements with no statute changes. Correction of 51% of all tampering was assumed to occur, but the correction of other defects was assumed to increase only slightly because there was no increased repair cost ceiling projected. The benefits of the program were projected to increase to 26.9% for HC, 16.3% for CO, and 11.4% for NOx. However, the HC calculation included a credit for the potential benefits of more effective repairs to PCV

systems that was expressed in terms of an exhaust emissions benefit of 4.8%. Without this credit, the HC benefits would have been 22.1%.

Under the "longer term improvements" scenario, the April 1987 report estimated the potential benefits of a maximum effort program that included the additional expense of loaded mode testing and annual inspections. 81% effectiveness was assumed for the correction of both tampering and non-tampering defects. Benefits were projected to rise to 39.7% for HC, 25.2% for CO, and 22.8% for NOx. Subtracting a 6.3% HC benefit for PCV defect correction and a 2.5% benefit (all pollutants) for annual inspections, the net benefits projected in the April 1987 report are 30.9% HC, 22.7% CO, and 20.3% NOx.

Updated Estimates of Potential Program Improvements

Since the publication of the April 1987 report, Sierra has attempted to estimate the extent to which non-tampering defect correction contributed to the current benefits of the Smog Check program. For those vehicles which experienced significant emission reductions as a result of Smog Check repairs, analysis of the detailed diagnostic information available on each vehicle indicates that the NOx emission benefits of the current Smog Check program are primarily associated with the correction of tampering. However, the HC and CO benefits are primarily associated with the correction of non-tampering defects.

A review of the diagnostic comments on the I/M Evaluation Program vehicles indicates that the correction of HC or CO related tampering is a significant factor in only 16% of the I/M repairs where large ($\geq 50\%$) HC and CO emission reductions are achieved. The correction of NOx-related tampering is a factor in 60% of the repair actions where large NOx emission reductions are achieved.

Using the results of this analysis, the benefits of the Smog Check program for 1986 can be apportioned as shown in Table 12. Based on the calculations shown in Table 12, it is apparent that the incremental benefits from the correction of all tampering would be higher than previously estimated. Specifically, they would be as illustrated in Table 13.

Non-Tampering Defects Correction - Using the same rationale as used in the April 1987 report, the theoretical benefits of correcting non-tampering defects can be estimated from the extent to which non-tampering related defects were identified in the roadside survey programs. However, this technique addressed only those elements of emission control systems that routinely have problems that are related to both tampering and non-tampering defects (e.g., catalyst and air injection system defects). Since air-fuel ratio maladjustment and ignition misfire problems were not considered to be related to tampering, the approach used in the April 1987 report underestimated the theoretical benefits of correcting all non-tampering related defects.

Table 12

Current Smog Check Program Benefits
Apportioned by Type of Defect Corrected

	<u>HC</u>	<u>CO</u>	<u>NOx</u>
Baseline, before I/M	2.11	23.7	1.55
After I/M	-1.85	-21.4	-1.49
	<hr/>	<hr/>	<hr/>
Total reduction (g/mi)	0.26	2.3	0.06
Grams/mile reduction from correction of tampering	0.04 (16%)	0.4 (16%)	0.04 (60%)
G/mi reduction from fixing non-tampering defects	0.22 (84%)	1.9 (84%)	0.02 (40%)
Percent reduction due to correction of tampering	2.0%	1.6%	2.3%
Percent reduction from fixing other defects	10.3%	8.2%	1.6%
	<hr/>	<hr/>	<hr/>
Total Reduction (%)	12.3%	9.8%	3.9%

Table 13

Incremental Benefits of Tampering Correction
in the Smog Check Program

	<u>HC</u>	<u>CO</u>	<u>NOx</u>
Reduction from fixing all tampering	28.9%	20.3%	14.8%
Reduction from non-tampering defects already being fixed	+10.3%	+8.2%	+1.6%
	<hr/>	<hr/>	<hr/>
Net reduction	39.2%	28.5%	16.4%
Current reductions	-12.3%	-9.8%	-3.9%
	<hr/>	<hr/>	<hr/>
Incremental reduction	26.9%	18.7%	12.5%

Based on the 1986 roadside survey, the contribution to excess emissions related to non-tampering defects in AIR and catalyst related systems was computed to be 22% for HC, 25.6% for CO and 63.3% for NOx (see "Evaluation of the California Smog Check Program - Technical Appendix" at page 175). Since the theoretical benefits of correcting all tampering have already been computed, the reduction due to the correction non-tampering defects can be computed as follows for hydrocarbons:

$$\begin{aligned} \% \text{ Reduction}_{\text{tot}} \times (1 - 0.22) &= \% \text{ Reduction}_{\text{tamp}} \\ \% \text{ Reduction}_{\text{tot}} \times (0.78) &= 28.9\% \\ \% \text{ Reduction}_{\text{tot}} &= 28.9\% + 0.78 = 37.1\% \\ \% \text{ Reduction}_{\text{non-tamp}} &= \% \text{ Reduction}_{\text{tot}} - \% \text{ Reduction}_{\text{tamp}} \\ \% \text{ Reduction}_{\text{non-tamp}} &= 37.1\% - 28.9\% = 8.2\% \end{aligned}$$

As indicated above, the theoretical non-tampering benefits are computed to be only 8.2% under this method. This is less than the 10.3% non-tampering benefits that were estimated to already be achieved under the current Smog Check program. Combined with the estimated potential benefits of correcting all tampering, the maximum HC benefits of I/M are estimated at 37.1% HC reduction using this method.

Similar calculations for CO indicated the total potential benefits of correcting non-tampering defects to be 7.0%. Again, this is less than the 8.2% reduction estimated to already be achieved under the current program. Combined with the estimated benefits of correcting all tampering, the maximum CO benefits of I/M are estimated at 27.3% using this method.

For NOx emissions, the same calculation method produces an estimate of potential non-tampering benefits of 25.5%, enormously higher than the 1.6% benefit from the correction of non-tampering benefits we estimate to be achieved currently. Combined with the estimated benefits of correcting all tampering, the maximum NOx benefits of I/M would be estimated at 40.3%.

The failure of this method to address air-fuel ratio maladjustment and ignition misfire problems is clearly resulting in an underestimate of the potential benefits of correcting non-tampering defects that were not adequately addressed in the early study. On the other hand, the estimated potential NOx benefits appear to be very high. Part of the problem with the NOx estimate is that it fails to account for the fact that there are significant NOx emission increases associated with the repair of some vehicles with severe HC and CO problems.

Rather than attempting to refine the "malperformance model" approach that Sierra's subcontractor relied on in the earlier analysis, Sierra has addressed the potential benefits of correcting non-tampering

related defects in a fundamentally different manner. Assuming the tampering benefits that come out of the malperformance model are reasonable approximations, we have made an estimate of the potential for non-tampering benefits based on an estimate of the emission performance that could be expected from a perfectly maintained fleet of vehicles with no tampering or non-tampering defects. Under this idealized assumption, the lifetime average HC and CO emissions of all cars and trucks are estimated to be equal to the emission standards they were certified to meet. (Federal emission standards for CO were assumed in model years where there are many "50-state" models certified.) Lifetime average NOx emissions were estimated to be 10% under the standards (due to the lower NOx deterioration that has been observed through in-use surveillance).

Using these assumptions, for the 1986 calendar year case evaluated in the April 1987 report, the fleet average emissions of vehicles subject to the program were calculated to be 0.76 g/mi HC, 8.7 g/mi CO, and 1.15 g/mi NOx. These theoretical optimum emission levels represent reductions in baseline emissions as illustrated in Table 14.

Table 14

Theoretical Maximum Benefits
of the Smog Check Program

	<u>HC</u>	<u>CO</u>	<u>NOx</u>
- Baseline, before I/M	2.11	23.7	1.55
If Average Emissions Were Equal to Standards	0.76	8.7	1.15
Theoretical reduction	64.0%	63.3%	25.8%

As indicated in the above table, it is conceivable that the ideal I/M program could result in emission reductions of slightly more than 60% for HC and CO and 25% for NOx. Compared to the methodology employed in the April 1987 report, the higher potential reductions for HC and CO and the lower potential reductions for NOx appear more reasonable. Sierra therefore computed potential non-tampering defects based on the difference between the 60% HC and CO reductions and the calculated benefits of the complete elimination of tampering. NOx related non-tampering defects were based on the difference between 25% and the estimated benefits of eliminating NOx tampering.

Obviously, the theoretical benefits of an improved Smog Check program need to be heavily discounted. Until there has been adequate time for a substantial upgrading of mechanic performance, the estimates from

the April 1987 report for mechanic performance still seem to be reasonable. Those estimates were based on assumption that a strong enforcement program and diligent efforts by Smog Check mechanics would result in mechanics trying their best to identify defects 90% of the time. It was further estimated that 75% of the mechanics are capable of identifying tampering related defects when they try their best and 75% percent of the repairs attempted would be successful. The net effect would be elimination of 51% of all tampering ($0.90 \times 0.75 \times 0.75$). When the cost ceiling is sufficiently high, this same efficiency could be applied to non-tampering related defects. (Note that the 75% defect identification rate for mechanics who try their best, accounts for some of the problems in identifying excess emissions with the current test procedures.)

It is assumed that the correction of more tampering related defects are primarily associated with measures that enhance program enforcement and upgrade mechanic qualifications. Once such improved performance is available, the correction of more non-tampering defects is dependent on the extent to which repair cost ceilings and warranty protection is adequate to cover the cost of full repair. The analysis of the benefits of the original version of SB 1997 was based on the conclusion that the new repair cost ceilings would be sufficient to allow almost all defects to be corrected that could be identified and properly repaired by the current Smog Check mechanics.

Based on this approach, the estimated short term emission reductions due to the original version of SB 1997 would be as shown in Table 15. The table summarizes the estimated emission reductions from an I/M program with higher cost ceilings and improved enforcement, but without substantially upgraded mechanics or substantially upgraded test procedures. As such, it provides a reasonable estimate of what could have been achieved under the original version of SB 1997 in the short term. As the table shows, the theoretical benefits are about 30% for HC and CO and 13% for NOx.

Keeping 1966 and Later Models in the Program - Because the earlier analysis indicated that significant HC and CO reductions were associated with the repair of older vehicles, the Review Committee recommended, and the Legislature agreed to keep 1966 and later model vehicles in the program indefinitely. Obviously, the effect of keeping 1966 and later models in the program increases over time as the number of model years subject to the program increases. Using EMFAC, Sierra computed how the 1966 and later models increase the total amount of motor vehicle emissions that are subject to control by the I/M program. To estimate the effects of this change early in the reauthorization period (early 1990s), Sierra compared 25 model years to 20 and computed that there are only 1.5% more vehicle miles travelled (VMT) subject to I/M. However, the emissions from the oldest five model years would be 5.5% of the total HC, 5.1% of the total CO and 2.8% of the total NOx. With an assumed 30% reduction in HC and CO emissions, the inclusion of these vehicles would have the effect of boosting the overall benefits of the program by about 1.5-1.7%. By the mid to late 1990's, the emissions from vehicles more than 20 years old would increase to about twice this amount and the

Table 15

Estimated Emission Reductions
Due to Potential I/M Improvements

	<u>HC</u>	<u>CO</u>	<u>NOx</u>
<u>Tampering Correction</u>			
Correct All Tampering	28.9%	20.3%	14.8%
Correct 51% of All Tampering	14.7%	10.4%	7.5%
Less Tampering Currently Corrected	2.0%	1.6%	2.3%
Net Improvement Possible	<u>12.7%</u>	<u>8.8%</u>	<u>5.2%</u>
<u>Correction of Non-Tampering Defects</u>			
Correct All Non-Tampering Defects	31.1%	39.7%	10.2%
Correct 51% of Above Defects	15.9%	20.2%	5.2%
Less Defects Currently Corrected	10.3%	8.2%	1.6%
Net Improvement Possible	<u>5.6%</u>	<u>12.0%</u>	<u>3.6%</u>
Emission Reductions From the Current Smog Check Program	<u>12.3%</u>	<u>9.8%</u>	<u>3.9%</u>
Total Emission Reduction With I/M Improvements	30.6%	30.6%	12.7%

incremental benefits of keeping 1966 and later models in the program would be equivalent to another 3% reduction in HC and CO emissions and about 0.7% reduction in NOx. This is illustrated in Table 16.

It should be noted that the estimates presented above will have to be refined as more information becomes available on the manner in which the Smog Check stations are affected by and respond to increased enforcement and more stringent qualification requirements imposed by BAR. For the original version of SB 1997, the "effective" emission reductions shown in Table 16 represented Sierra's best estimate of the potential reductions that would be achieved relative to the reductions that were being achieved under the baseline program.

Table 16

"Effective" Benefits of
Keeping 1966 and Later Models
in the Smog Check Program

	<u>HC</u>	<u>CO</u>	<u>NOx</u>
Total Emission Reduction With Other I/M Improvements	30.6%	30.6%	12.7%
Additional Reductions Due to Inclusion of all 1966 and Newer Cars and Light Trucks	+3.4%	+3.1%	+0.7%
"Effective" Emission Reduction With 1966 and Later Models	34.0%	33.8%	13.4%

Given the 51% effectiveness factor that was used to generate these projections, the requirements of SB 1997 for a 25% HC and CO reduction appeared to be very reasonable. One factor affecting the achievement of this goal is that the target reduction is based on the exhaust emissions that would occur in the absence of I/M, but all reductions (including PCV and evaporative emissions) count. This factor will also give BAR a good chance of meeting the 40% HC reduction target in areas that opt for NOx testing. The 20% NOx reduction target appears to be the most stringent requirement based on our latest analysis.

Maximum Potential Emission Reductions

As illustrated in Table 17, using a similar approach to the one described above, the benefits of a more stringent program with substantially upgraded mechanics and loaded mode testing (or more effective diagnostic analyzers) would be in the range of 50% for HC and CO and 20% for NOx (without including any credit for keeping older vehicles in the program for a longer period of time). The projection shown in Table 17 is based on the same 81% efficiency in the identification and correction of defects assumed for loaded mode testing in the April 1987 report, as opposed to the 51% efficiency assumed for short term improvements.

Achievement of the theoretical benefits shown in Table 17 would require substantially increased repair cost ceilings and improved mechanic performance. In addition, loaded mode testing might be required. The actual effect of a maximum effort I/M program is probably in between the range of estimates covered in Tables 15 and 17 for HC and CO. The high NOx correlation with the FTP previously

Table 17

Estimated Emission Reductions
Due to Maximum Potential I/M Improvements

	<u>HC</u>	<u>CO</u>	<u>NOx</u>
<u>Tampering Correction</u>			
Correct All Tampering	28.9%	20.3%	14.8%
Correct 81% of All Tampering	23.4%	16.4%	12.0%
Less Tampering Currently Corrected	2.0%	1.6%	2.3%
Net Improvement Possible	<u>21.4%</u>	<u>14.8%</u>	<u>9.7%</u>
<u>Correction of Non-Tampering Defects</u>			
Correct All Non-Tampering Defects	31.1%	39.7%	10.2%
Correct 81% of Above Defects	25.2%	32.2%	8.3%
Less Defects Currently Corrected	10.3%	8.2%	1.6%
Net Improvement Possible	<u>14.9%</u>	<u>24.0%</u>	<u>6.7%</u>
Emission Reductions From the Current Smog Check Program	<u>12.3%</u>	<u>9.8%</u>	<u>3.9%</u>
Total Emission Reduction With I/M Improvements	48.6%	48.6%	20.3%

demonstrated by Sierra* makes the theoretical NOx benefits shown in Table 17 more likely, provided the repair cost ceiling is adequate to cover the necessary NOx repairs.

Effect of Modifications to SB 1997

Several provisions of the original version of SB 1997 were the subject of debate as the bill moved through the legislative process. The key provisions which ended up being modified were the emissions warranty and the repair cost ceiling.

Warranty - Automobile manufacturers objected to the requirements for a 10 year/100,000 mile warranty on emissions related components (with a \$300 "deductible"). To estimate the possible effect of changes in the warranty provisions, Sierra had to estimate the percentage of

* "An Evaluation of Loaded Mode I/M Testing at Service Stations," Sierra Research, Inc., Report No. SR88-12-02, December 7, 1988.

emissions related defects that would be covered under shorter warranties.

Sierra estimated the full benefits of 10/100 to be some portion of the total benefits associated with the correction of non-tampering related defects. Recall from Table 17 that full correction of all non-tampering defects was estimated to reduce emissions by 31.1% for HC, 39.7% for CO, and 10.2% for NOx. To estimate the portion of this total that would be attributable to a 10/100 warranty, it was assumed that 16% of the defects would be above the repair cost ceiling^{*}; 81% could be detected and corrected by Smog Check mechanics in the future; 75% of these expensive defects would occur after 50,000 miles, and 62% of the emissions would be from vehicles affected by the warranty.[†] Using these assumptions, the amount of this benefit due to the extended warranty was estimated to be 1.9% for HC ($31.1\% \times 0.81 \times 0.16 \times 0.75 \times 0.62$), 2.4% for CO ($39.7\% \times 0.81 \times 0.16 \times 0.75 \times 0.62$), and 0.6% for NOx ($10.2\% \times 0.81 \times 0.16 \times 0.75 \times 0.62$).

Figure 23 shows the simple assumption that was made in order to provide an estimate of the possible effect of shortening the warranty period. A graph was constructed by fitting a smooth curve through the following three data points:

1. 100% of the benefits of a 10/100 warranty would be achieved under the original bill;
2. No benefits would occur with no warranty; and
3. 75% of all emissions related defects would occur after 50,000 miles of operation.

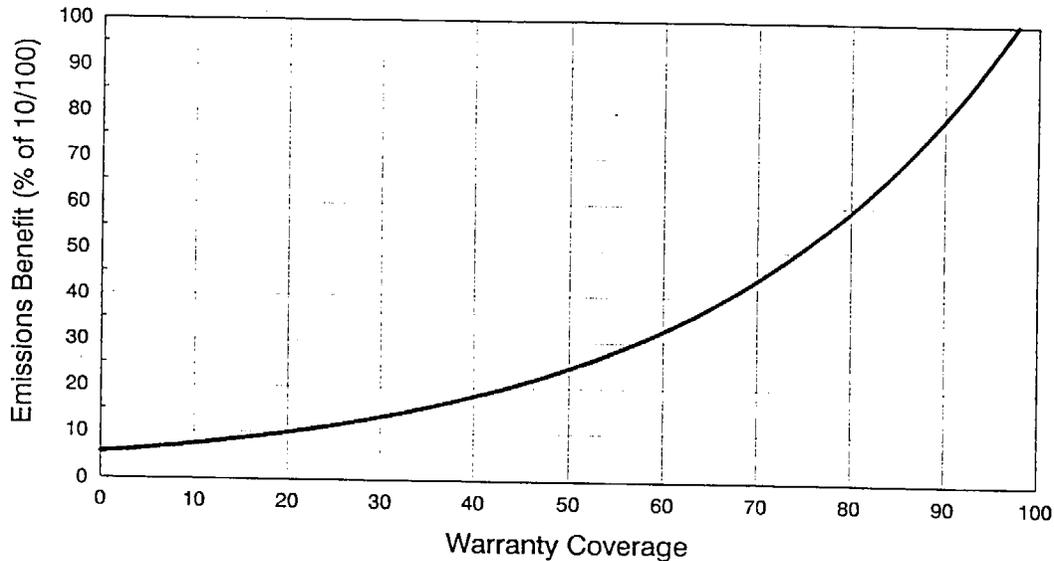
Note that the relationship illustrated in the figure is close to 25% at 50,000 miles, close to 0% at 0 miles and close to 100% at 100,000 miles. At 70,000 miles, the estimate is that 45% of the benefits of a 10/100 warranty would be obtained. This would indicate that only 27% of the incremental benefits of extending the warranty from 5/50 to 10/100 would be retained at the 7/70 warranty proposed during the consideration of the bill by the Legislature ($[45-25] \div 75 = 0.27$).

* In the April 1987 report, it was shown that 16% of the defects in 1980 and later model vehicles would not have been repaired under a \$150-\$200 repair cost ceiling. Accounting for inflation between 1986 and the year that SB 1997 becomes effective (1990), the estimated 16% level of unrepaired defects appeared to be a reasonable basis for an estimate of the effect of an extended warranty with a \$300 deductible.

† This last assumption was made to reflect a reasonable phase-in period for the new warranty requirements and to approximate the point in time when keeping 1966 and later vehicles in the program would also be maximized.

Figure 23

Effect of Emissions Warranty Coverage on Smog Check Program Benefits



Source :
I/M Review Committee estimates based on
population coverage and forecasted defect rate

In other words, the benefits of 7/70 would be about 0.5% for HC, 0.65% for CO and about 0.2% for NOx.

Because the 5/50 warranty was the baseline, the relationship between warranty coverage and emission benefits illustrated in Figure 23 is hard to visualize. To more clearly illustrate the potential incremental benefits of extending the warranty beyond 5/50, the relationship between warranty distance and emission benefits was translated into the form illustrated by Figures 24 and 25.

Figure 24 shows how the HC benefits of the original version of SB 1997 were projected to change with various revisions to the warranty provisions. Note that at the 5/50 level, the reduction in HC benefits is just under 6%. When 6% is multiplied by the 34% HC benefits estimated for the original bill, the loss in benefits is close to 1.9%. Similarly, Figure 25 shows that a 7% loss in benefits would be

Figure 24

**Effect of Warranty Amendments
to SB 1997
on Smog Check Program HC Benefits**

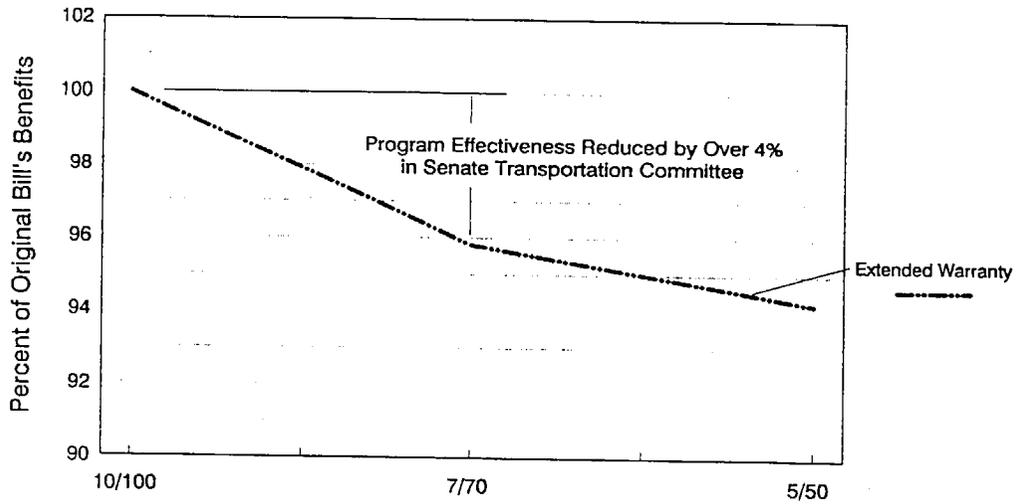
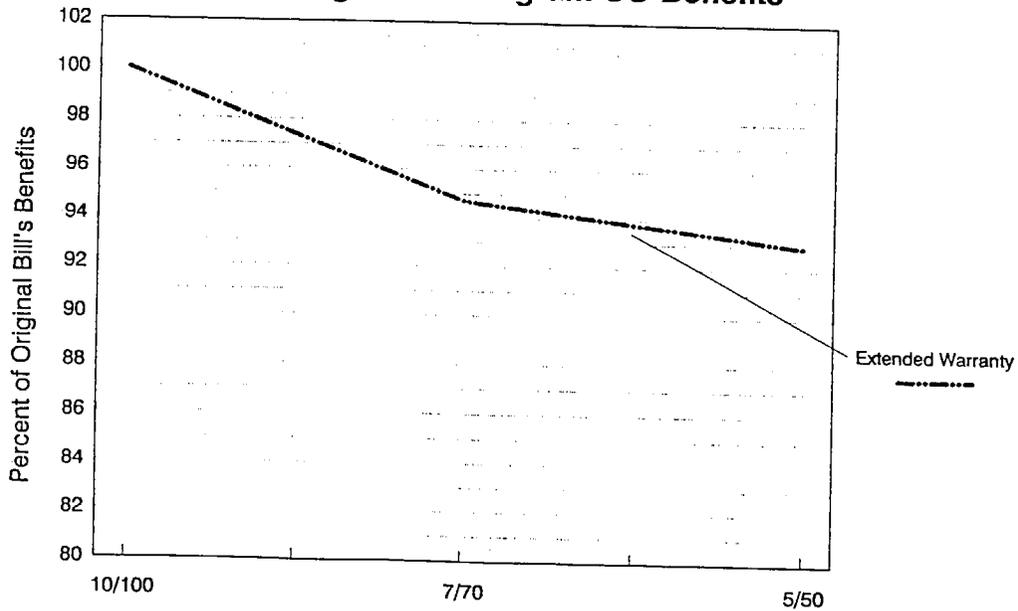


Figure 25

**Effect of Warranty Amendments
to SB 1997
on Smog Check Program CO Benefits**



associated with a reduction in the warranty to 5/50. When 7% is multiplied by the 33.8% CO benefits estimated for the original bill, the loss is close to 2.4%. At the 7/70 level, the loss in the incremental benefits associated with the 10/100 warranty provision of the original bill is shown to be 4-5% of the original benefits of the entire bill. This calculates a 1.4% drop in HC benefits and a 1.8% drop in CO benefits. Although not shown graphically, the loss in NOx benefits for 7/70 was calculated to be 0.4%.

Repair Cost Ceiling - Having determined that 1.9% HC, 2.4% CO, and 0.6% NOx benefits of an enhanced I/M program could be attributed to a 10/100 warranty, the remaining increase in non-tampering benefits was computed as follows:

Correct All Non-Tampering Defects	31.1%	39.7%	10.2%
Correct 51% of Above Defects	15.9%	20.2%	5.2%
Less Defects Currently Corrected	-10.3%	- 8.2%	-1.6%
Net Improvement Possible	<u>5.6%</u>	<u>12.0%</u>	<u>3.6%</u>
Minus 10/100 Warranty Benefits	-1.9%	-2.4%	-0.6%
<u>Potential Benefits of Higher Repair Cost Ceiling</u>	3.7%	9.6%	3.0%

Using a simplifying assumption that increased enforcement would deal with "tampering" related defects and increased cost ceilings would deal with "non-tampering" related defects, these percentages were the estimated benefits of the repair cost ceilings included in the original version of SB 1997.

Figures 26 and 27 graphically illustrates how the HC and CO benefits of the original version of SB 1997 were projected to change with various revisions to the repair cost ceilings for the various model year ranges. Note that at the \$50 level, the sum of the reduction in HC benefits is about 11% (7.3% for '80+, 2.3% for '75-'79, 0.75% for '72-'74, and 0.85% for pre-'72). When 11% is multiplied by the 34% HC benefits estimated for the original bill, the loss in benefits is 3.7%. Likewise, the sum of the reduction in CO benefits is about 29% (18.6% for '80+, 5.8% for '75-'79, 2.0% for '72-'74, and 2.1% for pre-'72). When 29% is multiplied by the 33.8% CO benefits estimated for the original bill, the loss in benefits is close to 9.6%.

The shape of the lines plotted in Figures 26 and 27 were based on the sensitivity to repair cost ceiling changes for each model year range indicated by the I/M Evaluation program data. For all of the vehicles with sufficient diagnostic comments, Sierra estimated the cost that

Figure 26

Effect of Repair Cost Ceiling Amendments to SB 1997 on Smog Check Program HC Benefits

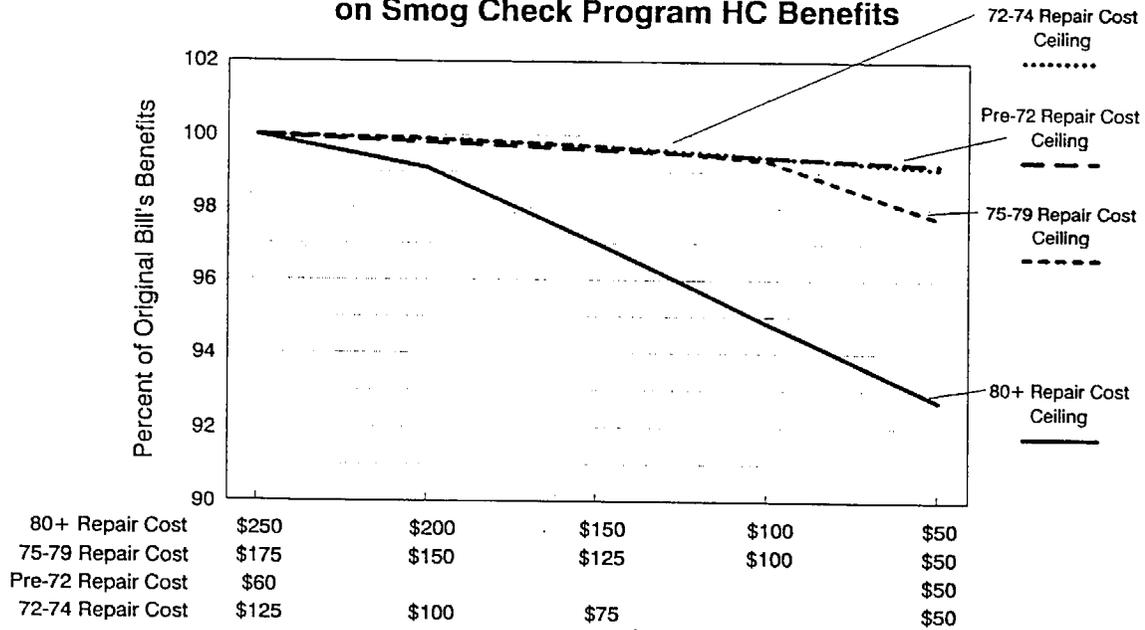
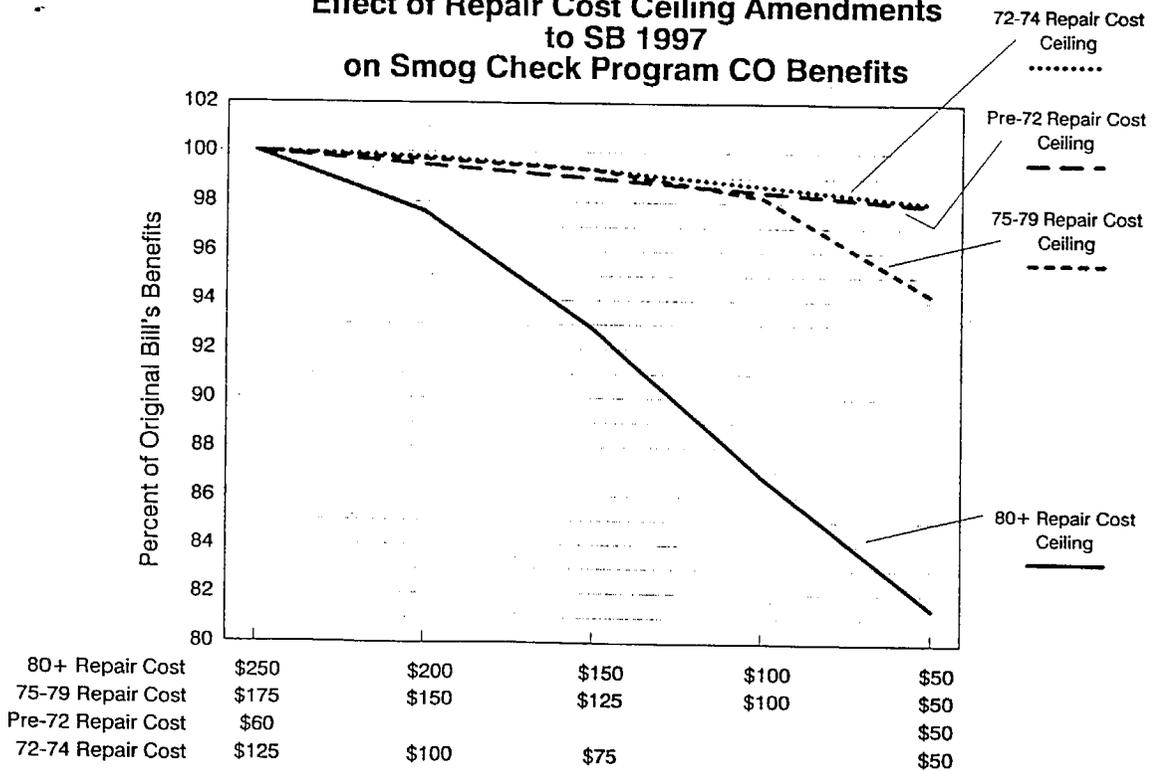


Figure 27

Effect of Repair Cost Ceiling Amendments to SB 1997 on Smog Check Program CO Benefits



would have been required to make full repairs. This enabled the construction of a cumulative distribution of repair completion as a function of repair cost ceiling.

For '80 and later models, the percent of incremental benefits retained as the cost ceiling dropped from \$250 were estimated to be 88% @ \$200; 61% @ \$150; and 29% @ \$100.

For '75-'79 models, the incremental benefits retained as the ceiling dropped from \$175 were 95% @ \$150; 88% @ \$125; and 69% @ \$100.

For '72-'74 models, the incremental benefits retained as the ceiling dropped from \$125 were 89% @ \$100; and 65% @ \$75.

For pre-'72 models, it was estimated that all of the benefits were lost when the ceiling dropped from \$60 to \$50.

Among these model year groups, the loss in benefits were distributed in proportion to each group's contribution to excess emissions that could not be repaired under the repair cost ceiling in the baseline program: 65% for 80+; 20.5% for '75-'79; 7% for '72-'74; and 7.5% for pre-'72. These factors were computed from the fraction of total emissions for each group (45% for 80+; 24% for '75-'79; 15% for '72-'74; and 16% for pre-'72) multiplied by the fraction of vehicles that couldn't be repaired under the \$50 ceiling (34% for 80+; 20% for '75-'79; 11% for '72-'74; and 11% for pre-'72).

Uniform reductions for HC (34%) and CO (33.8%) under the original version of SB 1997 were assumed for each model year group. Each group's portion of the incremental 3.7% HC/9.6% CO benefits projected for increased cost ceilings served as the basis for computing the correction factor to be used in estimating the effect of changes to the original repair cost ceilings being considered by the legislature. For example, a \$200 repair cost ceiling for 1980 and later models was computed to have a CO correction factor of 97.8% based on the following calculation:

$$\text{Original CO Benefit for All '80+ models} = 9.6\% \times 0.65 = 6.24\% \quad (1)$$

$$\text{Estimated Benefit @ \$200} = 6.24\% \times 0.88 = 5.49\% \quad (2)$$

$$\text{Percentage Points of Benefit Lost} = 6.24\% - 5.49\% = 0.75\% \quad (3)$$

$$\text{Portion of Total CO Benefits Lost} = 0.75 \div 34 = 2.2\% \quad (4)$$

$$\text{Correction Factor} = 100.0 - 2.2 = 97.8\% \quad (5)$$

* see April 1987 report Technical Appendix at pg. 222

Note on Figure 27, the "percent of original bill's benefits" is at the \$200 repair cost ceiling level is 97.8%.

As the cost ceiling graphs show, a much higher cost ceiling for '80+ models is the most significant. Since the cost ceiling benefits were distributed based on the 1987 vehicle population distribution, the future importance of a high cost ceiling for '80+ models is even more important than the graphs illustrate.

Net Effect of Amendments to SB 1997 - In the final version of the bill, the warranty was set at 7 years/70,000 miles for parts costing more than \$300. The repair cost ceilings were modified as follows:

<u>Model Year Range</u>	<u>Original Cost Ceilings</u>	<u>Amended Cost Ceilings</u>
Pre-1972	\$60	\$50
1972-1974	\$125	\$90
1975-1979	\$175	\$125
1980-1989	\$250	\$175
1990 and later	\$300	\$300

It should also be noted that in order to facilitate comparisons with the baseline program, Sierra's earlier calculations presented benefits in terms of the reduction in emissions relative to the 20 model years worth of vehicles subject to the original program. For example, hydrocarbon emission reductions were estimated to eventually increase by 3.4% by keeping 1966 and later models in the program indefinitely. In fact, there was no significant change in the percent reduction from vehicles subject to the program. The need for consistent benefits estimates, between those of the original program and those of SB 1997, was eliminated by the passage of the bill. Therefore, Sierra's estimates for the benefits of the final version of the bill are based only on the vehicles subject to the program.

By using the estimates for the original version of SB 1997 along with the adjustment factors from Figures 24-27, the benefits of the final version of the bill were estimated. Although not precisely calculated the effects of cost ceiling changes on NOx were estimated to be proportional to those for HC and CO. The final adjustments are presented in Table 18.

Table 18

Smog Check Program Benefit Adjustments
Based on Changes to SB 1997

	Emission Reductions		
	<u>HC</u>	<u>CO</u>	<u>NOx</u>
Benefits of Original Bill	34.0%	33.8%	13.4%
Adjustments:			
7/70 Warranty vs. 10/100	-1.4%	-1.8%	-0.3%
\$175 vs. \$250 Cost Ceiling for '80+	-0.7%	-1.7%	
\$125 vs. \$175 Cost Ceiling for '75-'79	-0.1%	-0.2%	-0.1%
\$90 vs. \$125 Cost Ceiling for '72-'74	-0.1%	-0.1%	
Subtotal	<u>31.7%</u>	<u>30.0%</u>	<u>13.0%</u>
Adjustment to Change Basis to Vehicles Subject to the Program	-3.4%	-3.1%	-0.7%
Net Benefits of SB 1997	<u>28.3%</u>	<u>26.9%</u>	<u>12.3%</u>

Following the adoption of SB 1997, Sierra was asked to estimate what the maximum benefits might ultimately be of eliminating the repair cost ceiling entirely. To make a first order approximation of this possibility, the estimate was based on the assumption that the benefits would be equal to restoring the original SB 1997 cost ceilings and the 10/100 warranty:

	<u>HC</u>	<u>CO</u>	<u>NOx</u>
Restore cost ceilings	0.9%	2.0%	0.1%
Restore 10/100 warranty	1.4%	1.8%	0.3%
Total	<u>2.3%</u>	<u>3.8%</u>	<u>0.4%</u>

ENHANCED I/M COST/EFFECTIVENESS

Based on the benefits of various Smog Check program enhancements presented above, cost/effectiveness calculations have been prepared for four scenarios:

1. Short-term SB 1997 enhancements;
2. Annual inspection frequency;

3. Potential long term enhancements under SB 1997 with loaded mode testing or improved diagnostic testing; and
4. Elimination of all waivers.

Expected Short-Term Cost/Effectiveness Under SB 1997

Table 19 summarize the cost/effectiveness calculations for an improved program under which the minimum performance targets of SB 1997 are achieved (25% reduction in HC and CO emissions) and there is a 10% reduction in NOx emissions. The calculations are based on the same average vehicle emissions as existed during the evaluation of the baseline program. The increase in repair cost to \$100 is based on the assumption that increasing emission reductions by 2-3 times will cause a corresponding increase in repair cost from the \$35 baseline cost.

The differences between Table 19 and the estimates for the baseline program presented earlier indicate that increased inspection costs and increased repair costs are associated with an upgraded Smog Check program under which mechanics perform at their current level of capability. However, the ratio of cost to effectiveness actually improves from \$1.35 per pound of HC plus NOx control to \$1.17. CO cost/effectiveness improves from \$0.19/pound to \$0.14/pound.

Table 20 shows how the cost/effectiveness of the improved program is projected to change when the average emissions of vehicles subject to the program is reduced to 1.0 grams per mile for HC and NOx and 10.0 g/mi for CO. Based on ARB's emissions factors model (EMFAC), this is projected to occur during the 1990s. As the table shows, the cost/effectiveness ratio for HC + NOx is projected to rise to \$2.30/pound. CO cost/effectiveness rises to \$0.32/pound. (Even if emission reductions could not be improved beyond the 12% HC and 4% NOx reductions achieved in 1986, the cost/effectiveness of the program would still be close to \$5/pound for HC+NOx, within the range of other HC control programs adopted by ARB and local air pollution control districts.)

The projected benefits of annual inspection frequency were estimated in Sierra's 1987 report at 3-5%. Since then, more sophisticated estimates of annual inspection frequency have been made using a new computer-based I/M model that Sierra is developing for ARB under a separate contract. Under the program changes occurring as a result of SB 1997, the computer-based model projects incremental HC and CO benefits of five percentage points with annual inspection frequency.

It is possible that annual inspection frequency could also introduce some economies of scale into I/M testing, thereby reducing the cost of each test. To investigate this possibility, Sierra performed an extensive analysis of Test Analyzer System data. For tests conducted during a one week period in September of 1988, Sierra analyzed the distribution of testing activity for 1,784 randomly selected Smog Check stations (about 25% of the total). The results of the analysis are presented in Figures 28 through 32.

Table 19

1986 Timeframe Estimate of the
Cost/Effectiveness of Improved Smog Check Program
Without Loaded Mode Testing

Costs:

\$30 + 2 =	\$15	(annual average inspection fee)
+ 6 + 2 =	3	(annual avg. cost for Smog Certificate)
+ (\$100 × 0.35) + 2 =	17.50	(annual avg. repair cost per vehicle)
	<u>\$35.50</u>	(total annual cost per vehicle)
+ 2		(50% of costs assigned to HC + NOx)
	<u>\$17.75</u>	(annual cost for HC + NOx control)
	\$17.75	(annual cost for CO control)

Emission Reductions:

2.11 g/mi HC × 25.0% =	0.53 g/mi	(HC reduction)
1.55 g/mi NOx × 10.0% =	0.16 g/mi	(NOx reduction)
	<u>0.69 g/mi</u>	(HC + NOx reduction)
	× 10,000 miles/year	(annual vehicle mileage)
	<u>15.20</u>	pounds of HC + NOx (annual reduction)
23.71 g/mi CO × 25.0% =	5.93 g/mi	(CO reduction)
	× 10,000 miles/year	(annual vehicle mileage)
	<u>130.56</u>	pounds of CO (annual reduction)

Cost/Effectiveness:

HC + NOx Cost/Effectiveness Ratio = \$17.75 ÷ 15.20 lbs. = \$1.17/pound

CO Cost/Effectiveness Ratio = \$17.75 ÷ 130.56 lbs. = \$0.14/pound

Notes: Cost for inspections is estimated to increase to approximately \$30 due to the cost of new analyzers and the additional time required for mechanics to perform more thorough inspections.

Average repair cost for improved I/M programs is expected to increase to about \$100, reflecting an increase in repair work.

Emission reduction estimates based on the minimum required reductions of SB 1997 (25% for HC and CO, 10% for NOx).

Table 20

1990s Timeframe Estimate of the
Cost/Effectiveness of an Improved Smog Check Program
Without Loaded Mode Testing

Costs:

	\$30 + 2 =	\$15	(annual average inspection fee)
	+ 6 + 2 =	3	(annual avg. cost for Smog Certificate)
	+ (\$100 × 0.35) + 2 =	17.50	(annual avg. repair cost per vehicle)
		<u>35.50</u>	(total annual cost per vehicle)
	+ 2		(50% of costs assigned to HC + NOx)
		<u>17.75</u>	(annual cost for HC + NOx control)
		17.75	(annual cost for CO control)

Emission Reductions:

1.00 g/mi HC × 25.0%	=	0.25 g/mi	(HC reduction)
1.00 g/mi NOx × 10.0%	=	0.10 g/mi	(NOx reduction)
		<u>0.35 g/mi</u>	(HC + NOx reduction)
		× 10,000 miles/year	(annual vehicle mileage)
		<u>7.71 pounds</u>	(annual reduction)
10.00 g/mi CO × 25.0%	=	2.50 g/mi	(CO reduction)
		× 10,000 miles/year	(annual vehicle mileage)
		<u>55.07 pounds</u>	(annual reduction)

Cost/Effectiveness:

HC + NOx Cost/Effectiveness Ratio = \$17.75 ÷ 7.71 lbs. = \$2.30/pound

CO Cost/Effectiveness Ratio = \$17.75 ÷ 55.07 lbs. = \$0.32/pound

Notes: Cost for inspections is estimated to increase to approximately \$30 due to the cost of new analyzers and the additional time required for mechanics to perform more thorough inspections.

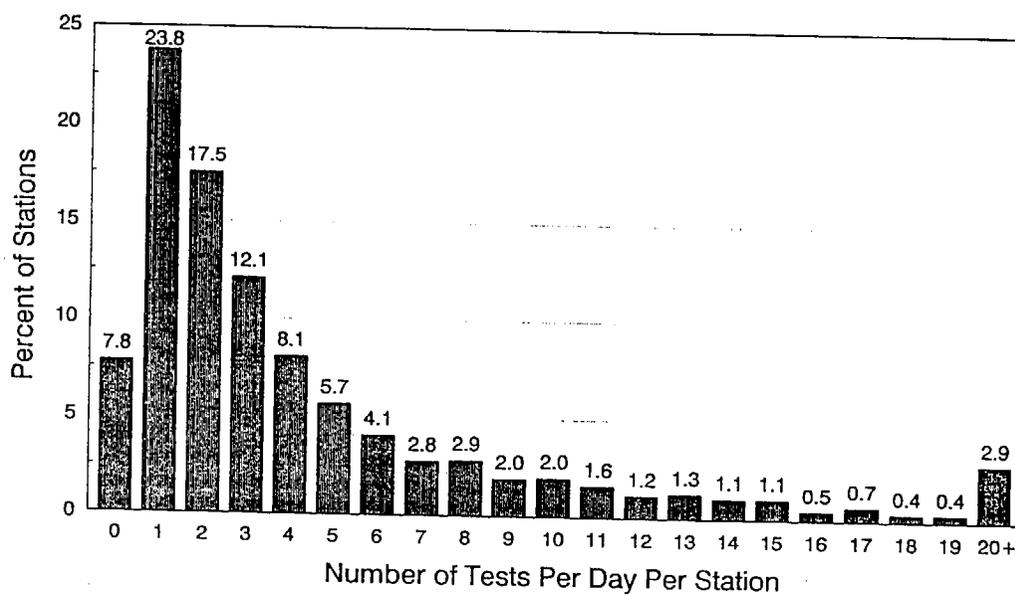
Average repair cost for improved I/M programs is expected to increase to about \$100, reflecting an increase in repair work.

Emission reduction estimates based on the minimum required reductions of SB 1997 (25% for HC and CO, 10% for NOx).

As shown in Figure 28, most Smog Check stations perform relatively few tests per day on the average. 23.8% average only one test per day. Almost 80% of the stations perform six or less tests per day. However, 2.9% of the stations perform twenty or more tests per day on the average.

Figure 28

Average Daily Smog Check Station Volume

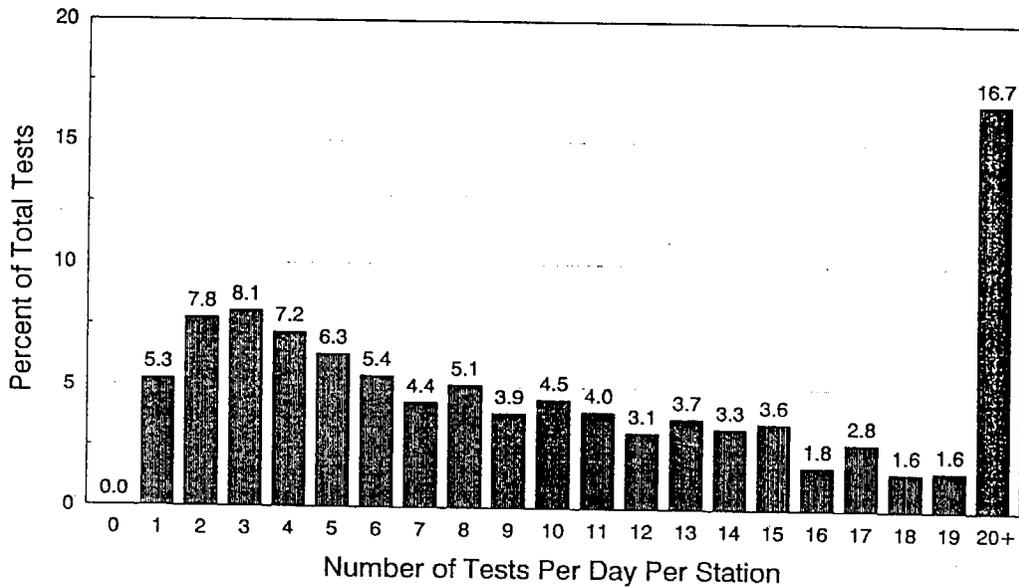


Average of 1,784 stations during
week in September of 1988.

Figure 29 shows a much flatter distribution for the percent of total tests performed by stations with various averages for number of tests per day. Note that only 40% of the tests are performed by stations that average six or less tests per day. Note also that 16.7% of the stations perform 20 or more tests per day.

Figure 29

Distribution of Total Tests By Average Daily Test Volume For Smog Check Stations

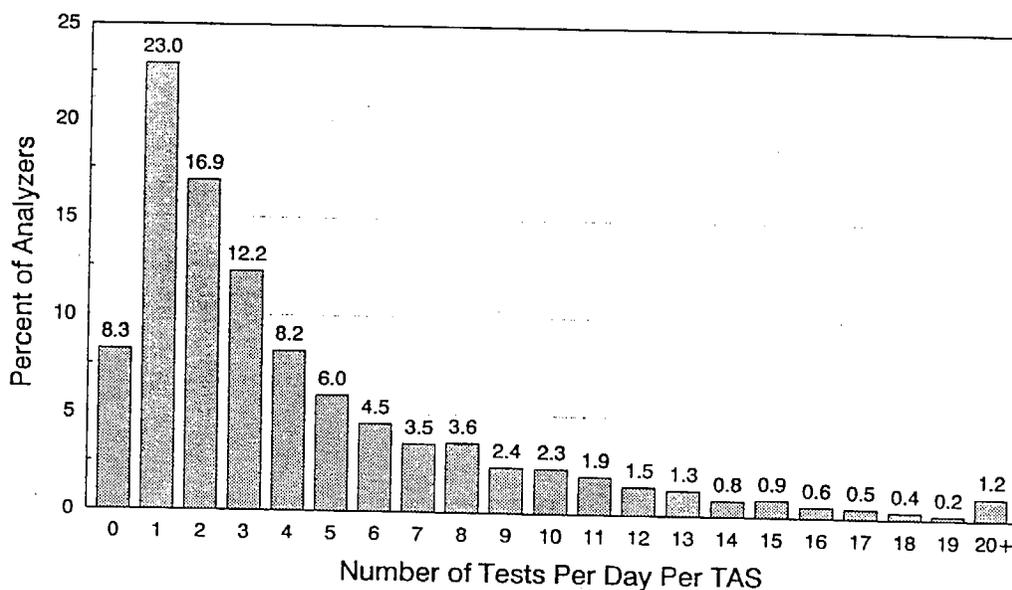


Average of 1,784 stations during week in September of 1988.

Figure 30 shows that the distribution of average daily Test Analyzer System usage looks very similar to the average daily Smog Check station volume. Most TAS machines perform relatively few tests per day on the average. 23% average only one test per day. As was the case with Smog Check stations, almost 80% of the analyzers are used for six or less tests per day. Note that only 1.2% of the analyzers are used to perform twenty or more tests per day on the average.

Figure 30

Average Daily Test Analyzer System Usage

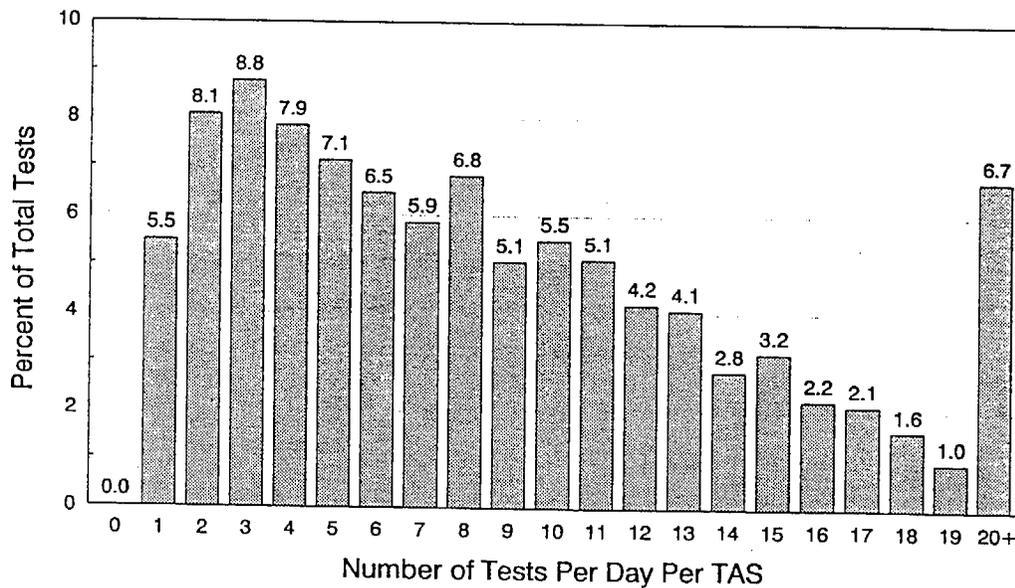


Average of 1,784 stations during week in September of 1988.

As was the case with Figure 29, Figure 31 shows a much flatter distribution for the percent of total tests performed by TAS machines with various averages for number of tests per day. 44% of the tests are performed by analyzers that average six or less tests per day. Note, however, that just 6.7% of the stations perform 20 or more tests per day. By comparing Figures 29 and 31, it is obvious that the high volume Smog Check stations have more than one analyzer.

Figure 31

**Distribution of Total Tests
By Average Daily Test Volume
For Test Analyzer Systems**

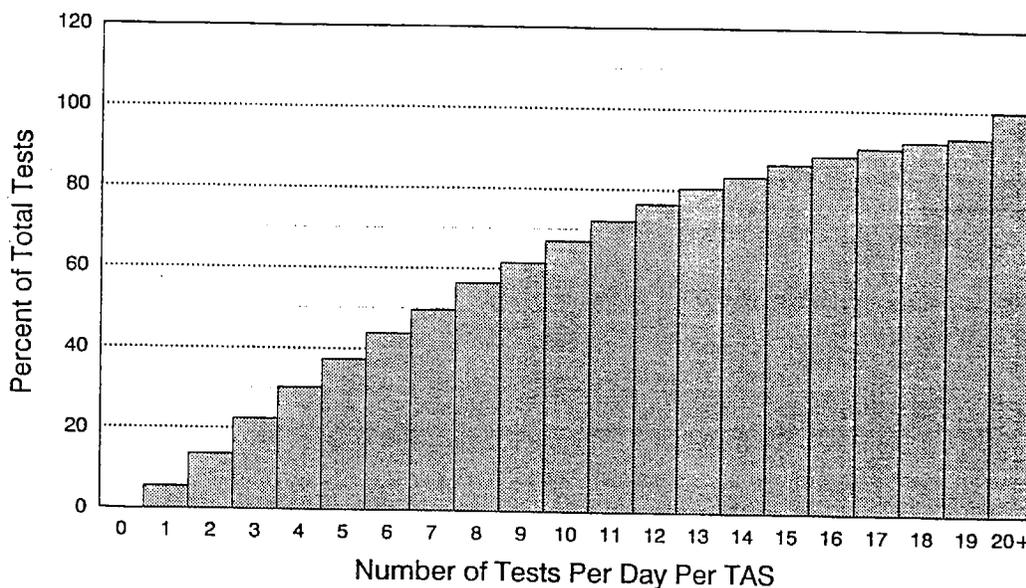


Average of 1,784 stations during week in September of 1988.

Figure 32 shows the cumulative distribution of tests by average daily volume for Test Analyzer Systems.

Figure 32

Cumulative Distribution of Tests By Average Daily Test Volume For Test Analyzer Systems



Average of 1,784 stations during week in September of 1988.

So many Smog Check stations are already doing such a high volume of testing that the utilization of analyzers and garage space may not be substantially improved under an annual inspection program. Because more than half of the testing volume is associated with stations that do more than six tests per day, no discounts were projected to the increased testing load associated with a change to annual inspection frequency. Table 21 summarizes the results of the calculation for what the cost/effectiveness of loaded mode testing would have been during the 1986 timeframe. Table 22 projects cost/effectiveness of annual inspection frequency when the average emissions of the vehicle fleet drop to 1.0 g/mi for HC and CO and 10 g/mi for CO.

Table 21

1986 Timeframe Estimate of the
 Cost/Effectiveness of Improved Smog Check Program
 With Annual Inspection Frequency

Costs:

	\$30	(annual inspection fee)
	6	(annual cost for Smog Certificate)
+ (\$75 × 0.35) =	26	(annual avg. repair cost per vehicle with 35% failure rate)
	<hr/>	
	\$62	(total annual cost per vehicle)
+ 2		(50% of costs assigned to HC + NOx)
	<hr/>	
	\$31	(annual cost for HC + NOx control)
	\$31	(annual cost for CO control)

Emission Reductions:

2.11 g/mi HC × 30.0% =	0.63 g/mi	(HC reduction)
1.55 g/mi NOx × 10.0% =	0.16 g/mi	(NOx reduction)
	<hr/>	
	0.79 g/mi	(HC + NOx reduction)
	× 10,000 miles/year	(annual vehicle mileage)
	<hr/>	
	17.4 pounds	of HC + NOx reduction
23.7 g/mi CO × 30.0% =	7.11 g/mi	(CO reduction)
	× 10,000 miles/year	(annual vehicle mileage)
	<hr/>	
	156.6 pounds	of CO reduction

Cost/Effectiveness:

HC + NOx Cost/Effectiveness Ratio = \$31 ÷ 17.4 lbs. = \$1.78/pound

CO Cost/Effectiveness Ratio = \$31 ÷ 156.6 lbs. = \$0.20/pound

Notes: Estimates based on estimated 5 percentage point increase in reductions of HC and CO above the minimum required reductions of SB 1997 (25%).

Estimates assume 50% reduction in average repair cost for added inspection cycle due to combined effects of lower failure rate and reduced repair requirements for more frequent inspections (illustrated above as 25% reduction in average repair cost for two years at constant failure rate).

Table 22

1990s Timeframe Estimate of the
 Cost/Effectiveness of Improved Smog Check Program
 With Annual Inspection Frequency

Costs:

	\$30	(annual inspection fee)
	6	(annual cost for Smog Certificate)
+ (\$75 × 0.35) =	26	(annual avg. repair cost per vehicle with 35% failure rate)
	<hr/>	
	\$62	(total annual cost per vehicle)
+ 2		(50% of costs assigned to HC + NOx)
	<hr/>	
	\$31	(annual cost for HC + NOx control)
	\$31	(annual cost for CO control)

Emission Reductions:

1.00 g/mi HC × 30.0% =	0.30 g/mi	(HC reduction)
1.00 g/mi NOx × 10.0% =	0.10 g/mi	(NOx reduction)
	<hr/>	
	0.40 g/mi	(HC + NOx reduction)
	× 10,000 miles/year	(annual vehicle mileage)
	<hr/>	
	8.8 pounds	of HC + NOx reduction
10.0 g/mi CO × 30.0% =	3.00 g/mi	(CO reduction)
	× 10,000 miles/year	(annual vehicle mileage)
	<hr/>	
	66.1 pounds	of CO reduction

Cost/Effectiveness:

HC + NOx Cost/Effectiveness Ratio = \$31 ÷ 8.8 lbs. = \$3.52/pound

CO Cost/Effectiveness Ratio = \$31 ÷ 66.1 lbs. = \$0.47/pound

Notes: Estimates based on estimated 5 percentage point increase in reductions of HC and CO above the minimum required reductions of SB 1997 (25%).

Estimates assume 50% reduction in average repair cost for added inspection cycle due to combined effects of lower failure rate and reduced repair requirements for more frequent inspections (illustrated above as 25% reduction in average repair cost for two years at constant failure rate).

Potential Long-Term Cost/Effectiveness Under SB 1997

There are at least two fundamentally different techniques that could be employed to maximize the benefits of I/M in the future. One technique involves the use of more sophisticated on-board diagnostic (OBD) systems. The ARB staff is currently pursuing the development of increasingly complex requirements for OBD systems that could theoretically enable the onboard computer to detect essentially all emissions-related defects. With an electronic link between the vehicles equipped with advanced OBD systems and the Test Analyzer System, it could be possible to have the TAS determine whether the OBD system has identified any emissions-related defects in the vehicle being tested. If this technology proves successful, the emissions reductions achieved during the Smog Check program could approach the theoretical maximum possible within the constraints of the repair cost ceilings that apply to the program. The increased cost associated with an OBD-based Smog Check program is expected to be primarily related to the increased cost of repairing the additional defects identified by the system. The cost of incorporating the necessary modifications into the BAR'94 analyzer currently under development are expected to be small.

One drawback of an OBD-based Smog Check program is that none of the vehicles already on the road are equipped with the necessary OBD systems. The current plans of the ARB staff are to require such systems on all light-duty vehicles by the 1995 model year. Until beyond the turn of the century, it will not be possible to rely on an OBD approach to achieve maximum I/M benefits. Until most vehicles are equipped with advanced OBD systems, maximum I/M benefits may require more expensive, loaded-mode testing.

Sierra's recent evaluation of loaded mode test procedures for BAR indicated that it may be feasible to use procedures that do not require transient testing. This minimizes the cost of equipment required to conduct loaded mode testing in Smog Check stations. Table 23 summarizes the expected cost of dynamometer testing based on Sierra's survey of equipment vendors. As the table shows, the cost of the NOx instrumentation was estimated at about \$4,000, and the dynamometer is about \$8,000. Other costs bring the total cost of steady state loaded mode testing equipment to \$16,500 per Smog Check station.

To estimate the effects of loaded mode testing, the worst case (i.e., highest cost) assumption would be that most currently licensed Smog Check stations get involved in loaded mode testing. If 8,000 stations are involved in the program and there are 1,000,000 tests per month, the increased cost per test associated with the amortization of a \$16,500 investment for each station would be about \$3 computed using a 10% cost of funds and a 5 year amortization period, as shown below.

Table 23

Incremental Costs for
Steady State Loaded Mode Testing

NOx Instrumentation	\$ 4,000
TAS Modifications to Interface with Dyno	1,000
Dynamometer	8,000
Site Preparation Charges	2,500
Miscellaneous equipment and supplies (cooling fans, etc.) ..	1,000
	\$16,500

$$\text{annualized cost} = \frac{\text{capital cost} \times i(1+i)^a}{(1+i)^a - 1}$$

where: a = amortization period and i = cost of funds.

$$\text{annualized cost} = \frac{\$16,500 \times .161}{0.61} = \$4,353$$

$$\text{annualized cost per test} = \$4,353 \div 1,500 = \$2.90$$

With maintenance and operating cost of the loaded mode testing equipment estimated at 33% of the capital cost, the total increase in test fee associated with the additional equipment would be about \$4. However, if the time required to conduct the test increased by about 10 minutes (to account for the time required to secure the vehicle to the dynamometer and remove it) the total inspection cost would be increased by another \$8, for a total of \$42 per inspection.

Repair cost would also be expected to increase because the failure rate would increase to about 50%. Increased defects in EGR systems will be detected. In addition, it should be easier to detect closed loop systems that have failed in a lean operating mode. The same average repair cost for a failed vehicle (i.e., \$100) should be

* Vehicles which exceeded 0.7 grams/mile NOx on the FTP were detected 80% of the time by the 2% error of commission standard for a new loaded mode test that Sierra recently developed under contract to BAR. On 1981 and later models, five out of six EGR disconnects were detected with this procedure. In addition, there were no errors of commission among the test vehicles.

sufficient to address these types of defects. The increase in repair cost per vehicle subject to the program would therefore be \$15 per inspection cycle, or \$7.50 per year.

This estimate of the same average repair cost for loaded mode failures is consistent with Sierra's earlier analysis of data from the I/M Evaluation program. Of six 1980 and later models that achieved NOx emission benefits of 50% or more, five had disconnected or leaking vacuum lines that resulted in failure of the EGR system. Review of the diagnostic comments on vehicles that were not repaired also indicates that simple vacuum line problems are a common cause of increased NOx emissions. Repair of these defects would be under \$10. The other successful NOx repair identified during the I/M Evaluation program involved replacement of the oxygen sensor. At an average cost of \$150, this repair will generally be covered by the increased repair cost ceilings that apply to the Smog Check program under SB 1997. Although the diagnostic information available from the I/M Evaluation program was inadequate to determine the significance of other sensor failures on NOx emissions, coolant temperature sensor failures can also cause a loss of NOx control. Repair of such sensors is under \$100.

Had a maximum effort I/M program been implemented in the 1986 timeframe, the results would have been as estimated in Table 24. As average emission levels improve the cost/effectiveness of maximum effort I/M programs would be expected to degrade, as shown in Table 25.

COMPARISONS WITH SIERRA'S I/M MODEL

Under a separate contract with ARB, Sierra Research is developing a computer model for simulating the effects of I/M under a variety of potential program provisions. The model uses a number of "technology categories" to separate advanced technology vehicles from older vehicles with fundamentally different emission control systems. Within each technology category, the fleet is divided into five different "emitter categories" or "regimes":

1. Normals;
2. Moderates;
3. Highs;
4. Very Highs; and
5. Supers.

Table 24

1986 Timeframe Cost/Effectiveness of
a Maximum Effort Smog Check Program
With Loaded Mode Testing

Costs:

	\$42 + 2 -	\$21.00	(annual average inspection fee)
	+ 6 + 2 -	3.00	(annual avg. cost for Smog Certificate)
	+ (\$100 × 0.50) + 2 -	25.00	(annual avg. repair cost per vehicle)
		<hr/>	
		\$49.00	(total annual cost per vehicle)
	+ 2	(50% of costs assigned to HC + NOx)	
		<hr/>	
		\$24.50	(annual cost for HC + NOx control)
		\$24.50	(annual cost for CO control)

Emission Reductions:

2.11 g/mi HC × 48.6%	=	1.03 g/mi	(HC reduction)
1.55 g/mi NOx × 20.3%	=	0.31 g/mi	(NOx reduction)
		<hr/>	
		1.34 g/mi	(HC + NOx reduction)
	× 10,000 miles/year		(annual vehicle mileage)
		<hr/>	
		29.52 pounds	of HC + NOx (annual reduction)
23.71 g/mi CO × 48.6%	=	11.52 g/mi	(CO reduction)
	× 10,000 miles/year		(annual vehicle mileage)
		<hr/>	
		253.74 pounds	of CO (annual reduction)

Cost/Effectiveness:

HC + NOx Cost/Effectiveness Ratio = \$24.50 ÷ 29.52 lbs. = \$0.83/pound

CO Cost/Effectiveness Ratio = \$24.50 ÷ 253.74 lbs. = \$0.10/pound

Notes: Cost for inspections is estimated to increase to approximately \$42 due to the cost of loaded mode testing equipment and longer testing time.

Average repair cost for improved I/M programs is expected to stay at about \$100 but the failure rate is estimated to increase to about 50%.

Table 25

1990s Timeframe Cost/Effectiveness of
a Maximum Effort Smog Check Program
With Loaded Mode Testing

Costs:

	\$42 + 2 =	\$21.00	(annual average inspection fee)
	+ 6 + 2 =	3.00	(annual avg. cost for Smog Certificate)
	+ (\$100 × 0.50) + 2 =	25.00	(annual avg. repair cost per vehicle)
		<u>\$49.00</u>	(total annual cost per vehicle)
	+ 2		(50% of costs assigned to HC + NOx)
		<u>\$24.50</u>	(annual cost for HC + NOx control)
		\$24.50	(annual cost for CO control)

Emission Reductions:

1.00 g/mi HC × 48.6%	=	0.49 g/mi	(HC reduction)
1.00 g/mi NOx × 20.3%	=	0.20 g/mi	(NOx reduction)
		<u>0.69 g/mi</u>	(HC + NOx reduction)
		× 10,000 miles/year	(annual vehicle mileage)
		<u>15.2</u>	pounds of HC + NOx (annual reduction)
10.00 g/mi CO × 48.6%	=	4.86 g/mi	(CO reduction)
		× 10,000 miles/year	(annual vehicle mileage)
		<u>107.05</u>	pounds of CO (annual reduction)

Cost/Effectiveness:

HC + NOx Cost/Effectiveness Ratio = \$24.50 ÷ 15.2 lbs. = \$1.61/pound

CO Cost/Effectiveness Ratio = \$24.50 ÷ 107.05 lbs. = \$0.23/pound

Vehicles that meet the standards they were certified to meet are in the "normal" category. Vehicles in this category are generally properly maintained and free from emissions-related defects. The only way vehicles in this category fail an I/M test is if they have been inadequately preconditioned (or are "pattern failure" vehicles), or have problems detected during an underhood inspection that have no significant effect on exhaust emissions (e.g., evaporative emissions control system defects, PCV disconnection, thermostatic air cleaner disconnection, etc.). Unless the problem is due to evaporative or crankcase emissions, vehicles in this category tend to have higher emissions if they fail a Smog Check and have repairs attempted.

Vehicles with minor problems are in the "moderate" category. Emissions of the moderates were greater than the standards, but less than twice the standards. Most vehicles in this category will pass an I/M test unless they have defects that can be identified during an underhood inspection.

Vehicles with more serious emissions defects are in the "high" category. The emissions of high emitters were 2-5 times the standards for hydrocarbons; 2-6 times the standards for CO; and 2-4 times the standards for NOx.

"Very high" emitters were 5-9 times the standards for HC; 6-10 times the standards for CO and 4-8 times the standards for NOx.

Finally, vehicles with gross defects are in the "super" emitter category (≥ 9 times the HC standard, ≥ 10 times the CO standard, ≥ 8 times the NOx standard).

Within the model, the distribution of the fleet among the five emitter categories is based on the actual distribution of emissions observed from vehicles recruited by ARB under the in-use surveillance and I/M evaluation programs. The effect of I/M on vehicles in each emitter category is based on what was observed during the I/M Evaluation Program and restorative maintenance/repair efforts by ARB staff. To represent the current level of mechanic training and enforcement, movement between categories is based on the I/M Evaluation Program. To represent the maximum theoretical benefits of I/M, the effect of repairs by ARB technicians are used by the model.

One of the advantages of the I/M model is that it provides for the simulation of I/M programs that differ from the current program in certain ways. For example, the effect of improving repair quality can be evaluated by using the data from repairs by ARB technicians. Future year programs can be simulated by modifying the population of vehicles within each technology category. Sierra has therefore attempted to use the new model to estimate the effect of the program enhancements mandated by SB 1997.

Table 26 shows how the emission benefits for the Smog Check program computed from the new I/M model compare to the manually calculated benefits used in the 1987 report to the Legislature from the California I/M Review Committee. Except for NOx emissions, the benefits predicted by the I/M model correspond reasonably well with the benefits calculated manually. The correlation between the predictions is not surprising given the fact that similar deterioration assumptions were used in Sierra's manual calculation of benefits. Had Sierra assumed the post-I/M deterioration for pre-1975 models to be as large as observed for the recaptured vehicles, our manual calculation of the benefits of the program would have been about 1% lower for HC and CO.

Table 26

Comparison of Predicted Benefits: Baseline Program

	--- Pollutant ---		
	<u>HC</u>	<u>CO</u>	<u>NOx</u>
I/M Model	10.6%	11.8%	0.0%
Manual Calculation	12.3	9.8	3.9

The discrepancy in NOx emissions benefits is a result of the I/M modeling approach in which each pollutant was analyzed separately. As explained in Sierra's report on the development of the I/M model, the lack of NOx benefits predicted is due to the inability of the idle test to detect NOx emission failures and the low degree of mechanic accuracy in identifying the NOx-related component defects through the visual/functional check. During the earlier analysis of the I/M Evaluation Program data, it was determined that 20% of the excess NOx emissions are identified "by accident" because some vehicles with high HC and CO emissions also have high NOx emissions. Because each pollutant was modeled separately, the "accidental" detection and correction of excess emissions of pollutants other than the one for which the analysis was being conducted is not addressed in the I/M model.

It should be noted that the benefit estimates manually calculated for the 1987 report to the Legislature were computed for one complete I/M cycle (about mid-1986). However, the deterioration characteristics of repaired vehicles appear to be such that benefits become compounded over time. Using the new I/M model, the Smog Check program benefits in 1988 are increased to about 16% for hydrocarbons and 18% for carbon monoxide. Reductions from the program are projected to peak around 1990, with approximately a 17% reduction in HC and a 18% reduction in CO, and then level off about 2012 with reductions of 17% HC and 11% CO. However, substantial changes to the program are anticipated to occur in the near future.

Under Senate Bill 1997, repair cost ceilings are being increased and several measures are being incorporated to increase mechanic performance. The model predicts that two-tier mechanic licensing requirements, increased cost limit for repairs and computerized emission test analyzers will increase the benefits of the program to approximately 27% HC, 26% CO and 4% NOx by 1995 and 28% HC, 22% CO and 4% NOx by 2010.

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Section 5

I/M REVIEW COMMITTEE SUPPORT

During the course of the contract, support to the I/M Review Committee under Tasks 3 and 5 encompassed a large number of work assignments, many of which were very short term in nature and did not require any memoranda or reports. Examples of such subtasks included: attending all meetings of the I/M Review Committee and providing technical support to Committee members; providing technical support to the I/M Review Committee and CARB staff during meetings with the California Highway Patrol to discuss a roadside inspection program for heavy-duty trucks; responding to telephone inquiries from the I/M Review Committee Chairman; and drafting letters for the I/M Review Committee to send to the Bureau of Automotive Repair, the Automotive Service Councils, and other parties.

A number of other subtasks performed for the I/M Review Committee were more time consuming in nature and culminated in the production of more tangible work products. These subtasks included:

- editing of the Review Committee's omnibus I/M bill, originally drafted by Sierra under a previous contract;
- performance of a comprehensive evaluation of Bureau of Automotive Repair Smog Check enforcement program (Appendix A);
- development of a series of "fact sheets" for use by the I/M Review Committee during the consideration of its omnibus I/M bill during the 1988 Legislative session (Appendix B);
- development of an implementation plan for a roadside emissions inspection program for heavy-duty trucks (Appendix C);
- drafting a presentation and paper for I/M Review Committee Chairman Sommerville commenting on EPA's methodology for auditing and evaluating I/M programs (Appendix D); and
- drafting the I/M Review Committee's 1989 report to the California Legislature (Appendix E).

The support provided by Sierra related to the Committee's I/M legislation (SB 1997) contributed to the enactment of the bill (Presley, Ch. 1544, Statutes of 1988) with relatively minor changes from its original form. Program enhancements required by the bill are currently being implemented. Sierra's evaluation of the BAR enforcement program identified several changes that BAR agreed would enhance the effectiveness of Smog Check program. The heavy-duty roadside emissions inspection program implementation plan prepared by Sierra is also being implemented at the present time. That program is

expected to lead to reductions in the number of smoking trucks on California roadways.

Section 6

TEST ANALYZER SYSTEM DEVELOPMENT SUPPORT

The Test Analyzer System (TAS) used in Smog Check stations is key to the effectiveness of California's decentralized I/M program. Introduced in 1984, the first version of the TAS provided computerized selection of standards, computer-controlled pass/fail decisions, computerized checking for exhaust system leaks, and automatic data recording for subsequent analysis. While this was a big improvement over the previously used analyzers, the 1984 version of the TAS provides very little in the way of diagnostic capability and very limited data storage capability. Greatly expanded capabilities were designed into a new "BAR'90" TAS specification developed by Sierra under a previous ARB contract.

Under this contract, Sierra provided additional support to ARB and BAR related to the completion of the BAR'90 detailed specifications. In addition to serving as a technical resource during BAR workshops, Sierra developed a detailed specification for a "Vehicle Information Data File" that will eventually be maintained within each BAR'90 analyzer. The vehicle information data file is designed to maximize the effectiveness of the Smog Check program by reducing the frequency of improper vehicle descriptions, ensuring that all of the components subject to visual and functional inspections have been accurately identified, allowing manufacturer specifications for maximum idle speed to be used instead of some universally applicable upper limit, allowing model-specific exhaust dilution limits to be used, allowing model-specific emission standards to be used in the future, allowing recall campaign requirements to be identified at the Smog Check station and allowing Smog Check mechanics to confirm recall completion, and providing model-specific diagnostic tips to Smog Check mechanics.

The concept developed by Sierra involves using two distinct types of records in the vehicle information file. As shown in Table 27, the first record type is called the "Model Identification Record". It contains fields with unique combinations of model year, type (e.g., gasoline-fueled passenger car), make (e.g., Buick), model (e.g., Riviera), number of cylinders, engine size, transmission type, and California certification indicated on the underhood label. With this information, it is possible to accurately estimate the weight of the vehicle and the applicable "engine family" (using the 12 byte EPA engine family designation scheme). (In rare cases where a unique engine family cannot be identified, a special engine family record would have to be constructed by merging the information for each of the possible engine families.) As shown in the following table, 36 bytes of information should be sufficient for this file. (Note that an agreed-upon translation from all possible model names to a four byte code is required.)

Table 27

Proposed Model Identification Record

Field		
<u>No.</u>	<u>Contents</u>	<u>Bytes</u>
Match With User Input:		
1.	model year	2
2.	type (PG, PD, LG, LD, MG, MD, HG, or HD)	2
3.	make (alphabetic)	4
4.	model (alphanumeric)	4
5.	number of cylinders	2
6.	engine size	3
7.	transmission type (M, A, or E)	1
8.	California label (Y, N, G, or U)	1
9.	last two VIN digits	2
Other Vehicle Characteristics:		
20.	loaded vehicle weight	3
21.	engine family ID	12
		36

Because there are many different models that may share a common engine family, Sierra proposed that all of the engine-family-specific information be contained in a separate 512 byte "Engine Family Information Record", as shown in Table 28. (Note in this record, the engine family identification field contains two additional bytes to cover the model year.) The Engine Family Information Record is proposed to contain all of the information needed to ensure that the visual and functional inspection entries are reasonable. In addition, the record is designed to allow engine-family-specific idle speeds, preconditioning routines, and emission standards. Space is reserved for the identification of up to four different emissions-related recalls that the vehicle may be involved in. Space has also been set aside for nine lines of text, at 40 characters per line. This could include hints to mechanics regarding problems that are known to exist on certain models. Space has also been set aside for adding expanded diagnostic capabilities in the future. For example, there is sufficient space provided to add internal resistance or voltage specifications for certain sensors that may be included in the system.

The definition of several elements of the vehicle information record requires coordination with ARB. For example, the draft we have provided assumes ARB will agree to establish and enforce a requirement for a seven digit recall campaign identification number for each emissions-related recall performed by vehicle manufacturers. (We selected seven digits because we know some manufacturers have used seven digit recall campaign identification numbers in the past.)

Table 28

Proposed Engine Family Information Record

Field		
<u>No.</u>	<u>Contents</u>	<u>Bytes</u>
1.	engine family ID	14
Emissions Control System Description:		
2.	catalyst (T, D, O, N, or E)	1
3.	air (A, P, N, or E)	1
4.	evap (number of canisters)	1
5.	PCV (Y, N, or E)	1
6.	fillpipe restrictor (Y or N)	1
7.	EGR (Y, N, or E)	1
8.	oxygen sensor (number or E)	1
9.	spare	1
10.	spare	1
11.	spare	1
12.	spare	1
13.	spare	1
Other Engine Characteristics:		
14.	maximum idle speed	3
15.	maximum allowable dilution	3
16.	preconditioning sequence	1
17.	spare	3
18.	spare	3
19.	spare	3
20.	spare	3
21.	spare	3
22.	spare	3
23.	spare	3
24.	spare	3
25.	spare	3
Engine Specific Emission Standards:		
26.	idle HC	4
27.	idle CO	2
28.	2500 HC	4
29.	2500 CO	2
30.	2500 NOx	4
31.	loaded HC-1	4
32.	loaded CO-1	2
33.	loaded NOx-1	4
34.	loaded HC-2	4
35.	loaded CO-2	2
36.	loaded NOx-2	4

----- continued on next page -----

Table 28, Engine Family Record (continued):

Field No.	Contents	Bytes
Recall Campaign Information:		
37.	Campaign I.D. Number	7
38.	Campaign I.D. Number	7
39.	Campaign I.D. Number	7
40.	Campaign I.D. Number	7
Model Specific Messages:		
41.	Message 1	40
42.	Message 2	40
43.	Message 3	40
44.	Message 4	40
45.	Message 5	40
46.	Message 6	40
47.	Message 7	40
48.	Message 8	40
49.	Message 9	40
Record Update Code:		
50.	Creation Date	6
51.	Comment	22
		512

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Section 7

TECHNOLOGY ASSESSMENT AND STANDARDS DEVELOPMENT

A major effort under Task 6 of the contract was the preparation of a draft of a report to the Legislature in response to Senate Concurrent Resolution 100. The final version of the report, entitled "Progress Report on Reducing Public Exposure to Diesel Engine Emissions," is contained in Appendix F. That report summarizes ARB's past efforts in controlling Diesel emissions and outlines the Board's plan for further controls. The report also describes related programs being conducted by the California Energy Commission and the South Coast Air Quality Management District.

Under Task 6, Sierra also provided additional support to ARB related to the modification and refinement of a Technical Support Document in support of new standards and test procedures for medium- and light-heavy-duty vehicles. The proposed changes would establish HC, CO, and NOx standards for medium-duty and light-heavy-duty trucks that are equivalent in stringency to the 0.25 g/mi HC, 3.4 g/mi CO, and 0.4 g/mi NOx standards for passenger cars and light trucks. For Diesel-powered vehicles, the particulate standards would be set to require the same degree of control as required by the 0.08 g/mi standard for light-duty vehicles.

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