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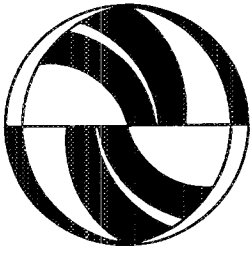
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**Clean for a Day:
Troubles with California's Smog Check**

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**The University of California
Transportation Center**

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**Clean for a Day:
Troubles with California's Smog Check**

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*Report to the California State Senate Committee on Transportation
August 1993*

UCTC No. 163

The University of California Transportation Center
University of California at Berkeley

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Executive Summary

Summary of the Report

We have carefully reviewed “Evaluation of the California Smog Check Program and Recommendations for Program Improvements: Fourth Report to the Legislature.” Overall, we find it a thorough and competent presentation of the basic facts, though we disagree with the conclusions. Our major concern is one of perspective. It appears that the authors of the report are simply too close to the issue, too enmeshed in the details of implementation. We think it worthwhile to step back from the technical issues to take an overall view of the inspection and maintenance (I/M) program for reducing auto emissions.

California’s current inspection program is designed to assure that cars are clean one day every two years—the inspection day. Successive programs have focused on improving that test, and on reducing inspection fraud. We worked hard at making that one day cleaner and cleaner, while ignoring the car’s performance on the other 729 days. The program recommended by the Fourth Report continues this clean-for-a-day focus.

The first extensive inspection program in California, the BAR84, failed. Then the state tried another extensive inspection program, the BAR90, and it failed. Now the EPA proposes that we try a third version. These programs have two main characteristics: they are universal and periodic. Universal, in that they test all cars¹ though we know that only about 15% of the cars

¹More precisely, inspection is required of all cars and trucks fueled by gasoline, propane, and compressed natural gas in areas where the program is implemented.

are dirty,² thus largely wasting the money and time of 85% of the drivers. Periodic, in that the inspections occur at fixed times with long intervals between tests. It has been said that such periodic testing is akin to a program that “controls” drunken driving by scheduling drivers for a breathalyzer test every two years. Obviously, it is the performance between tests that matters.

At the time the BAR84 and BAR90 programs were designed, the problems with universal periodic testing were known. But the designers had little choice—there was no economically feasible way to perform random testing on a large scale. It is now possible to perform such tests with remote sensors, and so it is time to reorient our approach.

Consider the three causes of high emissions: tampering, deterioration, and breakage of the vehicle’s emissions control system. How effective is periodic testing against them? Periodic inspection is unlikely to deter tampering: the car owner simply fixes it before inspection and re-tampers afterwards. Given the long interval between smog checks, he can look forward to two years of undisturbed driving. Periodic inspection does detect worn or broken emission components but, given the two-year inspection interval, only after they have polluted for a long time.

Rather than continuing to refine the periodic test, it seems wise to try a different approach, an approach that utilizes frequent, random testing to detect offending motorists between biennial inspections.

This new approach is strongly supported by recent research on I/M pro-

²EPA reply to questions during hearings on the Fourth I/M report, 29 July, 1992, page 7, gives the 15% figure. About a third of all cars will fail the emissions tests, but cars close to the passing line are difficult to repair, and may even come out dirtier after the repairs—see Table I below. More importantly, these data show that about half of total emissions are generated by only 15% of all cars.

grams. We now know:

- Most emissions come from only a small proportion of the vehicles. Compelling data, from several sources, show that half the total emissions come from about 15% of the cars.
- A properly performed BAR90 test will detect these gross emitters. Implication: given that the BAR90 can detect high emitters, and yet they are still on the road, we conclude the problem is enforcement rather than testing. We do not know whether the greatest effect would come from improving the performance of inspectors, from deterring motorists who tamper cars, or from testing vehicles more frequently to detect breakage and deterioration. But some kind of monitoring between inspections via remote sensing would deal with any of these causes.
- Though the IM240 test is better than the BAR90 for identifying emissions, the differences are not large compared to the effects of tampering, deterioration, and breakage between inspections. The largest advantage of centralized testing comes from the allegedly higher competence of centralized inspectors—they may know cars better, they may be more careful, and hence they may do a better inspection. We think this is unlikely, given the low wage rates assumed by the EPA. (The IM240 also has an advantage with its NO_x and purge testing, but if these are deemed critical, the BAR90 can be modified to perform them at relatively low cost.)
- A full IM240 program will take a long time to implement. In particular,

given California's environmental permit process, it may be difficult to gain siting permits for these stations—consider the amount of delay that a few home owners, or smog check stations, might cause.

- A full IM240 program is likely to seriously inconvenience motorists because of the added time to locate, drive to, and then wait for an inspection. The EPA says the queue will be only 5 minutes. But this measures the delay during a typical hour, not the delay experienced by a typical motorist. It is analogous to saying that “Los Angeles freeways are uncongested during a typical hour” because there are 18 non-rush hours, though this statement hardly describes the congestion experienced by most drivers.

Critics of remote sensing point out that it is only a one-second snapshot of a car's emissions, not a measure of the performance over an entire driving cycle.³ These one-second snapshot readings may be unusually high or low and hence the remote sensor will miss some polluters while falsely picking on some clean cars.

The way around the problem is to flag only those cars with very high emission readings. This guards against “false fails,”⁴ though it does allow some gross emitters to escape on any given sensing event. (The EPA used this same strategy to reduce the number of false fails on the IM240.) But if cars are monitored 2-3 times per year, by a remote sensor, then the chance that a gross emitter can escape detection becomes very low. Since the gross emitters are the major part of the emission problem, this strategy can have a great impact.

³But evidence suggests that these could be adequate to detect high-polluting vehicles.

⁴A false failure arises when a low-emitting car is tagged as a high emitter.

Recommendations

We see three major I/M alternatives: the IM240 program with some remote sensing to monitor effectiveness; the existing BAR90 program supplemented by remote sensing; and a pure remote sensing program without periodic inspection. We do not *know* which of these alternatives is best. Neither can the EPA. The evidence is not sufficient to make a considered judgement.

These uncertainties make it irrational to build a costly, extensive network of IM240 test stations. True, some analysts strongly believe it will work, but California has already implemented two other highly recommended I/M programs that did not turn out as expected. The program proposed in the Fourth Report is even more expensive, and the investments are irreversible if the program proves ineffective.

Neither remote sensing nor IM240 are mature I/M programs—we know little about their effectiveness under actual large scale implementation. Fresh, important information about what they can do, their limitations, and how to use them emerges every month. It makes sense to delay major commitments to these programs, while further exploring their potential. Toward that end we recommend the following Interim Program:

- Continue biennial inspections with the existing decentralized BAR90 stations. Supplement this with a fleet of remote sensors to randomly test cars between inspections, and add a few centralized IM240 test stations too.
- Require that any car flagged by the remote sensor must be inspected

at a special referee facility within 30 days. If it fails the test there, it must be repaired and then retested.

This interim program has many desirable features:

- This program can be implemented quickly. The initial referee facilities can be specially certified BAR90 stations; we phase-in the new IM240 test stations as they are built. And it only requires enough neighborhood-acceptable IM240 sites to provide inspection capacity for about 15% of the cars, the gross emitters.
- The program can be self-financing. Relatively low fines/fees at the referee stations can easily pay the cost of the remote sensing network.
- The benefits of the program begin quickly. It has the potential to strongly deter tampering, deterioration, and breakage between inspections, and fraud during inspections.
- It collects data needed to evaluate the three alternative I/M programs: 1) it field-tests and corrects any operational problems with the IM240 stations and the remote sensors; 2) it produces realistic data on waiting times, ping pong problems, repair costs, etc.
- The implementation is incremental: the untried new technology is phased-in gradually, with careful evaluation at each stage. In contrast, the EPA's centralized IM240 program is an expensive, giant leap into the unknown.

- The average daily reading of the remote sensors can directly measure the auto fleet's on-the-road emissions. For the first time we will have an actual gauge of effectiveness.
- This approach preserves Smog Check employment—at least in the short run, while we await evaluation of the results from this program.
- Remote sensing also has the advantage of sharing one of the important features of centralized testing—it separates testing and repair, and thus goes some way to meet the mandates of the EPA.

Our recommended Interim Program might be implemented on a statewide basis, or in a single geographic area. A promising variation on this idea would be to conduct a comparison test between the alternative programs: implement each on a small scale in a geographically distinct area of the state, then monitor the results to see which is most effective.

The I/M question turns on human issues, not engineering ones. How much fraud and tampering exist and how can we deter it; how can we encourage motorists to maintain their cars; how will inspection stations function in terms of waiting time, detection and repair of problems, and cost effectiveness. Only experience can resolve these questions. Theoretical arguments will not do it. The Interim Program is designed to provide an immediate I/M improvement while collecting the needed data.

By the end of the proposed testing period, we will know where we ought to go next, and how to get there. Before trying yet one more expensive universal inspection program, it is worth implementing this modest supplement to the existing I/M program. It is an excellent transition strategy, no matter where we want to end up.

Adopting the EPA program would be a mistake. It is expensive. It will entail years of delay before there is any effect. It is likely to seriously inconvenience drivers. And most of all, there is no evidence that leads us to believe the EPA program will actually reduce vehicular emissions.

Clean For a Day: Troubles with California's Smog Check

1 Introduction

California's inspection and maintenance (I/M) program for auto emission controls suffers from several widely acknowledged problems. The California I/M Review Committee, in its Fourth Report to the Legislature,⁵ makes two basic recommendations for reform. First, the existing BAR90 test machines should be replaced by a new dynamometer test machine. Second, the existing system of multiple, private testing centers should be replaced by a system of centralized, state controlled, testing centers.

We reviewed the I/M issue with particular emphasis on three topics: 1) The cost to the motorist—both dollar cost and inconvenience—of the new centralized I/M program versus the current decentralized program. 2) The possible uses of remote sensing as a supplement for I/M programs, or even a replacement for them. 3) The expected effectiveness of the different programs for reducing vehicle emissions.⁶

In preparing this report we reviewed "Evaluation of the California Smog Check Program and Recommendations for Program Improvements: Fourth Report to the Legislature" (hereafter, the Fourth Report) plus a great deal of the scientific literature. Overall, we find the Fourth Report to be a thorough

⁵Sommerville (1993), p. 22. We henceforth call this the Fourth Report, and call Sommerville (1991) the Third Report.

⁶The California Senate bill that authorized the Fourth Report asks that the report "recommend the most cost-effective way" of handling the I/M problem (Fourth Report, p. 30), and that the review committee find "the most effective and cost-effective frequency of inspection" (Fourth Report, p. 31). That is, our emphasis on efficiency is in line with the original intent of the California legislation.

and competent document, one that carries out the task assigned to it. We disagree with some details, but our major concern is one of perspective. Though it is vital to consider details of implementation, we also think it important to step back from the technical issues to take an overall view.

Doing so makes evident a quite different set of recommendations. Rather than continuing down the existing path in an ever more determined and expensive fashion, it becomes obvious that more attention must be given to vehicle emissions between inspections. Rather than ever more elaborate testing, we need to monitor the vehicle's actual performance, thereby focussing on outcomes.

Adding to the existing I/M program remote sensors which measure emissions will provide a fast, inexpensive, way to implement this new perspective. It will also generate the overall performance measures that can tell us whether centralized IM240 programs are needed.

2 Failure of Earlier Programs

Consider the history of California's I/M efforts. We tried three I/M programs, each successively tougher. 1) The state began by inspecting vehicles when they were sold or resold. After a few years, the state decided that I/M program was not working well. 2) So it decided to inspect all cars, and to use a more sophisticated testing machine, the BAR84. After a few years, the state decided this program was not working well either. 3) So it devised a still more sophisticated testing machine, the BAR90. Now a few years later, it appears that this program is not working well either. Just looking at the second and third I/M efforts, in the period since 1984, these programs have

cost about 2.4 billion dollars and used one hundred million hours of motorist time.⁷

What have these enormous expenditures accomplished? Not much. The Fourth Report estimates that in 1992 vehicle emissions were reduced by a small amount: 6.7 percent reduction in NO_x, 15.3 percent reduction in CO, and an 18.2 percent reduction in HC. But it is important to note that these figures are only estimates. They come from an abstract computer model of how the world is supposed to work. They do not come from measurements of actual results. Consider a simple analogy: suppose your mechanic proposes to sell you an expensive new ignition system for your car, claiming that it will improve your fuel economy by twenty percent. "How do you know it will give a twenty percent increase?" you ask. He replies that he has a theoretical mathematical model of how combustion occurs in the engine—it shows the complex interactions between the different variables and predicts the effect of changes in their values. And you ask, "But have you ever gone out and measured the change in gasoline consumption on an actual car after you installed the new ignition system?" And he replies that he has not.

That is how I/M programs are now evaluated. We have theoretical models of how they are supposed to work but almost no measures of actual effects. And what data we do have is hardly reassuring. It shows little or no improvement in vehicle emissions from the I/M program.

Whether one believes that the current I/M program is insufficiently effective (the conclusion of the Fourth Report) or is totally ineffective, it is clear that we ought to think through a different approach to the problem. The

⁷This is a rough estimate based on 10 million inspections per year, \$30/inspection, and 75 minutes of lost time for each inspection—time per inspection taken from Table 24 of the Fourth Report.

Fourth Report and the federal EPA propose to greatly expand our investment in the current approach of mandatory, periodic, inspection. But before spending more money to extend the current approach, it is worth considering how we got to our present condition.

2.1 Earlier Predictions

The major fact to notice is that each of the previous I/M programs was introduced with high hopes, based on expected benefits that subsequently turned out to be substantially over-estimated.

The first wide-ranging inspection and maintenance program in California was implemented in 1984. The federal Environmental Protection Agency (EPA), which mandated the program, estimated that it would reduce emissions of hydrocarbons and of carbon monoxide by 25 percent.⁸ The results were disappointing. In 1987, a legislative review committee reported that the program reduced hydrocarbon emissions by only 12.3 percent, and reduced carbon monoxide emissions by only 9.8 percent.⁹ Effectiveness was, at best, only half that predicted.

The Smog Check program was extended in 1990. (Among the changes was the use of more accurate testing equipment.) The report to the legislature that recommended these changes predicted emission reductions of 28 percent for hydrocarbons, 27 percent for carbon monoxide, and 12 percent for nitrous oxides. But the Fourth Report (p. 57) estimated that actual reductions were only a third to one-half of the predicted amounts. These disappointing results are based on computer models, not actual air quality measurements. Other

⁸Fourth Report, p. 33.

⁹Fourth Report, p. 34.

data find that the programs were even less effective, or perhaps even totally ineffective.

In 1989, 1990, 1991, and 1992 the state of California conducted random roadside surveys of automobiles. Recall that Smog Check programs are required only in those parts of the state with poor air quality. We would therefore expect to find lower emissions in areas where cars are subject to Smog Check than where they are not. The opposite holds. In areas of the state without Smog Checks, 23 percent of the cars were found to have defective or tampered emissions equipment. In areas of the state subject to a Smog Check, a larger proportion had such defects—25 percent. In areas of the state without Smog Checks, 33 percent of the cars were found to have excessive emissions. In areas of the state subject to a Smog Check, a higher proportion failed—38 percent. Obviously this comparison does not take into account any relevant demographic differences between the two areas: one might argue that big city folks are just more prone to corruption in the first place, hence the Smog Check was causing them to behave almost as honestly as people who live in small cities. But if Smog Checks have a large effect, then to account for the measured data we must assume that the difference in honesty between the populations was very large in the first place.¹⁰

Another way of evaluating the program is to compare the emissions of cars just before they had a Smog Check to cars just after a Smog Check. A 1989 roadside survey in California inspected 4,421 vehicles, giving many of them the equivalent of a Smog Check. Cars which were scheduled to receive a Smog Check within the next 90 days had a failure rate of 39 percent.

¹⁰Lawson (1993) provides a complete review of both the comparative tampering data, and the pre- post-inspection data discussed in the next paragraph.

The failure rate for cars which had gone through a Smog Check within the previous 90 days was higher—42 percent. A similar study in 1991 found similar results. Of 190 vehicles tested within 90 days *before* the Smog Check, 32 percent failed the roadside Smog Check. Of 218 vehicles tested within 90 days *after* the Smog Check, the failure rate was higher—37 percent.¹¹

3 Causes for Failure

Why such failures? The reasons offered are imperfect Smog Checks by private garages, the difficulty of repairing cars with high emissions, tampering of cars by their owners, and the difficulty of identifying the cars which cause high emissions. We consider these in more detail.

3.1 Smog Check Stations Do Not Identify Defects

The data suggest that inspectors often overlook defects. Thus, the Fourth Report describes a 1992 study in California which involved undercover cars; these cars were brought to Smog Check garages by hired personnel who presumably had no prior business relation with the garage. This study found that fewer than 60 percent of stations were able to identify *any* defect, and that only about 25 percent found all the defects in a car.¹² In a random roadside survey conducted in 1991, 33 percent of all cars failed the roadside inspection, compared to a 11 percent failure rate in Smog Check stations. The

¹¹Cited by Walsh (1993), pp. 9-10. As we shall see below, most of the emission reduction from a Smog Check program come from repairing 4 percent of the cars. A limited random sample of cars may therefore not capture the effects of the program.

¹²This ability to visually identify underhood defects has barely improved since a review in 1986, in spite of major efforts by the Bureau of Automotive Repair. See Fourth Report, p. 51, Table 12. The difference in failure rates may also be caused by car owners repairing tampered cars immediately before a scheduled inspection.

main problem with inspections at garages appears in underhood inspections: In 1989 Smog stations reported that only 10 percent of all vehicles failed the underhood inspection, whereas 33 percent of the cars examined in roadside inspections failed the underhood inspection.¹³

3.2 Corruption

The other explanation for inadequate inspections is corruption. A consumer may request an inspector to pass a car that should fail smog inspection. Alternatively, a garage may take the initiative in passing a car that should not—perhaps to assure a customer that the repairs he had just paid for were worthwhile. Another incentive operates in garages that advertise “Pass or Don’t Pay:” the garage earns the inspection fee only if it issues a smog certificate. We have seen no data bearing on the extent of this problem.

3.3 Garages Cannot Repair Cars

An effective Smog Check program must not only identify cars with excess emissions, but also repair the problems. Section 2.1 cites data indicating that emissions are not lower in cars that had just gone through a Smog Check, compared to cars about to do so. Tampering and corruption are possible reasons behind such a result. Simple inability to repair defective cars is another.

We analyzed repair histories on 682 cars that were part of an undercover study of Smog Checks in California. They are a subset of an 1,100 car I/M sample that had failed a Smog Check performed by the ARB. This subset had the following characteristics: they failed a Smog Check performed at

¹³Third Report, p. 19.

independent garages, were repaired, and were now certified by the garages to have passed the Smog Check. We ranked the 682 cars by their initial emissions levels, and split them into two groups: the cleanest half, those that had been closest to passing the original Smog Check; and the dirtiest half. After they were repaired, the average car in the clean half now had emissions which were actually 8 percent *higher*. The cleanest decile of cars had their emissions increase by over 16 percent. Only the dirtiest group of cars consistently benefited from repairs. The following table reports on emissions before repairs, and on the contribution of repairs to reducing emissions. A negative number indicates an increase in emissions.¹⁴

Decile	FTP HC emissions		FTP CO emissions	
	% of total	% of total reductions	% of total	% of total reductions
10th	44.2	83.6	31.7	67.6
9th	15.2	10.2	19.5	22.4
8th	10.7	5.2	14.4	22.7
7th	8.2	4.4	10.6	2.9
6th	6.6	2.4	7.8	0.8
5th	5.3	-3.6	5.7	-2.7
4th	3.9	0.8	4.2	-9.1
3rd	2.8	-1.5	2.9	-0.4
2nd	1.9	-1.1	2.0	-2.5
1st	1.1	-0.4	1.1	-1.8

Repair problems are not limited to California mechanics. The General Accounting Office (Peach (1992)) reports that current Smog Check programs in other states also have problems fixing out-of-compliance vehicles. For example, in a state program considered by the EPA to be one of the nation's

¹⁴Lawson (1990) shows a similar result on a different data base.

best, of all cars that had failed an inspection and then been repaired, nearly 40 percent were still unable to pass the emission test.

Consider two kinds of defective cars: those that deteriorated, and hence have unknown defects; and those that were tampered, and hence have defects known to the tamperer. Given the difficulty of diagnosing cars with unknown defects versus the ease of restoring a tampered car, an attack on tampering should have big effects.

3.4 Tampering

The Smog Check program may fail because car owners tamper with emissions devices: drivers may disconnect smog control devices to increase performance, reconnect the devices just before a smog inspection, and then disconnect them immediately after. Or rather than repair a defective part which reduces emissions, a driver or mechanic may remove the part. Tierney (1991) finds that in states with decentralized Smog Check programs, the tampering rates were 8 percent for catalytic converters, 11 percent for evaporative canisters, 12 percent for inlets, and 13 percent of fuel switching (e.g. using leaded instead of unleaded fuel). Studies in San Diego and Bakersfield found overall tampering rates of 11 and 16 percent (these rates are lower than found in almost all other states with I/M programs, but not much lower than in states with no I/M program).¹⁵ The rate of tampering in California also has declined over time, suggesting that better enforcement has some effect. But even a low rate of tampering can be responsible for a large fraction of total emissions given the importance of a few gross polluters.

¹⁵Data provided by the California Bureau of Automotive Repair, Program Evaluation and Planning Branch

4 The Problem of Gross Polluters

Most cars are clean. The dirtiest 10-15 percent, the gross polluters, produce about half the total emissions.¹⁶ These data provide a startling perspective on I/M programs: we need not inspect every car. Reducing the emissions of these gross polluters can reduce total emissions in the fleet by almost a half, and likely by more than the 32 percent improvement mandated by the EPA. A cost-effective I/M program should focus on the gross polluters.

Two extensive literature surveys document the basic facts: one coauthored by J.H. Seinfeld, a member of the first “blue ribbon” committee was just published in *Science*, the other by a contractor.¹⁷

To give further detail, we summarize two specific studies. Naghavi and Stopher (1993) used a remote sensing unit to measure exhaust emissions of carbon monoxide and hydrocarbons from over 24,000 vehicles in Baton Rouge, Louisiana. They find that more than half the carbon monoxide was emitted by 7 percent of the vehicles.¹⁸ About half the hydrocarbons were emitted by 20 percent of the vehicles measured.¹⁹ Over 80 percent of the vehicles were clean, emitting less than 1 percent carbon monoxide, and contributing only 24 percent of total emissions. For hydrocarbon emissions, 70 percent of the vehicles emit less than the mean. Stedman and Bishop (1990) conducted a similar study in Chicago. Half the carbon monoxide was emitted by 8 percent the vehicles. Twelve of the 671 vehicles (2 percent) were

¹⁶Typically, 10% of the cars account for half the HC, and 10% of the cars account for half the CO, though not necessarily the same 10%—however the two groups are correlated, and so it might require about 15% of the fleet to cut emissions of both HC and CO in half.

¹⁷Calvert, et al, 1993, p. 40; Hughes (1992), p. 1-1.

¹⁸Naghavi and Stopher (1993), p. 9.

¹⁹Page 10. The cars with high emissions of carbon monoxide need not, however be the same cars that emit high hydrocarbons.

responsible for 13 percent of the total carbon monoxide emissions.²⁰

These studies sampled the total auto population, clean and dirty. The same pattern of concentration holds among polluting cars. Among the 682 cars that had failed a Smog Check in California, shown in Table I, ten percent of these dirty cars accounted for 44 percent of the hydrocarbon emissions by the entire group of dirty cars.

4.1 Random Testing

If most emissions are caused by a small fraction of all cars, and if these emissions are caused by tampering, negligence, or improper repairs, then random testing has the advantage of surprise—the car-owner is in constant jeopardy. This should have a considerable deterrent effect.²¹ Thus random testing will catch many polluters and deter many others. A program of

²⁰Page xi. A draft report by Sierra Research notes the possibility that variability in the performance of a vehicle can cause remote sensing data to show that a few cars emit most of the pollution, and yet all cars could have identical average emissions over a typical driving cycle. That possibility, however, appears to be an academic curiosity. Our analysis of the results of the FTP tests performed on the 1,100 car sample, reported in the Fourth Report (see below) shows the same pattern: even in this sample of cars that had *all* failed a smog check, even using the FTP data, a tiny proportion of the vehicles produce most of the total emissions. Nor are the false failure rates found with remote sensors consistent with the hypotheses that they are merely identifying as polluters vehicles with momentary high emissions. Finally, the EPA projects that (on a national basis, and following a phase-in period) an IM240 program would fail about 15 percent of vehicles studied. In short, many separate sources of data support the same conclusion: an I/M program should focus on a small fraction of the vehicle fleet.

²¹The general literature on the criminal justice system indicates that the deterrent effect depends more on the chance of being caught than on the size of the penalty associated with being caught. Thus Heineke (1988), using data from official arrest records maintained by the California Department of Justice, finds large deterrent effects from increased certainty of punishment and much smaller, generally insignificant effects, from increased severity of sanction. Witte (1980) reaches a similar conclusion from her analysis of North Carolina prison releases: the certainty of punishment carried a greater deterrent effect than punishment severity.

random testing which commonly tests cars more frequently than once every two years has the added advantage of identifying high emissions caused by sudden failure of components.

5 Difficulties with IM240

In light of the issues described above, can we expect the proposed IM240 program, or a slightly modified one, to greatly reduce emissions? Consider its effect on tampering. The Fourth Report emphasizes that the current Smog Check program does not sufficiently deter tampering, and fails to identify many cars that were tampered (see Table 12, page 51). An implicit claim in the Report is that tampering will decline under centralized testing since tampered cars will not be able to obtain fraudulent certificates as easily as they purportedly can now. Even so, a centralized testing program may have little effect on tampering. A car owner can correct any tampering before the known date of the biennial test, pass it, then re-tamper afterwards, looking forward to two years of undisturbed driving. Centralized IM240 testing makes it somewhat more expensive to tamper compared to the current system (where imperfect inspections by garages may make it unnecessary for a driver to correct the tampering before the inspection). But the Report gives no evidence on the magnitude of the expected decline in tampering.

5.1 Costs

The Fourth Report argues that the IM240 program will reduce costs to motorists. How? There are two changes: a new testing device, and centralization of testing. Since the new testing device will be more expensive than the

current one, any cost savings must be due to the centralization itself. The Fourth Report says that centralization will produce better use of the testing equipment (more tests per hour). Another claimed saving results because centralized testing will decrease the driver's time-cost: the time to find an I/M station will decline, and time for the actual test will decline. We examine each of these statements in more detail below, but first we consider their economic logic.

Try a simple thought experiment. Imagine a *centralized* testing system based on the current BAR90 test equipment. It could offer even lower prices than the proposed new IM240 system: capital costs would be lower, and it would have equal time-reductions for motorists. Now consider that any entrepreneur could actually open this hypothetical system testing station right now. No special permissions or laws are needed to do so because it is nothing more than a high volume BAR90 facility. If the cost assumptions in the Fourth Report held true, this high volume BAR90 facility would take over the testing industry—it offers lower prices and greater convenience.

Yet no one has opened such a facility.²² No entrepreneur has started a high volume BAR90 testing station, though it should be an enormous economic success—according to the assumptions of the Fourth Report. Why not? Is it that no one has been smart enough to see this opportunity, or is it that the assumptions in the Fourth Report are wrong? Well, we know that entrepreneurs take advantage of high volume in other businesses: supermarkets wiped out medium sized stores and have, themselves, recently come

²²California has a few test-only stations that inspect 10,000-12,000 per year. But even at that size, they are less than a fifth of the testing volume assumed at centralized stations in the Fourth Report. Furthermore, these few medium-volume stations have not proven to be a competitive threat to the low volume stations that blanket California.

under attack from warehouse stores; similar warehouse stores wiped out the small stores that used to sell appliances, building supplies, and general consumer goods. Entrepreneurs take advantage of economies of scale when they exist in other areas, so we have to conclude that the assumptions used in the Fourth Report's analyses are problematic.

5.1.1 Capital Costs of Program Proposed in Fourth Report

A detailed examination of Table 16 in the Fourth Report shows that values of some important variables were chosen with little support: 1) The Report assumes that the costs of dynamometers will fall by half when purchased in large volume (page 81). No supporting data are given. But no such savings are allowed when considering the purchase of equipment by thousands of decentralized stations. 2) All the calculations are performed using the expected values of variables, such as for lane efficiency (see Figure 13, page 89). But as we know from the literature on queuing and from empirical observation, even a slight increase in variance can have catastrophic effects on waiting times and on output.

5.1.2 Time Costs of Program Proposed in Fourth Report

The Fourth Report does examine the "indirect costs" of the new program, its convenience and time-cost to the driver. Table 24 compares the time cost of the current and proposed systems. No documentation is given for the key numbers, and some do not seem entirely reasonable. We reproduce some of these:

TABLE II

Time-Using Activity	Current Program	Proposed Program
Time for driver to locate test facility	10 min.	5 min.
Time to drive to and from test facility	20 min.	30 min.
Waiting time for inspection	15 min.	5 min.
Time for inspection	30 min.	10 min.

Examining these assumptions in order: 1) Why should it be faster for a driver to discover a centralized I/M test facility under the proposed program? The current program has about 9,000 test facilities scattered everywhere, each easily spotted because of their BAR "Smog Check" signs. 2) The travel time to one of the current I/M testers seems high—they are everywhere. The travel time to a centralized test facility seems low—there will only be 90 of them spread over the areas of the state subject to the program. 3) The 5 minute queuing time projected for the centralized stations may be optimistic. The data cited in the report are for queuing time on a "typical" day, but drivers bunch up on some days, and we need to account for this.²³ The analogy would be to say that "Los Angeles freeways are uncongested during a typical hour" (because there are 18 non-rush hours), though this statement hardly describes the congestion experienced by most drivers. 4) The inspection time for decentralized stations may be too high. Many car owners ask for the I/M inspection as an add-on when they drop off their cars for routine servicing, so the extra inspection time to the driver is zero.

²³For example, one report has the average waiting time on Saturdays at almost fifteen minutes, more than double the average wait on other days; the wait was twenty-five minutes on one of four Saturdays in the month. These numbers may underestimate the wait for a typical driver if congestion is higher during those parts of the day when many owners come for an inspection.

Though these cost and time assumptions might be correct, they are undocumented assumptions. Our point is that many entrepreneurs had a chance to evaluate the same assumptions and concluded they are wrong. They did not build centralized high volume test stations because they concluded that the reduced dollar cost would not offset the extra time cost to the consumers.

5.2 Jobs

The Fourth Report projects a net increase of about five hundred jobs from implementation of centralized testing.²⁴ Since centralized testing stations are supposed to require fewer personnel than decentralized testing, the source of new jobs must be an increase in repair work. Such an argument, however, assumes that consumers who spend money on repairs would otherwise not have spent it at all. This is a basic economic fallacy. A person faced with an unexpected \$200 charge to repair his emissions system will reduce other expenditures: he may decide that he now cannot afford to go out to a restaurant, or that he cannot afford the body work on his car he had previously contemplated. Jobs will not increase; consumer spending is diverted, not increased.

Moreover, to the extent that excess emissions are caused by intentional tampering, a program which deters tampering will not increase repair work. On the contrary, it may reduce consumer demand for modifications of emission systems.

²⁴Fourth Report, page 104.

5.3 Accuracy

The IM240 system is often claimed to very accurately measure emissions. Some data show otherwise. According to the General Accounting Office²⁵:

We reviewed EPA data on vehicles that were initially tested at the Hammond, Indiana testing site and subsequently tested at EPA's contractor laboratory facility in New Carlisle, Indiana. We found that test results can vary substantially from one location to the other. We identified 64 vehicles—1986 model year or newer—that failed the IM240 test at the Hammond testing site and were sent for further test and repair services at the contractor's laboratory. In each case the laboratory emission test results varied from lane test results for at least one pollutant. Eighteen of the 64 vehicles, or 28 percent, that initially failed an IM240 test at the Hammond testing site passed a second IM240 test at the laboratory in New Carlisle, even though no repairs were made to the 18 vehicles.²⁶

5.4 The Experience in Vancouver, Canada

Data on the performance of centralized testing in other areas is sketchy. Wisconsin and Maine are reported to have successful programs. Vancouver, British Columbia does not. Since we have the most information on Vancouver's program, and since their experience shows the problems that California would have to avoid, we shall describe it at more length.²⁷ The Vancouver

²⁵Peach (1992)

²⁶The EPA notes that all these vehicles failed an FTP test and needed repair; the problem of false failures, however, remains.

²⁷The following information is based on conversations with a technical advisory representative from the Canadian Automobile Association.

program, begun in September 1992, consists of 12 test-only stations which use a dynamometer to test for HC, CO and NO_x, and which also use under-the-hood inspections to check for evaporative emissions. It was found that the underhood inspections were taking too long, so they were later discontinued to reduce motorist's waiting time.

The program has faced two difficulties: a labor strike for higher wages, and long wait times. The dispute over wages arose because the operator of the facilities hired untrained labor, trained them, but then continued to pay wages appropriate for unskilled labor.

The waits at the beginning of the Vancouver program were as long as 4 1/2 hours. These long waits occurred with roughly 39 lanes per 1 million vehicles in Vancouver, a *better* service ratio than proposed for California. The long wait times were caused in part by a 40 percent failure rate for inspected cars, instead of the 25-30 percent failure rate expected when the system was designed. Waiting times have since been significantly reduced, by halving the testing regimen, eliminating the under-the-hood test, and exempting vehicles built since 1986. "Ping-pong" effects are not significant because a vehicle repaired at a certified repair station obtains a waiver even if it does not pass emission standard upon re-inspection.

6 Remote Sensing

Although remote sensing has many attractive features as a component of Smog Check programs, critics question its accuracy: remote sensing only measures emissions for the one second interval when the car passes by. This sample may not accurately measure the vehicle's overall performance. Its

instantaneous emissions may be unusually high if it is still in cold start mode, or if the driver is accelerating or decelerating quickly. So the remote sensors might “fail” an innocent car. Likewise, a car’s instantaneous emissions might be unusually low if it is in some cruise modes. So the remote sensors might allow a guilty car to “pass”.

To gain perspective about the accuracy of remote sensors we must consider the accuracy of the alternative testing devices. The EPA assumes that the only accurate device for measuring emissions is the Federal Test Procedure (FTP) machine. The test begins with a cold start, following at least twelve hours of non-operation, followed by an hour-long test on a dynamometer under a variety of acceleration and deceleration loads designed to mimic the driving pattern a car might go through in an hour of typical city driving. There is considerable dispute as to whether the FTP driving cycle is typical of actual driving²⁸, but given the federal laws the FTP is the mandated standard and hence is “accurate” by definition.

All other emission testing devices—the BAR84, BAR90, IM240, ASM, or remote sensor—only approximate the results of the FTP. Sometimes they say a car is clean when it is not. Sometimes they say a car pollutes heavily when it does not; such a false “pass” allows a car to emit more pollutants than it should. The false pass problem may be especially severe with periodic tests which measure emissions only once every two years. If emissions are variable, especially by high-emitters (perhaps caused by intermittent electrical problems), then such periodic tests are likely to miss many of the high emitters. Inspection frequency becomes a critical variable.

A false “fail” on the test also has serious consequences: 1) The car will

²⁸Calvert, Heywood, Sawyer, and Seinfeld (1993), p. 41

be sent for unnecessary repairs, thus wasting the owner's money and time.
2) Some of the "repaired" cars will be made dirtier.²⁹

Consider the problem of false fails in broader perspective. The Environmental Protection Agency says that 85 percent of the cars on the road are clean enough to be ignored.³⁰ The current universal inspection law requires that these clean cars be inspected anyway, thus costing their owners substantial time and money, and creating the danger that some percentage of them will be erroneously failed, mis-repaired, and hence come out dirtier than they went in.

The major reason for false-fails and false-passes is that auto-emissions are not constant: a given car may have high or low emissions depending upon how it is driven at that particular moment. The FTP test averages the car's performance over an hour. Other emissions tests take very brief samples and hence their results are subject to more uncertainty: does a given high reading on the test indicate a real problem or is it only a transient condition? Thus, any test requires a careful empirical calibration of the cutpoint to be used in flagging dirty cars.

This problem is illustrated by the evaluation of remote sensing done in the Fourth Report.³¹ The researchers took 340 cars with known FTP test ratings and drove them by remote sensors. Consider their analysis of the CO test. They found that cars with high CO reading from the FTP test also had high CO reading on the remote sensor. But they also found much variability.

²⁹Recall that of all the cars that failed the Smog Check, Table I showed that the cleanest half of them actually had higher emissions after they were repaired.

³⁰EPA reply to questions during hearings on the Fourth I/M report, 29 July 1992, page 7.

³¹Pages 127-130.

Consider two examples. Suppose we get a remote sensor reading that indicates a car's emissions contain 1 percent CO. Should we pass or flag the car? According to the data in the Fourth Report, a 1 percent cutpoint would catch 78 percent of the high emitters, but it would also accuse 12 percent of the clean cars. This is too many false-fails.

Suppose we use a higher cutpoint and flag all cars that show 4 percent or higher on the remote sensing meter. According to the data in Table 35, the false accusation rate would drop to only 0.6 percent, but we would only catch 34 percent of the dirty cars. Thus to reduce the number of false fails, we apparently must let many guilty cars escape.

The Fourth Report concludes that it is impossible to choose a remote sensor cutpoint that provides a reasonable balance between effectiveness and false failures: either we miss most of the high emitters, or fail too many innocent cars.

This conclusion is valid if we are limited to a single remote sensing test of the vehicles every two years, but it is not true if all vehicles are subject to multiple remote sensor tests over the course of a year. Assume we use the 4 percent cutpoint, and assume that the average car goes by a remote sensor six times over two years. Under these assumptions a clean car would have only a 3.7 percent chance of being flagged over the biennium, while a dirty car would have only an 8 percent chance of escaping. (Appendix I considers these calculations in more detail. We recognize that the data in Table 35 are test results from vehicles operated under controlled conditions, but the general point remains valid: by increasing the cutpoint we can reduce the number of false failures, and by increasing the number of tests per year we can reduce the number of false passes.) A proper cutpoint for remote sensors

combined with multiple readings per year can generate both relatively few false fails and many correct fails of high emitters.

Compare this to the proposed IM240 program. The IM240 test also makes false failures. An EPA study at Hammond, Indiana measured each of 213 cars twice. The study found an R^2 of 0.66 between these measurements.³²; 20 percent of the cars were falsely failed.³³ Consider the consequences of a false fail with the remote sensors versus the IM240. Under remote sensing, cars that exceed the test cutpoint would be required to go to a centralized test facility to be evaluated. The car would pass, and would not be charged for the test, so the false fail on the remote sensor costs the owner only his lost time. But a false failure under the proposed IM240 program requires the owner to go for repairs and then back to the IM240 test again. Thus the owner bears the cost of the repair, plus the repair time, plus twice as much test time as a remote sensing fail. (Furthermore, remember that the IM240 program requires all owners to be tested every two years even though 85 percent do not need testing, thus the “false fail” rate of any universal inspection program is, in effect, at least 85 percent.)

Finally another aspect of emissions variability must be considered. On many vehicles the emissions control system is broken in such a fashion that the emissions vary randomly. This produces the testing variability noted by the GAO, and the “flipper” behavior noted by Lawson. Sometimes these vehicles are within standards, sometimes not. If such a vehicle is tested during one of its occasional clean periods, it receives a false pass and is free to pollute for two more years.

³²Hughes (1992), p. 2.18.

³³To reduce the number of falsely failed cars, the EPA now recommends a “two ways to pass criterion.”

The issue then is not testing accuracy, but testing frequency. It becomes critical to test frequently, even if we do so with less precision. Remote sensing has obvious advantages in this regard.

7 Summary of Problems with I/M Programs

We think it is worthwhile to step back from the technical issues to take an overall view of the I/M program. California's current inspection systems is designed to assure that cars are clean one day every two years—the inspection day. Successive generations of inspection programs focused on improving the accuracy of that one test and on reducing the possibility of fraud. We have worked hard at making that one day cleaner and cleaner, while ignoring the car's performance on the other 729 days. The program recommended by the Fourth Report continues this clean-for-a-day focus.

California has already tried one extensive inspection program, the BAR84, which failed. Then the state tried another extensive inspection program, the BAR90, and it failed. Now the EPA proposes that we try a third version. These programs have two main characteristics: they are universal and they are periodic. Universal, in that they test *all* cars,³⁴ though we know that only 15% of them are dirty³⁵—thus wasting the money and time of 85 percent of the drivers. Periodic, in that the inspections occur at fixed times with long intervals between tests. It has been said that such periodic testing is akin

³⁴More precisely, inspection is required of all cars and trucks fueled by gasoline, propane, and compressed natural gas in areas where the program is implemented.

³⁵EPA reply to questions during hearings on the Fourth I/M report, 29 July, 1992, page 7, gives the 15% figure. About a third of all cars will fail the emissions tests, but cars close to the passing line are difficult to repair, and may even come out dirtier after the repairs—see Table I above. More importantly, these data show that about half of total emissions are generated by only 15 percent of all cars.

to a program that “controls” drunken driving by scheduling drivers for a breathalyzer test every two years. Obviously, it is the performance between tests that matters.

At the time the BAR84 and BAR90 programs were designed, the problems with universal periodic testing were known. But the designers had little choice—there was no economically feasible way to perform random testing on a large scale. It is now possible to perform such tests with remote sensors, and so it is time to reorient our approach.

Consider the three causes of high emissions: tampering, deterioration, and breakage of the vehicle’s emissions control system. How effective are periodic or random inspection for dealing with these causes?

Periodic inspection is unlikely to deter tampering: the car owner simply fixes it before inspection and re-tamper afterwards—and given the long interval between smog checks, he can look forward to two years of undisturbed driving. Periodic inspection does detect worn or broken emission components, but only after they have polluted for a long time—given the two-year inspection interval.

Random inspection, on the other hand, does deter tampering and fraud, and is likely to detect broken components sooner than periodic inspection will. Random inspection using remote sensing will also catch deterioration, though, because of sensitivity problems it only does so after the problem becomes severe.

Given the importance of tampering, fraud, deterioration, and breakage, it seems wise to try a different approach. This new approach would concentrate on relatively frequent testing by remote sensors to detect the offending

motorists between inspections.³⁶ Remote sensing also has the advantage of sharing one of the important features of centralized testing—it separates testing and repair, and thus goes some way to meet the mandates of the EPA.

This new approach is strongly supported by recent research on I/M programs. We now know:

1. A small proportion of the vehicles produce most of the total emissions. Remote sensing tests typically find that about 10 percent of cars cause half the total emissions. The FTP tests performed on the 1,100 car sample in the Fourth Report give a similar result.
2. The Fourth Report discusses (p. 130, paragraph 2) a large-scale remote sensing test: cars identified by remote sensing as high emitters were pulled over and inspected with the BAR90 equipment. Ninety two percent of these cars failed the BAR90 test. Implication: given that the BAR90 can detect gross polluters, and yet many are on the road, we conclude that the problem is enforcement, rather than testing. Perhaps emission problems are too difficult to diagnose by neighborhood mechanics. Perhaps drivers tamper with the cars after they are inspected. Perhaps cars deteriorate quickly after the inspection. But for *any* of these reasons, enforcement between inspections via remote sensing would be a solution.
3. BAR90 versus IM240: Though the IM240 test is more accurate than the BAR90 test, the consequences of this difference are not large. IM240

³⁶Some critics question the accuracy of remote sensing. We examine this question below and conclude it will not be a problem.

has two alleged advantages: 1. Inspectors in centralized test stations can be better trained and benefit from greater experience, allowing them to perform better inspections. (Yet in the costing part of the report, such inspectors are supposed to be found by offering wages of only \$10.50 an hour.)³⁷ 2. The centralized testing station will be able to test evaporative emissions. But according to the EPA's own computer runs, the evaporative emissions portion of the IM240 is only expected to reduce overall emissions by 4.8 percent. (IM240 also automatically does a NOx test; the BAR90 testers would have to be modified if it is thought that this is critically important during the interim period.)

4. Disadvantages of IM240: 1. A full IM240 program will take a long time to implement. In particular, the environmental impact process required to site stations is likely to be considerable—few neighborhoods will welcome a high traffic, high noise, high pollution business. California's emissions will not decrease while the siting battle is fought. 2. The IM240 program does not reduce tampering or deterioration that occurs between biennial inspections. IM240 concentrates on making cars work once every two years, it ignores the issue of on-the-road performance in between—an issue that many observers believe to be far more important than IM240's advantage in testing accuracy.
5. Remote sensing can detect high emitters. From analysis of the data in the Fourth Report, it appears that we can choose a remote sensing failure cutpoint that produces few false-failures while detecting “enough” genuine high emitters. “Enough” provided each vehicle goes through a

³⁷Our calculations from worksheet data in Fourth Report, page 90.

remote sensing monitor about 2-3 times per year.

General Conclusion. Better enforcement will make the current BAR90 program more effective. Enforcement can be via random on-the-road inspections, using remote sensing to detect tailpipe emissions. And enforcement can be via better certification and monitoring of BAR90 inspector competence with programs like the new BAR TAS-records monitoring.

Adopting the EPA program at this time would be a serious mistake. It is expensive. It will entail years of delay before there is any emissions benefit. It is likely to cause serious inconvenience to drivers. And most of all, no evidence indicates it will solve the I/M problem.

8 Proposals

Implementation of IM240 appears to us to be costly, and unlikely to achieve the desired targets. We do not believe it wise to throw out an existing, though imperfect, program in favor of an expensive, untested program. Given the present knowledge about emissions, we think it wiser to modify and improve the current program while awaiting more definitive data on the real world operations of the IM240 system. This “delay” will bring more immediate benefits, at lower cost, and will also provide sufficient data and experience for the design of yet more effective programs. In particular, we recommend the following *Interim Program*:

1. Continue biennial inspections with the existing decentralized BAR90 stations.

2. Supplement this with a fleet of remote sensors to randomly test cars between inspections. The remote sensing will serve several purposes: identify gross polluters and require them to reduce emissions, identify which Smog Check garages are exceptionally lenient about passing gross polluters, and identify the types of cars which are the gross polluters, allowing for the design of programs which would target such vehicles.
3. Cars flagged by the remote sensor receive a citation requiring them to be inspected at a centralized IM240 facility within 30 days. If they fail the IM240, they must be repaired to pass it (subject to some dollar limit).

8.1 Performance Standards

We view the remote sensing component of our program as enforcing a desirable performance standard. The EPA refers to its IM240 program as a “performance standard.”³⁸ Performance standards are the most desirable way to achieve a goal: specify the desired end, specify a way of measuring attainment, and then allow the creativity of diverse actors to get to the goal in the most efficient way. But the federal Government Accounting Office points out that the EPA’s proposal does not contain any procedure for measuring the actual performance of its centralized program, or for certifying the results of some alternative program. The EPA issued a command and control mandate that effectively rules out any alternative programs from the start. It does not measure the effectiveness of the alternatives, it simply postulates their ineffectiveness because they are “untested”—a standard the EPA does

³⁸Fourth Report, p. 6.

not apply to IM240.

The most important EPA criterion that makes decentralized testing appear ineffective is EPA's decision that decentralized I/M programs are only half as effective as centralized ones.³⁹ Their logic for this appears to be that decentralized stations are either more prone to corruption or less competent at operating the tests. But in either case the key issue then is improved enforcement of standards. EPA proposes to solve the enforcement problem by centralizing the tests and separating tests from repairs—they assume this will decrease corruption and increase testing diligence. But remote sensing also inspects cars, and can monitor the output of BAR90 stations: if a car were passed corruptly or a test were done sloppily, remote sensing will detect it.

That is, remote sensing is a substitute way of dealing with the central rationale of the EPA program.

8.2 Financing

We can finance the program with no additional taxes. We offer owners of new cars (say those no more than 3 years old) an option: either go through a normal smog check, or send \$20 to DMV in lieu of the smog check; these fees pay for the remote sensing program, and we know that new cars do not need the same sort of rigorous I/M inspection in the first place.

³⁹Fourth Report, p. 6. No empirical support is given for this suspiciously round 0.50 parameter.

9 Conclusion

There are three major (pure) I/M alternatives: the IM240 program with some remote sensing to monitor effectiveness; the existing BAR90 program supplemented by remote sensing; and a pure remote sensing program without periodic inspection (explored in Appendix I). We do not *know* which of these alternatives is best. Neither can the EPA. There simply is not enough evidence to make a considered judgement.

Given these uncertainties, it is not rational to build a costly, extensive network of IM240 test stations. True, some analysts strongly believe it will work, but California has already implemented two other highly recommended I/M programs that did not turn out as expected. The proposed new program is even more expensive, and the investments are irreversible if the program proves ineffective.

Neither remote sensing nor IM240 are mature I/M programs—we know little about their effectiveness under actual large scale implementation. Fresh, important, information about what they can do and how to use them emerges every month. It makes sense to delay major commitments to these technologies, while further exploring their potential. Toward that end we recommended the Interim Program.

Our proposed Interim Program has several desirable features:

1. It is much faster to implement than a pure IM240 program. We need not find enough neighborhood-acceptable sites to provide inspection capacity for all the cars. We only need enough sites to inspect the gross emitters.
2. It is cheap to implement. (See Appendix I for costs of the remote

sensing portion of the program).

3. It may strongly deter tampering between inspections, and deter fraud during inspections.
4. It collects data needed to evaluate the three alternative I/M programs:
1) it field-tests and corrects any operational problems with both the IM240 stations and the remote sensors; 2) it produces realistic data on waiting times, ping pong problems, repair costs, etc.
5. The average fleet readings from the remote sensors can measure the effectiveness of the program.
6. Remote sensing shares one of the important features of centralized testing—it separates testing and repair, and thus goes some way toward meeting the mandates of the EPA.
7. Finally, this approach preserves Smog Check employment—at least in the short run, while we await evaluation of the results from this program.

An Interim Program can be implemented on a state-wide basis, or in a single geographic area. A promising variation on this idea would be to conduct a “shoot out” between the alternative programs: implement each alternative on a small scale in a geographically distinct area of the state, then monitor the results to see which is most effective. Details of such a shoot-out are described in Appendix II.

Finally, we wish to emphasize one primary point: at this time the I/M question turns on human issues, not scientific ones. How much fraud and

tampering exist and how can we deter it? How can we encourage motorists to maintain their cars? How well will the inspection stations function in terms of waiting time, detection, and cost effectiveness? It requires experience-based data to resolve these questions. Theoretical arguments will not suffice. The Interim Program is designed to immediately reduce emissions while collecting the needed data.

By the end of the proposed testing period, we will know where we ought to go next, and how to get there. Before trying yet one more expensive universal inspection program, it is worth implementing this modest supplement to the existing I/M program. It provides an excellent transition strategy no matter what the ultimate plan.

10 Appendix I: Remote Sensing

by Daniel Klein

Although remote sensing (RS) has yet to prove itself in a live program, many well-informed researchers feel that there is sound reason for expecting that a principally RS program will be most effective, dollar-for-dollar.

I begin by comparing RS to periodic inspection; I then sketch a possible RS program.

10.1 Remote sensing vs. periodic inspection

A generic RS program involves a fleet of remote sensors that read emissions and flag high emitters according to a flag criterion. Flagged cars are notified by mail and required to report for an inspection.

A generic periodic inspection program (or I/M) requires that all cars be inspected on a scheduled basis.

The superiority of RS over I/M flows from a few key points:

- **Pervasive Surveillance.** The inexpensive, on-road capability of RS means that an extensive remote sensing program would be affordable, enabling multiple readings and early detection of high emitters.
- **Element of Surprise.** RS holds the element of surprise; it is unscheduled and unforeseen, so tampering or gross negligence puts the car-owner in constant jeopardy. This jeopardy will induce car owners to take precautions not to be flagged, and the element of surprise means that more tampering and negligence will be detected.

- Selectivity. We know that a few cars generate most of the CO and HC pollution emissions. RS will thus burden only that minority. People are not required to report for inspection unless they are flagged by the system. Perhaps 80 percent of motorists will never have to report for inspection. The selectivity of RS translates into large cost savings.

Other important advantages of RS include:

- the swiftness with which it can be implemented;
- its flexibility, both geographically and over time;
- its generation of information about mobile emissions;
- its potential for a voluntary driver notification program.

10.1.1 Errors Must Be Construed on a System-wide Basis

Any kind of testing system makes two types of errors. A false failure occurs when, over a given time period, the system identifies a clean car as dirty. False failures are undesirable because they cause motorists to incur costs wastefully and unnecessarily. A false pass occurs when the system identifies a dirty car as clean; false passes are undesirable because high emitting cars are not cleaned.

Consider an RS program for Los Angeles that deploys 50 remote sensors, each reading 2000 vehicles per day (on average).⁴⁰ The fleet contains 8.5

⁴⁰I am assuming that each remote sensors operates 260 days per year, for eight-hours per day. The estimate of 2000 readings per eight-hour day is based on equipment capacity and experience. The Fourth Report (p. 127) reads: "It is estimated that about 1,000 vehicles per hour and over 8,000 vehicles per day may be monitored by the system." During a 4-day RS study in Baton Rouge, 24,000 readings were taken by two remote sensors. Assuming

million vehicles.⁴¹ Over a biennium the number of readings for the average car would be 6.1;⁴² cars that traveled more than average would be read more, and cars that traveled less would be read less.

The Fourth Report (Table 35, p. 129) presents information on how likely clean cars and dirty cars are to be identified as dirty,⁴³ given various CO cutpoints for the remote sensors readings. Consider the cutpoint of 4 percent CO emissions. For a car in the set of clean vehicles, there is, on average, a 0.64 percent chance that it will exceed the cutpoint at a single reading. This means that the average clean car, read six times during the biennium, stands a 3.8 percent chance of exceeding the cutpoint at least once during the biennium.⁴⁴

For a car in the set of dirty vehicles, there is, on average, a 66 percent chance that it will not exceed the cutpoint at a single reading. This means that the average clean car stands an 8 percent chance of not exceeding the cutpoint during the biennium.

eight-hour days, that translates into 3,000 readings per day; see Babak Naghavi and Peter R. Stopher, "Remote Sensing, Means, Medians, and Extreme Values: Some Implications for Reducing Automobile Emissions," Transportation Research Board pre-print, 1993, p. 8.

⁴¹This figure is based on the count of registered vehicles of 7.9 million (Fourth Report, p. 74), and then adjusting for unregistered vehicles (which account for about 7 percent of the fleet; p. 124).

⁴²If all cars traveled equally and therefore were read randomly (that is, according to a binomial distribution), 97 percent of the fleet would be read at least twice during the biennium, and 64 percent at least five times. In real life cars do not travel equally: those that travel more would be read more, and those that traveled less would be read less.

⁴³A dirty car, or high emitter, is defined as a vehicle with FTP emissions above 60 grams per mile.

⁴⁴I recognize that the data in Table 35 are test results from vehicles operated under controlled conditions, but my general point remains valid: by increasing the cutpoint we can reduce the number of false failures, and by increasing the number of tests per year we can reduce the number of false passes.

My calculations show the system generates few false failures and few false passes. Because RS is a pervasive system taking multiple readings, the rate of system-wide false failures and false passes can be made small by setting high cutpoints. Researchers at Resources for the Future come to a similar conclusion: "The remote sensing [single-]test identification rate is not a critical determinant of the effectiveness of remote sensing—it is important only that super polluting vehicles can be identified by the test."⁴⁵ The problem of false failures and false passes, therefore, is minor. Moreover, it can be significantly reduced in practice. The straight 4 percent CO flag criterion is crude. Consider a salesman who travels all over Los Angeles in his clean car. He travels so much that his chance of exceeding the 4 percent CO flag mark during the biennium is greater than the 3.8 percent calculated above. But for this motorist the system will have registered numerous clean readings, and on that basis can pardon a single dirty reading. The car would not be flagged. Such a policy represents a more refined flag criterion. Because a remote sensing program generates multiple readings, the flag criterion can be refined in several ways: to forgive first offenses, to calculate running averages for each car, to blend the readings for the different pollutants into a composite, to scan for "flipper" behavior (alternating between running clean and running dirty), and so on.

10.1.2 Costs to Drivers

RS imposes lower costs on drivers than does periodic inspection. Today, the proportion of cars that run clean is about 75-85 percent (Fourth Report, p.

⁴⁵See the "Conclusions" page of "Overview of RFF Analysis of Remote Sensing," April 1993.

10; EPA I/M-hearings reply). Under an RS program, the inspection costs (dollars, time, and attention) for the vast preponderance of drivers would be zero. Under scheduled inspection, every one of these clean drivers would be forced to incur the costs of inspection. This different treatment of clean cars is the main difference in costs imposed on car owners. The group that remote sensing does harm is the high emitters. But this harm is the linchpin of a successful smog program.

10.1.3 A Comparison of Overall Costs

The program costs of a pervasive RS program are lower than the costs of a periodic inspection program. The cost saving follows from a few distinctive features of RS:

- the mobile, on-road venue of remote sensing testing
- the brevity of each test (about one every 14 seconds)⁴⁶
- the selectivity of flagging and inspection

10.1.4 Costs of remote sensing

Estimating the costs of an RS program at this time is very imprecise. The technologies (remote sensors, automatic licenses plate readers, etc.) are in their infancy, and the degree of mass-production savings is yet to be established. Nonetheless, a rough upper-bound may be estimated.

⁴⁶This figure is based on the assumption that a remote sensor tests 2000 cars in an eight-hour day.

Based on information in the Hughes Environmental Systems report to the SCAQMD (pp. 5.13, 3.4 - 3.6), assume the following upper bound cost estimates:

- Remote Sensing Device (including vehicle)⁴⁷\$65,000
- Automatic License Plate Reader \$34,000
- Safety Equipment \$4,000
- 260-day salary and burden of remote sensors operator \$175,500⁴⁸

Assume that all equipment must be fully replaced every year, and that each remote sensors reads, on average, 2,000 vehicles per day, 260 days per year. Assume also that the annualized costs of the administration, centralized computing, notification, and postage sum to \$0.50 per reading; this is probably an upper bound since only a small minority of readings lead to notification.

The assumptions yield the result that the complete RS costs are 94 cents per reading. The only costs that this exercise has excluded are those of the test facility operations, the waiver referee operations, and follow-up enforcement.

Consider the most optimistic estimate of cost per test cited by the Fourth Report (p. 9), namely \$22 (for the centralized program using a steady-state procedure). Since the test is biennial, the yearly cost is \$11 per motorist.

⁴⁷The Hughes report (p. 5.13) cites a cost of \$45,000 per remote sensors, which includes the sensor and computer. I have added \$20,000 for a vehicle.

⁴⁸As a rough check on these assumptions, consider that Hughes is currently offering to provide a complete RS, in a van, with 2 operators, for \$7,500 per week as a turn-key operation.

Assume that the RS program requires 20 percent of such facilities and manpower each year to inspect flagged vehicles, and suppose the RS program makes 3 RS readings per motorist per year. This gives the following figures for cost per motorist per year:

Periodic Inspection Program: \$11

Remote Sensing Program: \$5

Hence, a pervasive RS program, reading the average car 3 times per year, would cost far less than a periodic inspection program. Every estimate entering this comparison was tilted to favor periodic inspection.⁴⁹ Besides being far less expensive, an RS program would most likely yield much greater smog reduction.

10.1.5 Disadvantages of Remote Sensing

Nontailpipe Emissions. The generic RS program does not get under the hood, except perhaps for flagged cars. Hence, an RS program does not test for nontailpipe emissions. Whether an I/M program can check effectively for nontailpipe emissions is a matter of doubt. There is little consensus on how important nontailpipe emissions are, and whether purge and pressure tests are cost effective. According to the EPA's recent runs of their Mobile 5 computer model, a full IM240 program for California will reduce total emissions by only 4.8 percent.

⁴⁹Consider an even-handed calculation. Suppose that the equipment lasts three years, operates 320 days per year, that a 320-day salary is \$125,000, that the remote sensors make 2708 readings per day, that the annualized cost of administration, etc., is \$0.20 per RS test, periodic inspection costs \$28 per test, and that the RS program requires only ten percent of the inspection facilities that are used in the periodic program. (The average car is then tested three times per year.) This gives a cost per motorist per year of \$14 for Periodic Inspection, and \$3.24 for remote sensing.

Other Problems with RS: it does not function as well in wet conditions, it may be restricted to single lane sites, it causes congestion when it funnels cars on a multi-lane road into a single lane, and it poses security problems.

Foiling RS. Will drivers devise some method to foil RS? The ingenuity of scofflaws has not yet been challenged. There are three basic approaches they might try:

(1) Tampering to alter the contents of the plume. This would require an additional gas source, to be mixed with the true exhaust, or an additive to the gasoline. These methods are expensive or inconvenient, and may interfere with the proper functioning of the car. Tampering would have to be deliberate. Heavy fines could be imposed for these varieties of tampering.

(2) Doing things to eliminate the plume, such as altering the tailpipe or turning off the car as it went passed by the RS unit. Again, these methods are expensive or inconvenient. Furthermore, cars that do not show a plume could be pursued on that basis, and heavy fines could be imposed for altering the tailpipe.

(3) Obstructing the license-plate, such as by splattering it with mud, or putting a trailer hitch in front of it. These problems could be mitigated by stepping up policing of license plate legibility.

(4) If the car has not warmed up yet, or if it is still in the enrichment mode, RS will produce false failures.

The scope for foiling RS is limited. Furthermore, the remote sensing strategy is itself in the early stages of development. The ingenuity of scofflaws will be met by the ingenuity of program officials.

10.1.6 Conclusion

Compared to a periodic inspection program, an RS program is likely to achieve larger emission reductions at lower costs to society. On the matter of not putting clean cars through the unnecessary trouble of inspection, RS outperforms periodic inspection because of its selectivity. On the matter of catching dirty cars, RS again wins because of its pervasive surveillance and the element of surprise.

10.2 A remote sensing program

The chief components of the program are as follows:

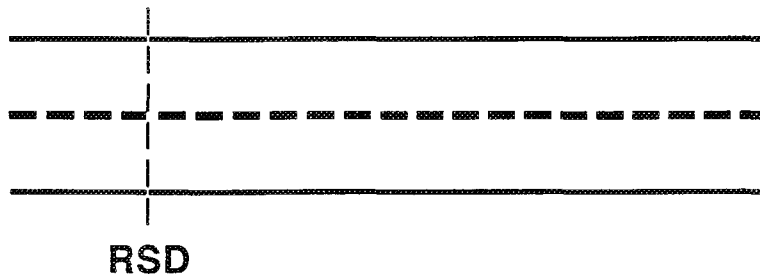
- (1) Mobile, on-road remote sensors, reading CO, HC, and NO_x.⁵⁰
- (2) Public-sector supported “I/RS/D” stations, which perform the following functions:
 - (a) dynamometer inspection of cars that have been flagged by remote sensors; failing cars must pay a fee, while passing cars pay no fee.
 - (b) provide an optional RS track, where any driver can receive an RS reading free of charge; the RS track plays no official role in smog approval.
 - (c) offer an optional diagnosis shop, operating for a fee; the diagnosis plays no official role in smog approval.

10.2.1 Inspection/Remote Sensor/Diagnosis Stations

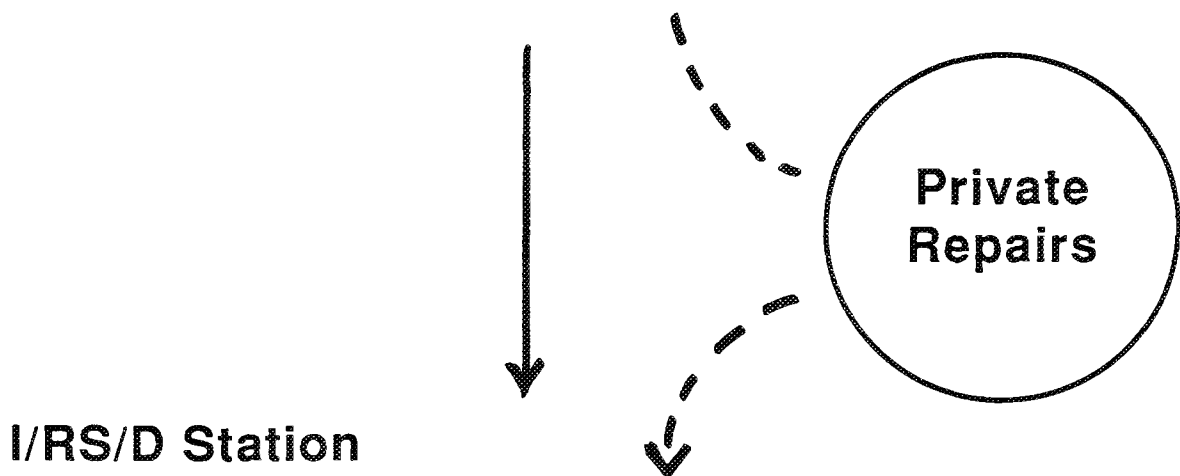
Cars flagged by an RS are required to report for a dynamometer inspection at a I/RS/D station within 30 days. If the car passes, the owner pays no charge. Immediately the car becomes fair game for flagging by remote sensors. If the

⁵⁰The NO_x channel of the RS is still in the development stage, but preliminary results are promising.

SCHEMATIC FOR REMOTE SENSING PROGRAM



RSD flags the high emitter and sends a citation requiring inspection.



I/RS/D Station

- 1) Dynamometer Inspection for flagged cars.
- 2) Optional free RS track.
- 3) Optional Diagnosis shop, for a fee.

car fails, the owner pays a testing fee; he must then repair the car and report back for retesting within 30 days. The fee will encourage flagged drivers to get their cars repaired before reporting for the dynamometer inspection.

Any car may go through the remote sensing track. This option is free and strictly voluntary. Going through the RS track will give the car-owner a good idea of whether his private mechanic has indeed repaired his car and whether he should proceed to the dynamometer inspection. The RS track plays no official role in smog approval.

Any motorist may also use the diagnosis shop operating at the I/RS/D station. For a fee it provides the car owner with a printed document stating the problems with the car and the repairs that seem to be in order. The diagnosis report is no promise of anything, and plays no official role in smog approval. This service should be optional and voluntary, since the individual car-owner has his own private opportunities to diagnosis and service his car, opportunities that might render official diagnosis redundant or inefficient. Some motorists may find it a useful supplement to the private market, including some who have not been flagged.

Gathering dynamometer inspection, the free RS track, and the diagnosis shop at a single location yields two benefits. First, it minimizes land, siting, and construction costs. Secondly, it makes life easier for car-owners. There are direct complementarities between the three services, so drivers gain by having “one-stop” convenience.

The number of I/RS/D stations can be small. Only the flagged cars need report for the inspections, not the entire fleet, so the inconvenience of travelling a long distance is suffered by few car-owners. Further, since the cars having to report to I/RS/D stations are, with few exceptions, dirty, the

long drive is an effective penalty and disincentive to being dirty.

10.2.2 Tampering

There is no on-road inspection in the program. On-road inspection is expensive, intrusive, and congestion-causing.⁵¹ The system controls tampering by keeping up a constant and palpable threat of detection by the remote sensors. Consider the die-hard tamperer. He cannot elude the remote sensors, so every few months he will be flagged and have to report for an inspection. On each such occasion he must do as follows: (a) de-tamper his car; (b) report for inspection; and (c) re-tamper his car. Thus, the trouble and expense of gaining some extra engine power, just for a few months, is excessive.

10.2.3 Citation-By-Mail Issues

Issuing inspection citations by mail is extremely cost effective, but one concern is that some of the citations will not be properly received. The Fourth Report (p.124) says that about 7 percent of vehicles are unregistered—a problem for any inspection program. But for a large portion of these vehicles the registration has merely lapsed, so a citation would be properly received. Some motorists will have mail forwarding problems, but in this matter a smog citation is no different from a phone bill. People are held responsible for seeing that their mail is properly forwarded.

Another issue is popular and political acceptability. Sometimes the idea of smog citation by mail is likened to photo- radar speeding citation by mail (a practice used in Pasadena and Folsom California, and Pleasant Valley,

⁵¹Perhaps a small number of on-road teams would be valuable. It would be one way to aid enforcement of vehicle registration.

Arizona). But comparing smog to speeding is problematic. Current speed limits are not analogous to smog cutpoints: virtually all motorists exceed speed limits on a regular basis, whereas only a small minority would exceed smog cutpoints. Many Americans feel that speed limits are too low and that enforcement is arbitrary. When traveling on a major highway, traveling at 70 m.p.h. is probably safer than traveling at 55 m.p.h.⁵² In contrast, motorists receiving a smog citation would be guilty of a real and certain harm to society. Finally, the problem of “vicarious responsibility”—that is, the driver is not the owner—is very minor in the case of smog. Emissions do not depend on who is behind the wheel.

Researchers have surveyed citizens on their attitudes toward photo-radar citations and found that 60 percent approved while only 35 percent disapproved.⁵³ If researchers find this much popular support for photo-radar, they are likely to find much more support for RS smog citation, which will be rightly perceived as improving the environment.

Another issue is privacy. In the interest of preserving individual privacy within the household, notifications and citations should not specify the exact time and place of readings. They should, for example, specify the week during which the reading was made, and say nothing of the location. (The exact information would be available for dispute resolution only.)

⁵²See Charles Lave, “Speeding, coordination, and the 55 mph limit,” *American Economic Review*, 75(5): 1159-1164, December 1985.

⁵³Cheryl W. Lynn, Wayne S. Ferguson, and Nicholas J. Garber, “Feasibility of Photo-Radar for Traffic Speed Enforcement in Virginia,” *Transportation Research Record*, no. 1375, 1992, pp. 11-16.

10.2.4 Driver Notification Program

An additional feature of the proposed program is driver notification for those cars that passed the RS flag criterion, but not with flying colors. The state would invest a postage stamp for each unclean car to notify its owner that he may wish to service his car. The notification letter would cite two good reasons for doing so: (a) improved gas mileage; and (b) reduced likelihood of being flagged by an RS unit in the future. The driver notification program would be a positive service to the car-owner, as well as a smog reduction tactic. It would prompt some people to reduce their emissions without compulsion. The remote sensing demonstration project conducted in Provo, Utah, included a driver notification group: the voluntary notification led to an 14 percent reduction in emissions compared to a counterpart control group that was not notified.⁵⁴

The program should also extend a "notice of appreciation" to clean cars, perhaps after a series of readings has been compiled. This would serve to reassure the driver of his clean status, and it would build good will with the public.

10.3 Concluding Remarks

I believe that this RS program, or something in the same spirit, is worthy of serious consideration. Compared to periodic I/M programs, the level of

⁵⁴High emitting cars that received notification but did not take advantage of the repair program experienced emission reductions of 28 percent, while a corresponding set of unnotified high emitters reduced only 14 percent. The difference can be attributed to the notification; see Donald H. Stedman, et al., "Provo Pollution Prevention Program: A Pilot Study of the Cost- Effectiveness of an On-Road Vehicle Emissions Reduction Program," University of Denver, January 1993, pp. 19-20.

driver expense and inconvenience is very low, the level of government labor costs is low, the level of government land and capital cost is low, and the level of intrusion and compulsion is low. At the same time, by taking full advantage of pervasiveness, selectivity and the element of surprise, the emissions reductions achieved by the remote sensing program would be excellent.

11 Appendix II: A Demonstration “Shoot Out”

Opinion is divided over the proper direction for I/M. There is support for the current decentralized program, a centralized program, a hybrid program, and a remote sensing program. The disparity of opinion, as well as the immaturity of two of these technologies, suggests that it is the wrong time to embark on an expensive, long-term program. It would be better to gain more information before making a commitment.

New information on what works will become available from both the California RSDs, and from programs in other states. California can act to obtain even more valuable information, by experimenting in program design over separate geographic areas. The idea is to implement a different I/M design in each area, e.g., Sacramento, Fresno, Bakersfield, San Diego, then use uniform measurement techniques to compare the programs. The programs would come face-to-face in a “shoot out.”

Consider the following experimental demonstrations:

Demonstrations	Type of Program
Hybrid	current I/M plus RS and some IM240
Pure RS	RS with no periodic inspection
Centralized	EPA’s centralized IM240 program

The site of each demonstration might be chosen by the state, or the state might ask for volunteers—offering incentives to participate. The demonstrations would help answer the critically important questions:

How much does the average emissions level change?

What are the dollar costs of the program?

How much inconvenience do they cause motorists?

11.1 Using “Experiments” in Other States

Emission control policy is going through changes in the other states as well. These changes can be thought of as “natural experiments,” and it is desirable to carefully and fully monitor their results. There is much to be learned from them.

11.2 Requirements for a Monitoring Program

A monitoring program which is both credible and effective must have three features: First, the state must assure that at least some of the monitoring is performed by independent parties. Emissions policy is not fully insulated from political and bureaucratic conflicts, and independent monitoring will help ensure that the findings are genuine. There must be separation between I/M design and evaluation. Second, monitoring should be uniform over time: methods used in 1993 should be repeated in 1996. That way we know that differences between 1993 and 1996 come from changes in the thing measured, and not changes in the thing doing the measuring.⁵⁵ Third, there should be multiple monitoring methods. We should take measurements with numerous devices. That gives greater confidence in their results.

The primary emission-monitoring methods to consider are: 1) remote sensing at sites with a variety of speed and load characteristics; 2) random roadside pullovers using IM240s; 3) random roadside pullovers using BAR90s. Monitoring sites should not be announced in advance, but the same sites should be used each year to assure comparable data.

⁵⁵We also need to correct for changes in fleet characteristics, and changes in the economy.

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