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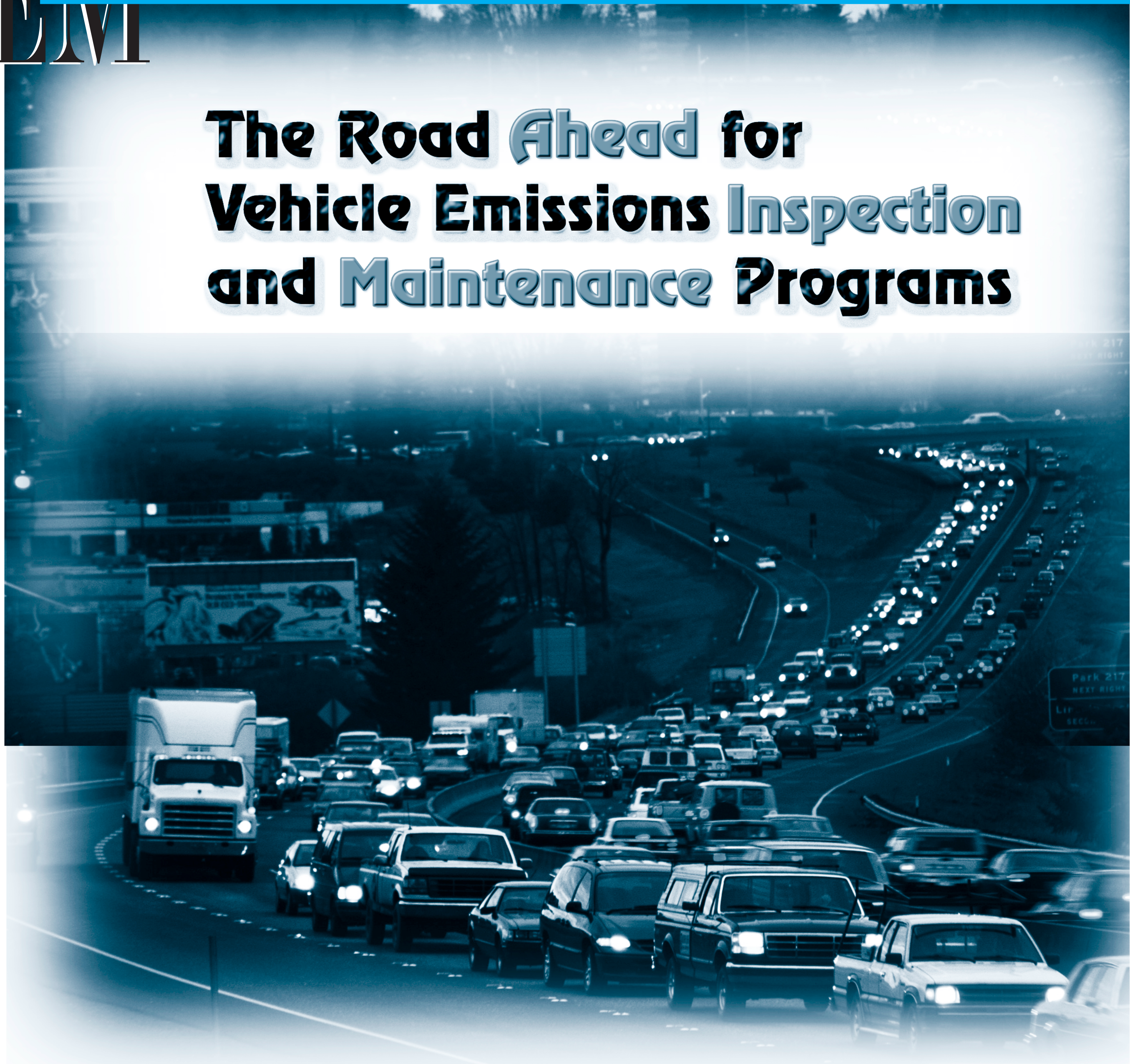

The Road Ahead for Vehicle Emissions Inspection and Maintenance Programs

by K. John Holmes and Ralph J. Cicerone

This article is a summary of a report by the National Research Council's Committee on Vehicle Emissions Inspection and Maintenance Programs, authored by Ralph J. Cicerone (chair), David T. Allen, Matthew J. Barth, J. Hugh Ellis, Gerald R. Gallagher, Deborah Z. Gordon, Robert A. Harley, Harold M. Haskew, Douglas R. Lawson, Virginia D. McConnell, Alison K. Pollack, and Robert S. Slott. The authors of this article take full responsibility for any errors in the contents of this summary. The authors would also like to acknowledge Ramya Chari for her efforts in preparing the original report, as well as this article.

According to a recent study by the National Research Council, vehicle emissions inspection and maintenance programs are missing opportunities to reduce air pollution by expending too many resources to inspect "cleaner" low-emitting vehicles and not effectively dealing with the dirtiest ones. This article summarizes the study's findings.

INTRODUCTION

Vehicle emissions inspection and maintenance (I/M) programs are one of the most common control methods used by areas to reduce the impacts of vehicle emissions. I/M programs are designed to identify vehicles that have higher than allowable emissions and ensure that such vehicles are repaired or removed from the fleet. These programs form a major component of state implementation plans (SIPs), the plans developed by areas to show how they will come into and maintain attainment with ambient air quality standards. They are administered by the U.S. Environmental Protection Agency (EPA), which must also review and approve all SIPs submitted by the states.

I/M programs, however, have been controversial. There has been a general sense that the actual emissions reduction benefits of these programs have been smaller than those predicted by emissions models. Program design issues have also been contentious. Questions about whether facilities that test should also repair vehicles and what kinds of test should be administered have been at the heart of many I/M debates. The controversy over the adoption of centralized testing using equipment that measures emissions under a driving load, which was mandated in the Clean Air Act Amendments of 1990 (CAAA) and rescinded in the Highway Safety Act of 1995, was one such debate. Currently, much of the discussion over the future of I/M programs revolves around how new vehicle emissions controls, onboard diagnostic systems, and remote sensing of vehicle emissions will be incorporated into these programs.

A hearing of the House Subcommittee on Oversight and Investigations in 1995 focused the attention of Congress on I/M programs. It also focused its attention on the computer model used to estimate the emissions reduction benefits, EPA's Mobile Source Emissions Factor Model (MOBILE). As a result, Congress directed EPA to arrange for a study by the National Research Council to review the effectiveness of I/M programs for controlling motor vehicle emissions. The National Research Council convened the Committee on Vehicle Emissions Inspection and Maintenance Programs. The results of its deliberations are described in *Evaluating Vehicle Emissions Inspection and Maintenance Programs*[1] and summarized in this article. Congress also directed EPA to initiate a National Research Council review of MOBILE, which was described earlier.[2,3]

CHARACTERISTICS OF VEHICLE EMISSIONS

Motor vehicle emissions are a significant proportion of overall anthropogenic emissions, and can be particularly critical in urban settings. Nationwide estimates of on-road motor vehicle emissions put their contribution at 56% of the total carbon monoxide (CO) emissions, 32% of the total (evaporative plus tailpipe) hydrocarbon (HC) emissions, and 30% of the total oxides of nitrogen (NO_x) emissions (here, HC denotes organic compounds that are emitted as vapors under atmospheric conditions).[4] These figures rise when one considers urban areas. On the basis of its models, EPA suggests that vehicles typically contribute between 35% and 70% of HC and NO_x emissions, and 90% or more of CO emissions in cities with high levels of air pollution.[4,5]

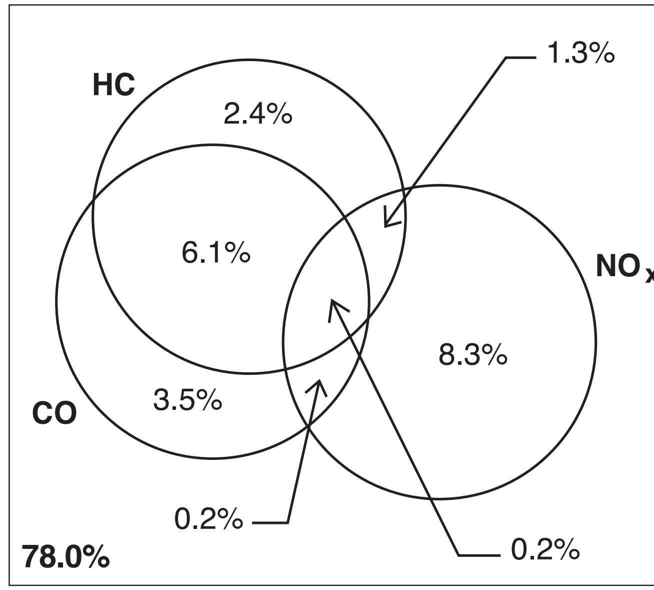

Figure 1. Degree of overlap among the highest 10% of emitters of CO, HC, and NO_x in the light-duty vehicle fleet. Based on results of emissions tests administered on 12,977 vehicles in California random roadside inspections tested from June 9, 1998 to October 29, 1999. Note that the sizes of the overlapping areas are not drawn to scale. Of the vehicles tested, 78% did not fall in the top 10% for any of CO, HC, or NO_x. (Diagram prepared by Gregory S. Noblet, University of California, Berkeley)

In terms of I/M programs, it is the distribution of emissions within the vehicle fleet that is important. Data from multiple sources show vehicle emissions to be skewed such that a small fraction of vehicles contribute a large fraction of emissions.[6-11] A general characterization is that approximately 10% of the fleet contributes 50% or more of the emissions for any single pollutant. However, as shown in Figure 1, the vehicles that are high emitters for HC and CO tend not to overlap with high emitters of NO_x. This is important because only about 1 in 10 vehicles actually fail a test in a typical I/M program. Correctly identifying high-emissions vehicles and ensuring that these vehicles receive proper repairs is a major challenge for developing effective I/M programs. Falsely failing vehicles with low emissions and falsely passing vehicles with high emissions reduces the benefits and overall effectiveness of these programs.

VEHICLE EMISSIONS CONTROL TECHNOLOGIES

Critical in the application of I/M programs is an understanding of basic technological innovations that affect the design, operation, and durability of emissions control systems. The earliest tailpipe controls required frequent adjustments to maintain performance. These early controls included the introduction of the first oxidation catalytic converters (two-way

Table 1. Data and methods for evaluating emissions benefits of I/M.

Emissions Data

- *In-program data* — data collected from I/M emissions tests results.
- *Roadside pullovers and other recruitment studies* — data collected from studies that recruit a relatively small number of vehicles for controlled emissions tests, either at a roadside testing station or a laboratory test facility.
- *Remote sensing data* — data collected by roadside remote sensing testing devices that record emissions as a vehicle passes.

Evaluation Methods

- *Reference method* — compares vehicle emissions measured by a program with vehicle emissions in a different area that have a reference program, either a null program (non-I/M case) or benchmark program.
- *Step method* — compares emissions of vehicles in a single area that have and have not been tested in the I/M program.
- *Comprehensive method* — estimates emissions impacts for each group of possible test outcomes (initially pass, fail/pass, and fail/never pass).

catalysts), which permitted major reductions in CO and HC emissions. The introduction of computer controls and onboard diagnostic (OBD) systems on vehicles permitted the adoption of closed-loop fuel controls. Under closed-loop operations, the fuel metering system automatically adjusts the air-fuel ratio for optimal emissions control. This new generation of computer-controlled fuel-metering systems enabled the adoption of three-way catalysts that could simultaneously oxidize CO and HC, as well as reduce NO_x emissions. The introduction of OBD systems, including the OBDII system required on all model-year 1996 and newer vehicles, allowed the continual monitoring of the catalyst and emissions control components (more later).

A general increase in vehicle durability has accompanied these improvements. The average age of in-use passenger cars increased from a mean of 5.6 years in 1970 to 8.8 years in 1998 and the average lifetime of a 1990 model-year passenger car was 2.7 years longer (14.0 years) than that of a 1970 model-year car.[12] These trends have resulted in a large change in the percentage of older vehicles in the fleet. In 1970, the percentage of vehicles 15 years and older was only 2.9%; in 1998, the percentage had risen to 13.2%.

These changes in the nature of vehicle technology and durability have implications for future I/M programs. Current testing programs for late-models within the vehicle fleet are not *inspection* and *maintenance* programs, but rather *inspection* and *repair* programs. If a late-model car has excessive emissions, it is often the result of a system component failure. Reducing emissions then requires that component to be replaced, as opposed to undergoing maintenance by adjusting

Table 2. Possible performance indicators for use in both shortened and comprehensive state evaluations of I/M programs.

- Failure rates by model year
- Estimates of the average emissions of passing vehicles and average emissions of failing vehicles
- Average emission rates after repairs for failing vehicles that obtain repairs and pass a retest
- Average costs for repairs
- Share of failing vehicles that do not pass the I/M test, their average emissions, and an estimate of the number of those still driven in the area

the carburetor or other engine functions, which was the case when vehicle I/M programs were initially introduced. However, the increased durability and lack of need for periodic maintenance in the sense of engine "tuning" should reduce the testing burden. New technology vehicles are cleaner, and capable of remaining cleaner for a longer period of time.

Despite these improvements, the possible need for high-cost repairs toward the end of a vehicle's life remains. Older vehicles will still tend to be owned by people in lower-income groups who are least able to afford emissions-related repairs. Thus, behavioral and economic issues will continue to play central roles in maintaining low emissions throughout vehicle lifetimes.

I/M PROGRAM ELEMENTS

Each I/M program is composed of numerous individual pieces. They are somewhat unique in terms of the tests used to gauge emissions, the level of emissions that defines whether a vehicle fails an emissions test (the cut point), the compliance plan, the training requirements for repair technicians, and other elements. One essential element for an I/M program is the test type used for estimating vehicle tailpipe emissions. Most tailpipe emissions tests require that a vehicle have its emissions measured under idle or driving conditions at a testing facility. An idle test is the most basic and it measures the concentrations of CO and HC in exhaust emissions from an idling vehicle. The limitations of such a test include the inability to directly estimate mass emissions and the inability to estimate NO_x emissions, which requires the vehicle to be under a driving load. The most complex emissions test in use is the IM240, a 240-second test that simulates the loads a vehicle might be under during urban driving. This test is able to measure mass emissions of CO, HC, and NO_x, albeit at a higher cost for testing equipment.

The CAAA mandated that areas with the worst air quality adopt an enhanced I/M program that had testing at centralized, test-only facilities using a computerized, loaded mode test such as the IM240.[13] Using the MOBILE model, EPA estimated that by the year 2000 such a program would reduce HC emissions from on-road motor vehicles by 28%, CO by 31%, and NO_x by 9% over areas with no I/M program.[13] However, opposition by states and other interest groups resulted in the elimination of the IM240 mandate and in the implementation of an array of test types and network configurations. For an example of some of the issues associated with the IM240 mandate, see the exchange between the California Inspection and Maintenance Review Committee (IMRC) and the EPA summarized by the IMRC.[14,15]

METHODS AND DATA FOR ESTIMATING EMISSIONS IMPACTS

Evaluations are critical for assessing whether I/M programs are providing the expected emissions benefits. Evaluations are also essential for guiding improvements and defining the road ahead for I/M programs. Previous evaluations of I/M's emissions benefits have been based on MOBILE, as well as direct estimates of vehicle emissions, such as those measured by remote sensing or in the I/M program itself. The committee believes the latter evaluations are more credible.

I/M programs impact emissions in various ways, including improvements in maintenance, repairs made in anticipation of an emissions test, repairs made as a result of failing a test, and scrappage of vehicles that are unable to pass. As shown in Table 1, there are a variety of data sources and methods for evaluating emissions benefits. Each data source and evaluation method has its own shortcomings. One of the most fundamental problems in estimating the emissions impact of I/M programs is the difficulty of developing a single evaluation method that can account for all emission impacts. The committee feels it is essential that a few programs undergo repeated, long-term evaluations using multiple data sources and methods to assess fundamental uncertainties associated with I/M's impacts on vehicle emissions.

The committee recognizes that not all jurisdictions will be able to devote the resources needed to perform comprehensive evaluations using multiple sources of primary data. However, states with enhanced I/M programs are mandated by the CAAA to perform biennial evaluations of their programs' emissions impacts. The majority of these evaluations have not been completed and are overdue. The committee recommended that guidelines for shortened evaluation methods be developed and peer reviewed by EPA to expedite compliance with the CAAA.

Both the comprehensive and the shortened program evaluations should include a consistent set of performance indicators, some of which are shown in Table 2. Although such indicators do not prove a direct estimation of emissions reductions, they can help track the performance of a program over time and provide relatively concise indicators of a program's success.

One critical caveat is that the above discussion pertains to estimating *tailpipe* emissions reductions as opposed to *evaporative* emissions. Evaporative emissions represent a significant and

Table 3. Probability of failure and ownership income by model year.

Model Year	Probability Vehicle Will Fail Initial Test (%)	Probability a Failed Vehicle Will Never Pass (%)	Average Income of Owner, in National Sample ($)
1981	45.4	43.7	38,400
1982	41.2	38.1	35,500
1983	38.5	38.9	39,000
1984	35.9	37.2	40,800
1985	28.8	32.8	41,700
1986	19.8	27.6	44,100
1987	14.2	25.1	46,000
1988	12.2	22.9	47,300
1989	8.1	18.5	48,000
1990	5.6	15.8	51,200
1991	6.8	18.6	52,000
1992	4.4	13.1	53,600
1993	2.6	8.1	54,900
1994	1.2	1.8	57,400
1995	1.0	1.1	61,000

Sources: Harrington and McConnell.[27]
Columns 1 and 2: Arizona enhanced I/M database, 1995–96.
Column 3: 1995 nationwide personal transportation survey.[28]

poorly characterized source of overall vehicle hydrocarbon emissions. These emissions are very difficult and expensive to measure, requiring special equipment, invasive test methods, and long test times. I/M tests typically involve a targeted visual inspection of evaporative control components, such as a gas-cap check. The evaporative emissions reductions possible from these limited inspections are difficult, if not impossible, to estimate. One needs to know the frequencies and impacts of evaporative system failures, the ability to detect failure, and the ability of the service industry to make effective and durable repairs.

ESTIMATES AND UNCERTAINTIES OF EMISSIONS IMPACTS

The committee concluded that I/M programs are providing emissions reductions that are from zero to approximately one-half of the reductions predicted by the models. This conclusion was based on a review of state-sponsored evaluations of the Colorado and California programs and independent evaluations of the same programs, as well as programs in Arizona, Minnesota, and Georgia.[16-21] The estimated emissions reductions are dependent on the pollutant and version of the model used for the original forecast. In general, they are lowest for idle test programs performed at facilities that test and repair vehicles and highest for hybrid or centralized transient test programs.

There are many uncertainties in evaluating the emissions impacts of I/M programs. The committee concluded that understanding the emissions characteristics of vehicles that do not comply with program requirements and the adequacy of emissions-related repairs were particularly important. Program noncompliance, either by avoiding the test altogether or by never returning after initially failing an I/M test, lowers the emissions benefits of an I/M program. Studies have indicated that 10–27% of all vehicles that failed an emissions test never received a passing mark.[16,18,21] Many of these vehicles are observed to be still operating on the road. Another 5–10% of vehicles on the road have been found to be eligible, but never participate in testing.[18] An extensive effort to collect these measures of program avoidance is needed to better assess their impact on emissions reductions.

Effective and durable repairs are also needed for an I/M program to succeed. Studies also show that repairs done in I/M programs do not cost as much and result in emissions reductions smaller than those done in laboratory studies of repairs.[7,18,22-26] These findings suggest that repairs done in I/M programs might not be as complete and long-lasting as they could be. A desire to pass the test at the minimal possible cost affects the type of repairs motorists obtain. Additional studies linking costs of repair, type of repair, emissions benefits, and the duration of those repairs are needed to document whether effective repairs are being done in I/M programs and how those repairs compare with repairs provided under laboratory conditions where cost considerations are less and technician training is likely higher.

EVALUATING I/M PROGRAMS: OTHER IMPACTS

How do the costs of repair fall on different income groups in society? The answer will affect the ability of I/M to eliminate or substantially reduce high-emitting vehicles. Table 3 indicates that older vehicles are more likely to be owned by households

Table 4. Summary of recommendations from NRC Committee to Review Vehicle Emissions Inspection and Maintenance Programs.

Prospective Estimates of Emissions Reductions from I/M Programs
- EPA and states should expect lower emissions-reduction benefits from I/M programs as currently configured

High-Emitting Vehicles
- I/M programs should focus primarily on identification, diagnosis, and repair of the highest-emitting vehicles along with verification of those repaired

Evaluating I/M Emissions Reductions
- EPA should provide additional guidance for carrying out I/M evaluations, including:
  - Comprehensive, long-term evaluations using multiple data sources and analytic techniques for a select number of programs
  - All programs collecting a consistent set of indicators to help track performance

Research Issues in I/M Evaluation
- Comprehensive evaluations of I/M programs should be used to address major uncertainties in the emissions-reduction benefits from I/M programs, including:
  - The distribution of the duration of repairs for vehicles that fail an initial I/M test
  - The extent of pre-inspection repairs
  - The extent to which temporary repairs and test fraud result in vehicles registering low emissions only for the purpose of passing an I/M test (the "clean for a day" phenomena)
  - The fate of vehicles that fail their initial I/M test and never pass (unresolved failures)
  - Consequences of I/M programs for nontailpipe HC reductions

NO_x and Particulate Matter (PM) Emissions
- Because heavy-duty diesel vehicles are a significant source of NO_x and PM emissions, I/M programs that target these pollutants might have to incorporate heavy-duty diesel vehicles to a greater extent

Remote Sensing
- Remote sensing should have an increased role in assessing motor vehicle emissions and I/M program effectiveness, determining the extent of pre-inspection repairs, and estimating the extent of certain types of noncompliance

Onboard Diagnostics
- An independent evaluation should be established to review the effectiveness and cost-effectiveness of OBDII testing programs before moving forward with full implementation of OBDII rule requirements

Use of the MOBILE Model
- The methodology used in MOBILE for estimating I/M benefits should be reevaluated and more pessimistic defaults used in the model to encourage users to readily incorporate data from current I/M program evaluations into assessments for future years

Importance of Cost-Effectiveness and Public Response to I/M
- I/M programs should be improved by identifying ways to make them more cost-effective and more readily understood, and by easing the testing burden for vehicle owners

with lower than average incomes. It also indicates that older vehicles are much less likely than new vehicles to eventually pass the emissions test. Another study found that households in low-income neighborhoods in Los Angeles tended to have older vehicles, as well as higher-emitting vehicles for their age.[29]

Assigning motorists the liability for repairs means that those least able to pay are likely to be paying the highest costs. Politically, it has been difficult to enforce a regulation that appears to have such a regressive incidence. States have responded by allowing waivers for vehicle owners who have paid up to some repair cost minimum. That response is clearly not the best solution for achieving improved air quality; alternatives, such as repair subsidies and repair insurance, might offer more cost-effective solutions.

The importance of I/M's economic and social impacts demonstrates the need for these programs to be evaluated on more than just their benefits. The committee thought that costs and cost-effectiveness (in dollars per unit mass of emissions reductions) are important for determining if social resources are being well spent, and for decisions about improving I/M program design. The distribution of costs among motorists can also affect public acceptance of I/M and be a key factor affecting behavior and ultimately emissions reductions. Other factors that influence emission reductions and are important evaluation criteria in their own right are compliance levels and public acceptance.

EMERGING TESTING TECHNOLOGIES

New emissions testing techniques, such as those relying on vehicle emissions profiles, remote sensing, and OBDII, are being deployed in I/M programs around the country. These new testing approaches are intended to provide faster, more convenient testing and be better able to identify vehicles with malfunctioning emissions control systems. Motor vehicle emissions profiling uses emissions data, such as the past performance of a vehicle in its I/M test, as well as the performance of similar makes and models, to help assess the likelihood of whether a vehicle will pass or fail an I/M inspection. It is intended to improve the effectiveness of I/M programs by targeting vehicles most likely to fail more frequent or thorough inspections and potentially exempting from testing vehicles with a small likelihood of failing. Remote sensing is a technique used to measure emissions from individual vehicles as they drive by a roadside sensor. It offers the possibility of testing a vehicle's exhaust emissions without the need for it to be brought to a testing facility. Using the OBDII system to determine the status of a vehicle's emissions control system offers the possibility of detecting problems in the exhaust and evaporative controls before emissions become excessive.

However, these new tests have had mixed results in their initial implementations. Though the use of low-emitter profiles to exclude newer vehicles from testing have been relatively

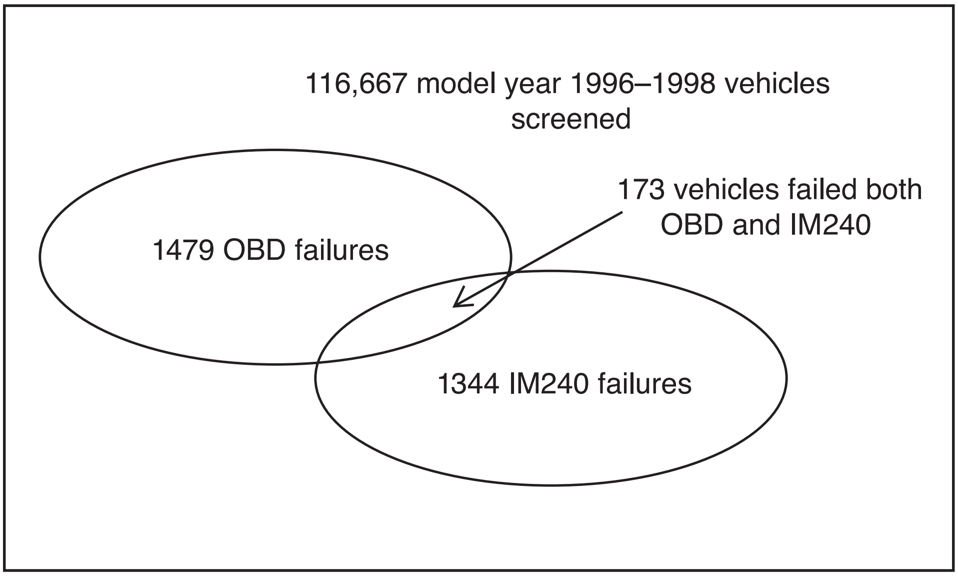

Figure 2. Number of OBD and IM240 failures for model year 1996–1998 vehicles.

successful, high-emitter profiles used in California to target vehicles thought to be more prone to failure for more rigorous testing did not result in an increased identification rate of high emitters. Remote sensing is currently being used in Colorado and Missouri to identify clean vehicles so that they may avoid visiting an emissions test station for scheduled testing. For example, in the St. Louis area, if a vehicle has two or more successive low-emissions readings measured by remote sensing, the vehicle owner can opt to be excused from scheduled emissions testing. The use of remote sensing for identifying high emitters in Arizona, however, was terminated by state legislators because of problems, including high costs for identifying high-emitting vehicle, false failures, and difficulties in finding appropriate remote-sensing sites.

Currently, the most controversial new vehicle emissions testing strategy is the use of OBD technologies in I/M programs. EPA recently finalized a rule that requires states to begin implementing OBD testing in I/M programs for 1996 and newer OBDII-equipped vehicles.[30] If the OBD I/M program is operating properly, inspections using OBDII will fail vehicles if either the vehicle's emissions-control components are, or have been, malfunctioning or if the sensors monitoring emissions-control components are malfunctioning. This program is in contrast to a traditional I/M emissions-testing program where a vehicle is inspected to determine if it is emitting, at the time of its appearance at the testing station, more pollutants than are allowed by a set emissions standard.

The committee was particularly interested in several technical analyses of OBD I/M. The OBDII system is designed to illuminate the malfunction indicator light (MIL) and issue a diagnostic trouble code, which can then be downloaded from the vehicle's computer, if a problem is detected that might cause emissions to exceed 1.5 times the vehicle emissions certification standard. In addition, MIL illumination occurs if the system determines that a monitor or sensor is not responding properly, even without increased emissions. Analysis by EPA[31] and University of California, Riverside,[32] indicated that a significant fraction of vehicles that failed OBD I/M had emissions below the vehicle's certification standards. Current I/M programs do not fail vehicles unless they have tailpipe emissions that are typically three to seven times higher than the certification standards.

Studies by EPA[31] and Barrett[33] looked at both the relative failure rates for MIL failures versus lane IM240 testing. For 1996 model-year vehicles, the OBD failure rate from the Wisconsin lane data was 2.4%, and the IM240 failure rate was 2.1%. However, the percentage of vehicles that failed both was only 0.2%, which indicates that only a small fraction (about 10%) of vehicles failing one also failed the other. Figure 2 shows the results from both the Wisconsin and Colorado data. The large discrepancies between IM240 and OBD test failures are a major concern, especially since it appears that many vehicles with higher emissions that failed the IM240 test did not fail the OBD test.

The committee found that the current data set for evaluating the effectiveness of OBDII for I/M testing was inadequate. It recommended that an independent evaluation be established, with appropriate funding, using researchers outside EPA to review the effectiveness and cost-effectiveness of OBDII testing programs. Failing a large number of vehicles with emissions below 1.5-times the certification standards could undermine a commitment to find high-emitting vehicles and ensure that they are repaired. The OBDII failure point might be too low for a cost-effective and publicly acceptable I/M program, especially for older OBDII vehicles.

CONCLUSIONS

Over the past 35 years, controlling emissions has emerged as a critical facet of vehicle operations. Emissions control has been largely accomplished through a coupling of new technologies that directly reduce emissions with modifications to vehicle operations that minimize pollutant formation. For these technologies to be effective in reducing pollution, they need to be properly functioning throughout the lifetime of a vehicle. I/M programs are intended to ensure that the emissions control system installed on a new vehicle operates throughout a vehicle's lifetime.

The National Research Council Committee that was convened to study I/M programs made a number of findings and recommendations. Some have been discussed in this article. Table 4 provides a complete list of the recommendations. Overall, the committee found that, despite the smaller than forecasted benefits, there is a need for programs that repair or eliminate high-emitting vehicles from the fleet, given the major influence these vehicles have on total emissions. The committee held lively debates on the relative merits of a variety of approaches for doing I/M testing, such as traditional tailpipe testing, OBDII testing, or remote sensing screening. In the end, the committee thought that states should be given flexibility to choose a regime that meets their emissions-reduction goals at the lowest cost to the public.

Any program designed to repair high-emitting vehicles might raise serious fairness concerns, because high emitters are more likely to be owned by persons of limited economic means. The committee recommends that policies be explored to provide financial or other incentives for motorists of high-emitting vehicles to seek repairs or vehicle replacement. Future changes to I/M might have different distributional income effects on motorists. For example, the addition of OBDII systems to vehicles could increase the future costs of vehicle repairs. That increase could create a greater burden for low-income drivers, who will operate OBDII vehicles at the end of the vehicles' lifetimes.

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