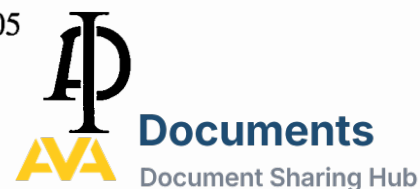


File
CEUM

THE COST-EFFECTIVENESS OF VEHICLE INSPECTION AND MAINTENANCE PROGRAMS

**RESEARCH STUDY #067
DECEMBER 1992**

American Petroleum Institute
1220 L Street Northwest
Washington, D.C. 20005



The Cost-Effectiveness of Vehicle Inspection and Maintenance Programs

**Robert C. Anderson
Thomas J. Lareau**

Research Study #067

December 1992

The contents of this paper are for the purposes of study and discussion of government legislative or regulatory proposals and do not necessarily represent the views of the American Petroleum Institute or any of its members.

American Petroleum Institute
1220 L Street Northwest
Washington, D.C. 20005



Documents
Document Sharing Hub

TABLE OF CONTENTS

EXECUTIVE SUMMARY	vii
I. INTRODUCTION	1
Background: The Role of I/M in Controlling Mobile Source Emissions	1
Elements of Cost-Effectiveness Analysis of I/M	2
II. A STRUCTURAL MODEL OF I/M PROCESS	5
How I/M Affects Emissions	5
Description of Model	5
Cost Components	6
1. Inspection Test	6
2. Repairs	7
3. Motorist Mileage and Time	8
4. Fuel Savings Offset	9
Critical Probabilities	9
1. Prob [Inspection]	9
2. Prob [Pass or Fail Inspection]	10
3. Prob [Correct Pass Pass]	14
4. Prob [Correct Fail Fail]	15
5. Prob [Repair Correct Fail]	17
I/M Emission Reductions	19
III. COST-EFFECTIVENESS OF I/M STRATEGIES	23
Decision Tree Algorithm	23
Allocation of Cost to VOC, NO _x and CO Emission Reductions	24
Existing I/M	25
Enhanced I/M	26
Cost-Effectiveness of Inspection Components	28
IV. OPTIONS FOR IMPROVING ENHANCED I/M PROGRAMS	31
Two-Speed Idle Test Coupled with Evaporative Tests	31
Modified BAR90 with Evaporative Tests	31
Remote Sensing	31
Basing Inspection Frequency on Vehicle Age, Manufacturer, or Previous Test Results	33
Other Policies	34
V. SUMMARY AND CONCLUSIONS	37
APPENDIX	39

NOTES	43
BIBLIOGRAPHY	45

LIST OF TABLES

1.	Failure Rate of Emission Analyzers By Program	16
2.	Cost and VOC Reduction for Probability Paths in Figure 2	23
3.	Summary of Cost and Emission Parameter Estimates	24
4.	Estimated I/M Cost-Effectiveness	26
5.	C/E of I/M Adjusted for Joint Control of CO and NO _x	27
6.	RFF Estimates of Incremental I/M Cost-Effectiveness	28
7.	Manufacturer-Specific Failure Rates	35

LIST OF FIGURES

1.	Impact of I/M on Emissions	5
2.	I/M Vehicle Process	6
3.	Compliance Rates	11
4.	Failure Rates	12
5.	Evaporative System Failure Rate	13
6.	Percent of Improper Test in Covert Audits of Decentralized Programs	15
7.	Waiver Rates	18
8.	Mean Hydrocarbon Emissions	20
9.	Overall Failure Rates for Passenger Vehicles	34

Executive Summary

Several states began automobile inspection and maintenance (I/M) programs during the 1970s as part of their effort to reduce carbon monoxide and ozone precursor emissions. The Clean Air Act Amendments of 1977 gave I/M a boost by requiring I/M in CO and ozone nonattainment areas. By 1991, 101 urban areas in 35 states and the District of Columbia had instituted I/M programs.

I/M programs have evolved differently across the states. Some states rely on central testing facilities run by the state or an outside contractor, while the remaining I/M programs are decentralized with testing at individual licensed garages. Some programs use stickers affixed to the windshield to aid in enforcement; other programs link inspections and registration by computer. Programs also differ in the frequency of vehicle inspection, tailpipe emission levels vehicles must meet, the expenditure limit for repairs, and other variables.

The Clean Air Act Amendments of 1990 further increased the scope of inspection and maintenance; the Environmental Protection Agency's (EPA) final I/M rule [November, 1992] requires an I/M program in 181 areas and 83 of these areas will have to implement an "enhanced" I/M program. While EPA has the responsibility of specifying a series of I/M enhancements, states have discretion in the actual design of their programs. States are limited in their choice, though, since the credit that a state earns in its State Implementation Plan for its I/M program will be determined by the EPA and EPA's view of what constitutes good I/M design.

EPA recently has developed new guidelines for I/M program enhancements. The EPA analysis builds upon three principles: one, that many existing I/M programs are less effective than desired; two, that an effective program for new technology vehicles must involve fundamentally different forms of emission testing than has been

practiced to date; and, three, that programs that separate testing from repair are more effective. Since the EPA guidance is likely to shape the form of I/M programs for years to come, it is appropriate to conduct an independent policy evaluation while there is still flexibility in the design of state programs.

This paper offers an evaluation of inspection and maintenance from the perspective of cost-effectiveness: program costs divided by program effectiveness. Effectiveness is measured in tons of pollutants removed: volatile organic compounds (VOC), carbon monoxide (CO) and nitrogen oxides (NO_x). Where possible, individual program components are evaluated with respect to cost-effectiveness.

Of the 101 state I/M programs currently in operation, few achieve more than a small portion of the intended emission benefits. Vehicle emission data collected in random roadside audits and by remote sensing suggest that existing state programs reduce emissions by much less than their designed objective. In some instances, I/M programs produced no measurable improvement. Consequently, it is not surprising that our estimates indicate that the cost-effectiveness of existing I/M programs is unattractive -- averaging over \$16,000 per ton of VOC in centralized programs and over \$35,000 per ton of VOC in decentralized programs. If adjustments are made for the value of carbon monoxide reductions in areas not in attainment for that pollutant, our estimates of the cost-effectiveness of existing I/M programs improve to about \$ 11,000 per ton of VOC in centralized programs and \$25,000 per ton of VOC in decentralized programs. However, a more detailed analysis would show a wide variation in cost-effectiveness among state programs due to differences in program design, enforcement and compliance.

The disappointing results can be explained in part by the limitations of idle speed exhaust tests to correctly identify high emission (particularly newer) vehicles. The disappointing results also are due in part to circumvention of proper testing by drivers, temporary adjustments by mechanics, inspector errors, waivers, repair difficulties, and enforcement problems. Drivers who prepare their vehicles specifically to pass an I/M test, register out of state, or otherwise evade proper testing are difficult to control under current I/M procedures, especially when enforcement is weak.

EPA's I/M enhancements recognize many of the limitations in existing programs, especially as they apply to new technology vehicles. For the first time, evaporative system emissions would be tested and repaired if necessary. EPA's new I/M program also utilizes a transient test with the vehicle cycled through acceleration, cruise and deceleration modes on a dynamometer that closely approximates the longer and more expensive Federal Test Procedure used to certify new vehicle engines and exhaust systems.

EPA has indicated that their enhancements have a cost-effectiveness in the range of \$1300 to \$2000 per ton of VOC, depending upon the magnitude of credits given for the control of other pollutants and the value assigned to driver time. The results of this study and other independent analysis suggests that these estimates may be optimistic. Only the evaporative system tests are likely to have a cost-effectiveness in this range.

Our analysis does show that EPA's enhanced I/M represents an improvement over existing I/M programs and reduces fleet emissions by about a factor of three. Without crediting CO and NO_x benefits, we estimate that the cost-effectiveness of enhanced I/M would be about \$14,000 per ton for centralized facilities and about \$27,000 per ton in decentralized facilities, improvements of about 15 and 25 percent respectively over well administered existing I/M programs. In areas that are out of attainment for CO and where NO_x concentrations affect ozone nonattainment, we estimate the cost-effectiveness of enhanced I/M would be \$10,400 per

ton of VOC for centralized facilities and \$21,200 per ton of VOC in decentralized facilities.

Both the cost and effectiveness of EPA's enhancements could be improved with relatively modest changes in program design. Some of the more promising alternatives include (1) less frequent testing of the evaporative system, coupled with mandatory replacement of failure-prone components at that time; (2) screening of vehicles with remote sensing and subjecting only a subset to an I/M test; (3) basing testing frequency on vehicle age, mileage and/or make, possibly in conjunction with remote sensing data; and (4) incorporating buyback and scrappage alternatives for vehicles that cannot be repaired within stated waiver limits.

The EPA rulemaking also extends coverage of basic I/M, with few changes over current design, to approximately 50 new areas. It is EPA's view that basic I/M is far less cost-effective than enhanced I/M, a view that our analysis supports. Because the new basic I/M areas are only marginally out of attainment, I/M would have to have a low cost per ton to be cost-effective since many relatively inexpensive control measures have not been taken that have been implemented in more severe nonattainment areas. However, basic I/M has relatively high costs per ton. A cost-effective solution matches the cost of control to the severity of the problem. It would be more cost-effective to require evaporative system testing for all vehicles or to improve basic I/M along the lines we outline for enhanced I/M: periodic test and repair of evaporative system components and targeting of vehicles likely to fail an I/M test rather than uniform testing frequencies for all vehicles.

Over time, as enhanced I/M is implemented, it will be important to assess how well the state I/M programs are performing. EPA has proposed to use remote sensing as an auditing device within enhanced I/M areas. Broader use of remote sensing to compare emissions in I/M areas to emissions in non-I/M areas would be a logical extension of using remote sensing as an enforcement tool. Such comparisons would provide the data necessary to assess the success of I/M programs.

I. Introduction

Background: The Role of I/M in Controlling Mobile Source Emissions

Inspection and maintenance (I/M) programs were required under Sections 110 and 172 of the Clean Air Act Amendments of 1970 for states that were unable to meet ambient air quality standards for ozone or carbon monoxide (CO). Yet, by 1977 only four states had I/M programs: Arizona, California, New Jersey, and Oregon. Amendments to the Clean Air Act in 1977 required that states adopt I/M programs if the 1979 revision to the state implementation plan did not project attainment of ambient ozone and CO standards by 1982. A number of additional states implemented I/M programs at that time. By 1991, 101 urban areas in 35 states and the District of Columbia maintained I/M programs. EPA's recent I/M rulemaking [November, 1992] requires I/M programs in 181 areas, and 83 of these areas will have to implement an enhanced I/M program.

I/M programs are intended to identify vehicles with emissions above prescribed limits and to have such vehicles repaired. State I/M programs have evolved with wide variation in many key aspects, including: (1) whether testing is centralized in a few locations or decentralized at numerous certified stations; (2) the age of vehicles covered; (3) whether the program is enforced through certification of inspection at the time of registration renewal, through stickers displayed on the windshield, or through computer matching of registrations and I/M tests; (4) whether the inspection frequency is annual or biennial; (5) whether the emission test is performed at idle, at two speeds, or on a dynamometer; (6) whether there are separate visual checks for tampering; (7) waiver limits on the cost of repairs; (8) the types of vehicles exempted, (9) emission cutpoints that have to be met; (10) the nature of any accompanying safety inspections; (11) fees charged for the inspection; and (12) whether inspection is separated from maintenance.¹

As each of these parameters is made stricter, I/M program costs rise and emissions tend to fall. For example, increasing the inspection frequency from once every two years to once every year would provide a small improvement in emissions, but would roughly double the cost. Similarly, including more vehicles should make a program more effective, but again increase the program costs. States generally adopt programs they view as reasonable for their individual circumstances. States and areas facing serious air quality problems are more likely to have relatively strict I/M programs. Conversely, states that are close to attainment usually adopt less ambitious I/M programs.

Any existing I/M program can be made stricter through so-called *enhancements*. Enhancements include dynamometer tests and purge and pressure evaporative tests, as proposed by EPA [July, 1992], or remote sensing and other techniques to reduce the cost of identifying high emitters.² Enhanced I/M programs may also include improvements in enforcement and other institutional changes designed to improve the efficacy of I/M programs. Whether strengthening a program is good policy depends upon the cost effectiveness of I/M enhancements relative to other emission control opportunities. While the 1990 Clean Air Act Amendments require all serious, severe, or extreme ozone non-attainment areas to implement enhanced I/M programs, the EPA can allow considerable flexibility in the design of individual programs.

Because areas differ in the structure of existing I/M programs, the same enhancements are likely to reduce emissions by different amounts across areas. The control of volatile organic compounds (VOC), a principal focus (along with CO control) of existing I/M programs also will have differential impacts on ozone formation depending upon the ratio of VOC to nitrogen oxides (NO_x) in the area. In some areas controlling VOC may have virtually no ozone benefit unless NO_x also is reduced.

Further, the desirability of various I/M program enhancements is likely to vary with the availability of other emission opportunities in an area, including stationary source controls.

In the first section of the paper, we begin by reviewing the elements of cost and effectiveness that should be included in assessments of I/M or enhancements to I/M. (Reviews of previous cost-effectiveness studies of I/M, describing which elements were included and which were omitted, are in the appendix of this study.) The second section of the paper presents a formal decision tree model of the I/M process and provides estimates of the critical probabilities, costs, and emissions reductions needed to implement the model. The third section presents cost-effectiveness estimates of current and enhanced I/M programs for both centralized and decentralized variants. The final section examines alternatives for making I/M more cost effective, such as reducing the frequency of inspection for newer vehicles, basing the frequency of testing on historic I/M failure rates for make and model, and using remote sensing to identify high emitters.

Elements of Cost-Effectiveness Analysis of I/M

Since cost-effectiveness is the guiding principle for analyzing many air emissions reduction policies, it is important to define what is measured in a cost-effectiveness analysis and to judge its usefulness. A number of broad methodological issues stand out, as well as several narrower issues in the quantification of costs and effects.

Perhaps the most important broad methodological consideration is the baseline from which costs and effectiveness are computed. If modifications are being evaluated that utilize the facility and equipment of an existing program, the most appropriate baseline is the existing program. One may term calculations derived in this fashion "incremental" cost-effectiveness. If the existing program is mostly or fully abandoned for an alternative, the most appropriate baseline is a no program alternative. In this situation, if the existing program were used as the baseline, one would derive erroneous

results. For example, consider a situation in which the existing program is very poorly designed. Minor program changes could show up as attractive relative to the current program yet be unattractive relative to wholesale redesign of the program.

EPA's enhanced I/M program would not use any of the existing emissions test equipment for 1986 and newer models and may or may not use existing inspection facilities. Thus, the appropriate baseline depends on the extent to which existing facilities are used or modified to accommodate enhanced inspections. If a state converts from decentralized to centralized testing, the appropriate baseline is one that assumes no prior I/M program. If centralized test facilities are used currently and facility modifications are included properly as costs, an incremental approach is most appropriate. In the case of EPA's recommended changes to I/M programs for pre-1986 vehicles, which do not replace but rather add to current test procedures, the appropriate baseline is one that calculates costs incrementally.

Another important consideration is how to measure the effects of I/M when a number of policies affecting emissions are implemented contemporaneously. The 1990 Clean Air Act Amendments require enhanced I/M in serious, severe and extreme ozone nonattainment areas. The Amendments also require reformulated gasoline in nine of the same areas (other areas can choose to "opt-in" to use of reformulated gasoline), with the specification that it achieve a 15 percent VOC reduction. Additionally, the Amendments specify that 1994 and later model year vehicles have on-board diagnostic systems designed to assist in the detection and repair of emission equipment failures. Finally, the Amendments set lower tailpipe standards for automobiles and light-duty trucks, along with the requirement that emission control equipment be certified for 100,000 miles of use -- up from a previous requirement of certification for 50,000 miles.

In calculating the impact of enhanced I/M as one of many emission reduction programs, it is

important to note that enhanced I/M is one of the few programs whose design is not fixed.³ Consequently, enhanced I/M should be designed and evaluated relative to a baseline that incorporates all other statutorily required and specified emission-reducing activities. EPA's own assessment of enhanced I/M does not follow this protocol. Rather, it ignores all other emission-reducing actions that will take place as a result of the Amendments and uses pre-1990 conditions as its baseline. This has the effects of overstating the emissions reductions that can be achieved and understating costs per ton.

A final overall methodological consideration is that it is desirable to evaluate the costs and effectiveness of individual components of an I/M program. In that way, one can evaluate the attractiveness of the individual parts and select from among those parts to design the most cost-effective approach. While data limitations make it impossible to pursue this course as far as might be desirable, McConnell and Harrington [1992] as well as this study examine program components in some detail.

Effectiveness could be quantified by a variety of measures: (1) the mass of source emissions removed; (2) the impact on air quality; (3) changes in the exposure of individuals, such as person days of exposure to ozone levels above the federal standard; (4) some measure of adverse health effects avoided; or (5) the value of health effects avoided. As the effectiveness measure moves from item 1 to item 5, effectiveness becomes more like a benefits measure appropriate for a benefit-cost assessment. While the best policy information

typically exists in benefit-cost calculations, or measures near to that, the I/M literature focuses exclusively on emissions reductions as a measure of effectiveness. This study uses emissions as the measure for effectiveness for the same reason all prior analyses of I/M focus on emissions: alternative measures are vastly more difficult to quantify. Measurement of the emissions reduced should include: (i) those from repairs performed as a consequence of failed emissions tests; (ii) those due to vehicle retirements induced by an I/M program, net of new vehicle emissions; and (iii) those attributed to improved maintenance fostered by an effective inspection program.

Cost estimates should include both tangible (mandated private expenditures and administrative costs) and intangible components (the value of individuals' time). Specifically, the cost of I/M programs should include estimates of: (i) the direct cost to the motorist of the vehicle inspection (which covers the cost of inspection equipment and facilities and the variable cost of doing an inspection); (ii) the nonmonetary cost to motorists (incorporating the value of the motorist's time); (iii) the costs of second inspections and referee facilities for failed vehicles; (iv) repair costs; (v) administrative costs; (vi) enforcement costs; and (vii) fuel savings, a cost offset.

Many previous studies either fail to properly account for the above elements, or do not properly use the available information. Some costs are included while others are left out. Nonetheless, most of these studies contain information valuable for evaluation of existing and enhanced I/M programs. A review of prior analyses is included as an appendix of this study.

II. A Structural Model of I/M Process

How I/M Affects Emissions

Newly manufactured vehicles must comply with applicable emission requirements. In recent years, federal law has specified performance standards that must be met for the first 50,000 miles of a car's life. Generally, new vehicles produce emissions well below the specified limit to allow for deterioration in performance over the first 50,000 miles.

Several factors affect the rate of increase in emissions with vehicle use. Prominent among these factors are general deterioration due solely to use and time, design features specific to the particular make and model, driving habits of the operator, and routine maintenance. Vehicle inspection and maintenance programs are designed to offset the increase in emissions over time and encourage proper maintenance.

Figure 1 portrays three alternative scenarios: a policy of no I/M, existing I/M, and enhanced I/M. Without I/M, vehicle emissions increase steadily with vehicle age (and use). I/M acts to decrease emissions at the date of inspections, here depicted as a biennial inspection frequency. Each inspection

shifts the emission profile incrementally relative to the no I/M alternative, so that there is a growing gap between the two emission profiles. Most evidence suggests that exhaust emission benefits from inspection induced maintenance degrade back to the baseline level over one to two years, but there could be some long-term benefits that persist. Enhanced I/M decreases emissions with each inspection relative to existing I/M.

Description of Model

As indicated in the introduction, the I/M process is complicated. A simplified conceptual model of the process is shown in Figure 2. While a more detailed depiction is possible, Figure 2 is sufficient to illustrate the key determinants of the process that should be included in a cost-effective-ness calculation.

The first split in the decision tree shown in Figure 2 shows that not all operating vehicles undergo an I/M test. This occurs because some vehicles are registered in another state, some state programs exempt certain classes of vehicles, and some vehicles that are subject to I/M evade the process. For vehicles that are tested and pass, the inspection test result may be correct (vehicle operating within legal emission limits) or incorrect (the test fails to identify a high emitter). For vehicles that fail, the inspection test result may be correct (high emitter identified) or incorrect (low emitter falsely identified). In the former case (inspection identifies high emitter), the vehicle may be repaired (and then retested) or waived. In the latter case (inspection incorrectly fails low emission vehicle), the vehicle may be retested and pass, waived, or repaired (unnecessarily). Repair waiver limits vary among the states.

In the following subsections, costs, probabilities of occurrence, and emission reductions are dis-

Figure 1: Impact of I/M on Emissions

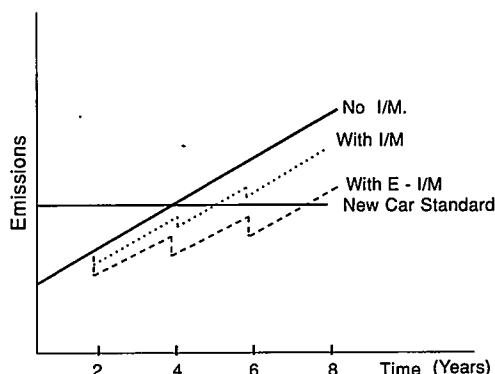
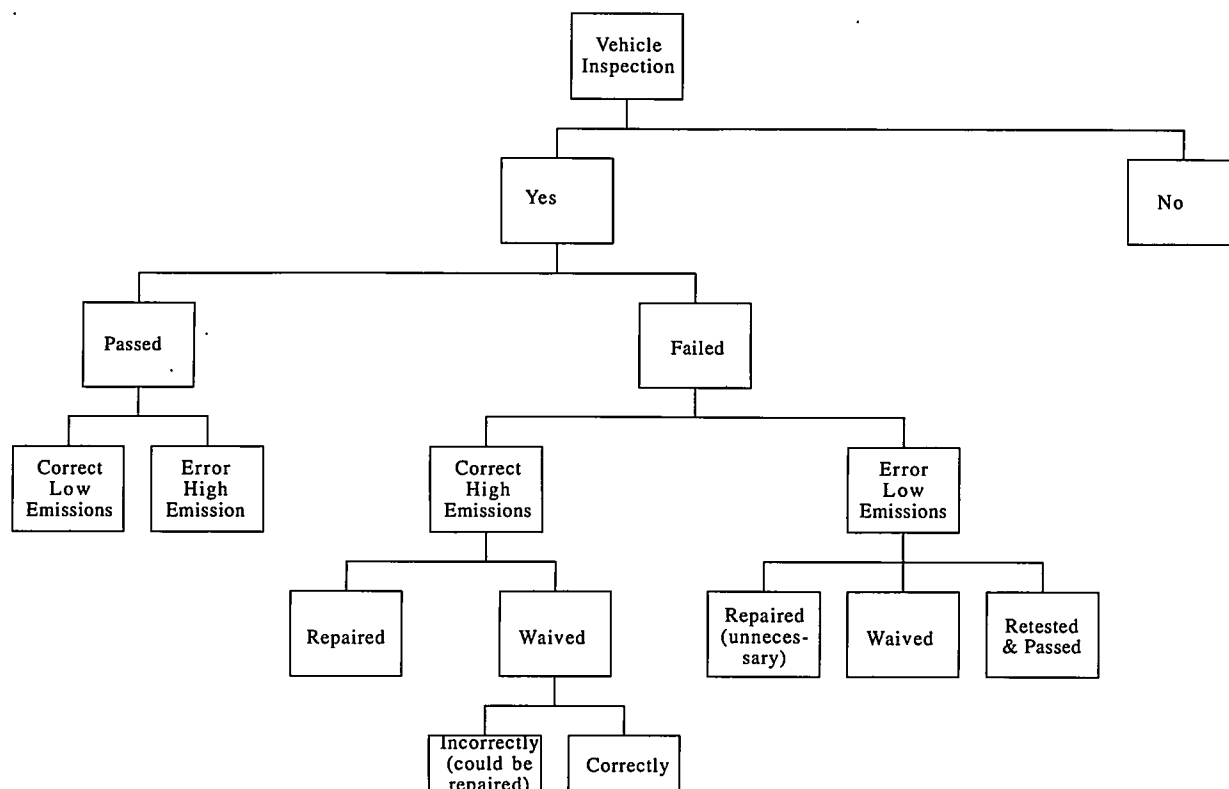


Figure 2: I/M Vehicle Process



cussed. Estimates are provided for typical current I/M programs. Later we examine a variety of enhanced program alternatives, including what has been described by EPA [February, 1992]. EPA's enhanced program uses a loaded dynamometer test and an evaporative test with a general tightening of test requirements, waiver limits and enforcement. An alternative version of enhanced I/M has been proposed by ARCO that includes enhancing a California BAR90 inspection with a NO_x analyzer, and adding simple chassis dynamometer and evaporative system tests. Other I/M enhancements could include remote sensing and varying inspection frequency according to observed failure rates for particular vehicle makes/models and age. These latter variants could be coupled with either EPA's or ARCO's version of enhanced I/M.

Cost Components

The cost, critical probability and emission reduction assumptions discussed in this section are summarized in Table 2 in Section III, where they are used to compute cost-effectiveness. Our purpose is to use all available information to provide a range estimate for each parameter, reflecting our best judgment of a 95 percent confidence interval. This provides a foundation for estimating a confidence interval for cost-effectiveness derived from the decision tree model outlined above.

1. Inspection Test Across current I/M programs, the charge for emission inspections varies from zero to about \$30. A few jurisdictions with centralized facilities subsidize inspections with general tax receipts or vehicle registration receipts.

Most centralized facilities charge from \$6 to \$10 for an emission inspection.

States with private garage (decentralized) programs generally regulate the maximum charge. The maximum fee in Alaska is \$32; in Colorado \$11.20; in Virginia \$13.50; in New Mexico \$16; in Pennsylvania \$9.01; and in New York \$19.92. EPA [February, 1992] notes that some of these fees are likely to be below the cost of performing an inspection. Stations may make up for these losses by providing repair services. Only California has no maximum.

In our analysis in Section III, we use an estimated range of \$9 to \$12 for existing centralized inspection cost (after adjusting for state subsidies) and \$9 to \$20 for existing decentralized inspection cost.

The cost of inspections would increase if an enhanced I/M program were adopted. According to equipment vendors, dynamometers range in cost from \$150,000 to \$300,000. EPA puts the cost at \$45,000, but also adds \$95,000 for a constant volume sampler and tailpipe analyzers required for transient tests. ARCO [1992] estimates that the cost of its enhancements would be \$25,000 over existing BAR90 equipment. ARCO's equipment configuration utilizes a less expensive dynamometer and a modified BAR90 analyzer rather than the more expensive inertia weight dynamometer and lab grade analyzer EPA recommends.

EPA [February, 1992] estimates that the added direct costs of a centralized enhanced inspection would be about \$16.50 per vehicle compared to current I/M costs of \$8.50 at centralized facilities. EPA also estimates that the added direct costs of decentralized enhanced I/M programs would be about \$39.00, compared to current decentralized direct costs of about \$18.

Other estimates of the direct cost of an enhanced inspection indicate that EPA may have underestimated equipment costs, labor costs (EPA assumed a \$6.00 wage) and the cost of inspection

facilities. In recent testimony to a Virginia Senate study committee, Virginia environmental officials estimated that the cost of centralized I/M would be \$24 per test in contrast to EPA's estimate of \$17.⁴ Similarly, McConnell and Harrington [1992] estimate that the direct cost of an enhanced inspection is \$26. Finally, the California I/M Review Committee [October, 1992] estimated that the enhanced inspection test would cost \$29 in a centralized program and from \$46 to \$56 in a decentralized program, depending on how many stations choose to continue to provide inspections.

Part of the difference in inspection cost estimates between EPA and others arises from different assumptions of the appropriate baseline. EPA calculates the cost of enhanced inspections incrementally, accounting for expansion of facilities to conduct evaporative tests. The other estimates include added facility costs to perform separate enhanced tests. In states with existing centralized testing, some expansion would be necessary to accommodate two test protocols -- enhanced on newer vehicles and standard idle tests for older vehicles. In states with decentralized programs, conversion to centralized inspection may be necessary. In that case, new facilities will be necessary.

In our cost-effectiveness analysis in Section III, we assume that the direct cost of enhanced inspection ranges from \$17 (assuming only facilities expansion) to \$29 (new facilities required and equipment more expensive). In the case of decentralized enhanced inspections (which EPA does not recommend), new facilities will not be needed. Estimates range from \$39 (EPA) to \$56 (California). We use a range of \$35-\$55 in Section III.

2. Repairs Average repair costs for vehicles that are repaired depend loosely on waiver limits, and these vary widely among the states. Idaho has the lowest waiver limit -- \$15 for 1980 and older vehicles and \$30 for newer vehicles. Most jurisdictions have waiver limits in the \$50 to \$200 range. The 1990 Clean Air Act Amendments direct EPA to raise the waiver limit to \$450 for areas implementing enhanced I/M.

EPA [February, 1992] notes that the average repair cost for the Louisville I/M program in 1989 was \$54. A California study showed average repair costs of \$75 for 1980 and newer vehicles. A study of Oregon repair records indicated average repair costs of about \$50 during 1985 and 1986.

Data with which to estimate the average costs of repair under higher waiver limits and loaded mode testing is limited. Haskew *et al.* [1989] took a sample of 24 GM vehicles that had failed the Michigan I/M test and performed repairs optimally (selecting cheapest, most effective repairs first) until the vehicles could pass. They found costs averaged \$245.44. Three vehicles had repair costs in excess of \$450. Deleting these three data points reduced the repair cost average to \$155.

EPA [Landham, 1986] tested 100 late-model cars that failed the Maryland I/M test. The average repair cost in this study was \$110. Adjusting this estimate to 1992 price levels would indicate average repair costs of about \$140.

EPA [February, 1992] assumes that vehicles that fail the VOC or CO portions of their enhanced test would incur repairs averaging \$120, based on current state experience and the difficulty of diagnosing and repairing vehicles that fail only a loaded mode test. For vehicles that fail the NO_x portion of the test, EPA based its estimate of \$103 on a sample of nine vehicles. EPA probably underestimated repair costs, since they used unadjusted old cost data. Further, EPA [February, 1992] states that only 1 percent of identified high emitting vehicles would be waived. In contrast, Haskew *et al.* [1989] results imply a waiver rate of 12 percent, when the waiver limit is \$450.

In sum, under existing I/M programs, the evidence indicates that average repair costs are about \$30-\$35 for a \$50 waiver limit. For enhanced I/M, with its \$450 waiver limit, we believe average repair costs will range from \$120 to \$150. These estimates are used in the cost-effectiveness calculations that follow in Section III.

3. Motorist Mileage and Time Motorist time and mileage costs were first analyzed by McConnell [1990] and have subsequently been included in recent reports by EPA [February, 1992] and McConnell and Harrington [1992]. McConnell [1990] estimated that these indirect cost elements account for about one-third of total I/M cost. This share would drop if a more expensive I/M program is required.

McConnell's [1990] analysis focused on the Maryland program, which relies on centralized facilities. In 1984, McConnell surveyed 250 drivers who had arrived for their inspection, asking questions on the distance traveled, the time required for the trip and for the inspection, and for their recollection of the time taken in the past to have failed vehicles repaired.

McConnell found that the average number of minutes required to have a vehicle inspected and repaired and reinspected if necessary varied for different classes of drivers. Those that took time off from work lost an average of 100 minutes; those that gave up recreational and leisure lost an average of 42 minutes. A number of economic studies provide a basis for valuing driver time. Some studies put this value at roughly a driver's pre-tax hourly wage, while other studies estimate that drivers value their time at roughly one-half that rate.⁵ Using these values to bracket the results, McConnell estimated that Maryland drivers value the time needed to get their cars inspected at between \$5.10 and \$8.57. To this McConnell added a value for mileage, \$2.44 in 1984 and \$2.09 in 1991, determined by multiplying a mileage rate (9 to 17 cents per mile depending upon the vehicle model) times distance traveled and averaging over the sample.

There is little data on whether centralized programs have longer or shorter queues relative to decentralized programs. Under decentralized programs it is possible to make appointments or leave a car for awhile and eliminate waiting; however many motorists find it more convenient to simply wait for their inspections. So differences in

the average inspection time are unknown. However, since the travel distance to a centralized facility is greater on the average than to a decentralized facility, overall motorist cost should be somewhat less under decentralized programs.

In our cost-effectiveness analysis, we conclude that a reasonable estimate of a motorist's time and mileage is \$7.00-\$10.00 in centralized programs and \$6.00-\$9.00 under decentralized programs.

4. Fuel Saving Offset There may be a modest cost offset associated with the repair of a vehicle that does not pass the vehicle inspection. A gain in vehicle fuel efficiency occurs when an evaporative loss is identified and fixed or when engine repairs or adjustments following a tailpipe emissions failure lead to improved combustion efficiency.

EPA [February, 1992] estimates that a repaired vehicle would get a 5.9 percent gain in fuel economy for an evaporative repair, an 8 percent gain from an engine system repair identified by an idle exhaust test on 1981 and newer vehicles, no change on pre-1981 vehicles, and a 12.6 percent gain from an engine system repair identified by the IM240 test. Assuming an average 5 percent fuel efficiency gain, a gasoline price of \$1.25 per gallon, and 400 gallons of fuel use per year, the annual savings would be \$25. However, EPA's estimates of fuel savings were based on relatively small samples, six repaired vehicles in one case, a sample that EPA acknowledges as a "slim database."

If fuel savings of the magnitude estimated by EPA could be obtained annually, it would pay for a major portion (if not all) of the cost of a tuneup and routine maintenance every year or two. But EPA's estimate is clearly overstated. Some owners would have had their cars tuned-up and generally maintained *even if they had not failed an inspection*. Thus, some part of any calculated fuel economy benefit should not be attributed to I/M. Further, other studies that examine the fuel economy benefit, for example Rueff [1992], report much lower gains, ranging from none to 3 percent on ten vehicles. Given that there is evidence of modest

fuel savings and EPA's estimated fuel savings seemingly are too high, we assume that a reasonable fuel savings credit ranges from zero to \$10 for current I/M and from \$5 to \$20 per failed vehicle for enhanced I/M. The enhanced I/M fuel savings is higher than current I/M given EPA's evidence of higher savings for the IM240 test and the addition of evaporative tests.

Critical Probabilities⁶

1. Prob [Inspection] The probability of a vehicle being inspected varies widely from one I/M program to another. Vehicles that are not inspected may be divided into two categories: exemptions and noncompliers.

All programs have certain exemptions, for example out-of state registrations. In many I/M programs vehicles older than a certain age are exempted, this despite the fact that older vehicles generally benefit more from inspections than do newer vehicles. Government vehicles may be exempted in some jurisdictions. With the exception of California (and there only recently) states exempt diesel vehicles from I/M. Spot checks of high polluting vehicles at roadside pullovers show that some vehicles manufactured as diesels have been converted to gasoline.

Exemptions will affect the cost-effectiveness of I/M if the vehicles being exempted are systematically different in emissions characteristics from those being inspected. Exempting older vehicles and diesels is likely to adversely affect I/M cost effectiveness. Older vehicles as a class produce greater emissions per mile of travel. Consequently, including such vehicles *may* offer opportunities for improving the cost effectiveness of I/M. Diesels have been excluded from I/M emissions inspections; this is not justified if they have been converted to gasoline power. Some owners may register their vehicles out-of-state to avoid an inspection the owner believes would result in a failure. Others register out of state to avoid personal property taxes, and also would not get their car(s) inspected.

The I/M enforcement mechanism, as well as priorities of police and traffic officers, affect compliance among vehicles that are subject to inspection. Programs that are tied to vehicle registration generally have higher compliance rates than programs that are enforced through stickers obtained at the time of inspection. Forgery of stickers has been a problem in some jurisdictions.

Compliance rates shown in Figure 3, reproduced from Mueller [1990], indicate that the percentage of vehicles subject to inspection in 26 different I/M programs during the years 1985 and 1986 approaches 100 percent in some programs, but is as low as 55 percent elsewhere.⁷ More recent information from the California Smog Check evaluation [December, 1991] shows that 6.8 percent of the vehicles were being operated with registrations that had expired more than 30 days earlier. About 1.5 percent were being operated with registrations that expired more than one year earlier. None of these vehicles is likely to have gone through the state's smog check program during the past year.

For current I/M programs, we estimate that the Prob [Inspection], which reflects both exemptions and compliance, ranges from 0.83 to 0.97. Though some programs have not achieved this level of compliance, they are considered outliers in our analysis. Under enhanced I/M, many leakage deficiencies are assumed to be corrected. However, with the higher waiver limit of \$450, out-of-state registration could become more of a problem, as could failure to register altogether. Taking these considerations into account, we estimate that the Prob [Inspection] for enhanced I/M ranges from 0.92 to 0.98.

2. Prob [Pass or Fail | Inspection] Given that a vehicle is inspected, the probability of a failure varies considerably among states under current I/M programs. This variability results from several factors, including different emission cutpoints, whether manual or computerized analyzers are used, and whether programs are centralized or decentralized. Numerous inspection record errors

in manual testing are the basis for EPA's decision to attribute only one-half of normal I/M credits to programs that rely on manual testing. Because underhood inspections, which account for nearly one-half of the failures in decentralized programs, rarely are found in centralized programs, one would expect decentralized programs to have higher failure rates, other things equal. In fact, the reverse is observed. For that reason, manual analyzer programs are being phased out. Decentralized programs generally have lower failure rates than centralized programs, suggesting that both intentional and unintentional inspector errors are far higher in decentralized programs.

Figure 4, also reproduced from Mueller [1990], depicts failure rates for 27 different I/M programs based on EPA audits in 1986 and 1987. The dashed line at 20 percent is EPA's target failure rate for what they believe are well designed I/M programs. For the purposes of our analysis, we estimate that the probability of failing an inspection ranges from 0.05 to 0.20 in decentralized current programs, and from 0.15 to 0.25 in centralized current programs.

The probability of failing EPA's enhanced I/M test would be high until the program successfully identifies and repairs high emission vehicles. The magnitude of this failure rate in the first cycle is not readily apparent in EPA's 1992 report. However, there are several reasons for believing that the probabilities of failing an enhanced inspection are higher than the corresponding failure probabilities under current I/M programs. First, because the exhaust IM240 test protocol is more rigorous than existing I/M, the initial failure rate on the IM240 test is likely to be higher. Second, the addition of evaporative tests increases the probability of an inspection failure. Figure 5, based on EPA data graphed in Radian [1991], shows the expected failure rate of evaporative emissions control systems by model year. As indicated, the combined failure rate of purge and pressure tests ranges from 5 percent on new vehicles to 45 percent for older vehicles. The overall combined failure rate for the fleet is over 21