IMS-001/FE-1

Effects of Inspection and Maintenance Programs on Fuel Economy

March 1979

Inspection and Maintenance Staff
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Office of Air, Noise, and Radiation
U.S. Environmental Protection Agency

Introduction

The primary goal of inspection and maintenance (I/M) programs is to improve air quality by reducing emissions from motor vehicles. Many studies have indicated that I/M programs will achieve this goal. In addition several studies have indicated that fuel economy improvement can be expected to occur as a result of maintenance performed on vehicles failing an I/M test. Most studies which have been performed have looked at pre-1975 model year vehicles and have had expert mechanics performing the maintenance work. It is the intention of the present report to consider both the results from past studies and the results from more recent studies in order to provide EPA's best estimates of fuel economy benefit which can be attributed to I/M maintenance.

The results of this study are discussed in the body of the report by model year groups, which reflect the level of emission control technology: pre-1975, 1975-80, and 1981+. Attachment 1 provides a short tabular summary of studies which relate to I/M's effect on fuel economy. Attachment 2 provides a bibliography which gives references for most of the studies summarized in Attachment 1 and alluded to in the body of the report. The following section summarizes EPA's best estimates of I/M's effect on fuel economy.

Summary

On the basis of past studies on pre-1975 model year cars, EPA has indicated that the fuel economy of cars failing an I/M test will likely improve following maintenance. Recently, with the availability of data from Oregon's I/M program and further data and information on catalyst and microprocessor controlled systems, it has become clear that I/M's effect on fuel economy is not as straightforward as was previously thought. All available data on the question of I/M's effect on fuel economy have therefore been studied in order to better quantify what this effect will be.

Many past I/M studies have indicated a fuel economy benefit due to such maintenance, and more recent EPA studies have also indicated that a fuel economy benefit is obtained following restorative maintenance performed to manufacturers' specifications by skilled mechanics. However, data from the Portland Study, covering 1972-77 model year cars, show no net gain in fleet average fuel economy due to maintenance performed in response to failing an idle test in Oregon's I/M program. The apparent contradiction between the field data from Portland and these other studies is explainable. The past I/M studies have in most cases included maintenance which was either performed by skilled mechanics or which was (by the study's definition) more extensive than the typical I/M tune-up performed in response to an I/M program. In addition, very few mechanics in the Portland area have been specifically trained in emission-oriented maintenance. This is in contrast to the emission-oriented maintenance to manufacturers' specifications which has been performed in EPA's studies of the effects of restorative maintenance. EPA concludes that the failure to observe a net gain in fuel economy in Portland only implies that any basic, idle test I/M program which is unsupported by an emission-oriented mechanic training program should also be expected to show no net gain in fuel economy. EPA also concludes on the basis of the other studies that a net fuel economy gain due to I/M maintenance is possible for pre-1980 model year cars, if the I/M program is supported by mechanic training.

For 1980 model year cars technology will change somewhat from that currently used outside of California. Data on 1975-77 model year California cars have been used to estimate the effect of I/M on 1980 model year Federal cars. (The technologies are expected to be very similar, as are the emission standards.) Even with skilled mechanics performing repairs to manufacturer's specification, no significant fuel economy improvement is seen. This is a somewhat unexpected result which requires further investigation when data on 1980 model year Federal cars are available.

For 1981 and later models, fuel economy improvements due to emission-related maintenance are expected. These improvements are expected to be more substantial than the improvements possible for pre-1980 model year cars, primarily because engine control system failures will often cause the air/fuel mixture to enrichen over all modes of vehicle operation, not just during idle operation, and thus degrade both fuel economy and emissions.

The table below provides EPA's best estimates of fuel economy improvement of failed cars following maintenance.

Average Fuel Economy Improvements for Failed Vehicles due to I/M

Model Year	Without Emission-Oriented Mechanic Training	With Emission-Oriented Mechanic Training
pre-1975	0%	3-4%
1975-1979	0%	3-4%
1980	0%	?
1981+	?	9-30%

Discussion: Pre-1975 Model Year Cars

By the early 1980s when most I/M programs will be operational, pre-1975 models will account for less than 20% of the annual vehicle miles traveled (VMT) for passenger cars and by 1987 this will be reduced to

3%. Therefore, from the standpoint of I/M, pre-1975 models are relatively less important than 1975 and later models in terms of both emission reductions achievable and fuel economy effects.

All past studies which have evaluated fuel economy benefit due to I/M for pre-75 models have reported improvements in fuel economy resulting from maintenance. Most of these studies have measured fuel economy during city, as opposed to highway, driving cycles. The city cycle includes more idle operation than the city/highway combination used by EPA to measure typical passenger car fuel economy. In most of these studies, mechanics performing the maintenance had a higher than average level of expertise. As Attachment 1 shows, reported fuel economy improvements from past studies (studies 6-13) have ranged from 2% to 14%. For past studies which best typify anticipated I/M situations (studies 6, 8, and 10), the range in fuel economy improvements is 2% to 4% for pre-1975 models. In two of these three studies city driving cycles were used to measure fuel economy. In all three studies the maintenance performed on failed cars was either more extensive than would usually be necessary in a real I/M program or was performed by trained mechanics.

EPA's Portland Study, which is now in progress, provides before and after maintenance fuel economy data from a real I/M program.[1/] Analysis of the data on the 1972-74 model year failed cars tested in this program indicates that although maintenance performed on failed vehicles significantly improves fuel economy during city driving,[2/] the improvement is relatively small. There is no statistically significant effect during a typical city/highway combination of driving. City/highway combined fuel economy changes from 16.8 miles per gallon (MPG) initially to 16.9 MPG on failed cars after maintenance.

Although there is no net fuel economy gain or loss for all 1972-74 model year cars in the Portland Study taken together, the worst idle HC and CO emitters in the sample, as identified by Oregon's state inspection test, obtained a substantial fuel economy benefit after maintenance. These 11 cars' fuel economy went from 16.9 MPG before maintenance to 17.9 MPG after maintenance, an improvement of 6%.

The results for 1972-74 models are summarized in Table 1. To summarize verbally, for a typical combination of city/highway driving, no net gain or loss in fuel economy for pre-1975 models is observed in Portland. However, on especially high idle emitters the possibility of improved fuel economy after maintenance for failed cars is increased. Also, based on past studies which were designed to evaluate I/M's effect on fuel economy (notably studies 6, 8, and 10 in Attachment 1), it appears that a fuel economy benefit of approximately 3% may occur if an emission-oriented mechanic training program is in place. Very little emission-oriented training of practicing mechanics has occurred in the Portland area to date.

[1/] Vehicles are passed or failed according to Oregon's state inspection test (basically an idle test) and failed vehicles are maintained by practicing mechanics in the Portland area.

[2/] In the statistical sense at the 0.05 level of significance.

Table 1

Fuel Economy Before and After Maintenance[1/]
1972-74 Model Year Failed Vehicles in the Portland Study

		Urban			Highway			Combined		
	N	Before Maintenance	After Maintenance	Percent Change	Before Maintenance	After Maintenance	Percent Change	Before Maintenance	After Maintenance	Percent Change
All 1972-74 Models	93	14.48	14.69	1.4[2/]	20.89	20.75	-0.7	16.80	16.91	0.6
1972 Models	38	13.72	13.74	0.1	19.62	19.37	-1.3	15.87	15.81	0.4
1973 Models	26	13.55	14.01	3.4[2/]	20.06	20.04	-0.1	15.87	16.21	2.1[2/]
1974 Models	29	16.73	19.96	1.9	23.77	23.73	-0.2	19.30	19.46	0.8
Highest Idle HC Emitters	20	13.63	13.89	1.9	19.71	19.74	0.1	15.82	16.04	1.3
Highest Idle CO Emitters	20	15.50	15.56	0.4[2/]	22.90	23.18	1.2	18.14	19.00	4.7[2/]
Highest Idle HC <u>and</u> CO Emitters	11	14.52	15.69	8.1	21.26	21.78	2.4	16.93	17.95	6.0

[1/] Fuel economy is measured in miles per gallon.

[2/] This change was statistically significant at the 0.05 level through the application of a paired t-test. Groups with less than 20 vehicles were not evaluated for statistical significance due to small sample size.

1975-80 Model Year Cars

In the early 1980s when most I/M programs will be operational, 1975-80 model year cars will account for 65% of the VMT for passenger cars, and by 1987 will still account for 27%. Therefore the effect of I/M on these vehicles from the standpoint of fuel economy is an important consideration. I/M's effect on fuel economy for 1975-80 model year failed vehicles is estimated from studies of 1975-77 model year cars' data. All studies are relatively recent.

Of the available studies, the study which best typifies anticipated I/M situations is EPA's Portland Study. In the Portland Study the change in fuel economy for failed vehicles after maintenance is small and is statistically insignificant. Before and after maintenance combined city/highway fuel economies were 17.9 miles per gallon and 17.8 miles per gallon, respectively. Although 1975-77 model year failed vehicles saw virtually no fuel economy change as a group, the 1977 model year failed vehicles on the average received a statistically significant fuel economy penalty of 3-4% following maintenance. The design of 1977 model year vehicles is very similar to the design of 1975-76 models, except that the control of oxides of nitrogen is more stringent. Thus, there is no obvious reason to expect I/M's effect on fuel economy to be different for the 1977 models. A detailed review of the emissions data, diagnostics, and maintenance reported for these vehicles is now underway and indicates that improper adjustment of ignition timing and improper operation of vacuum advance units in their before maintenance condition may explain some fuel economy penalties following maintenance.

As was the case for the 1972-74 models, it was anticipated that the worst idle emitters among the 1975-1977 models might see fuel economy improvements following maintenance. Therefore, the highest idle emitters were identified so that fuel economy effects for this sample could be analyzed. The results of this analysis indicated that those vehicles with the highest idle HC and CO levels received a fuel economy penalty. From a theoretical standpoint, there is no good explanation for this.

The Portland Study results discussed above for 1975-77 models are summarized in Table 2. Results from other studies are described in the following paragraphs.

In addition to the data from the Portland Study, EPA has analyzed data from its Restorative Maintenance (RM) Programs in an I/M-oriented fashion. The vehicles were screened for passage or failure of the idle test using idle HC and CO standards of 225 ppm and 1.0%, respectively, the standards applied to the majority of 1975 and later model year cars in Oregon's I/M program. FTP emission-oriented maintenance (as opposed to idle emission-oriented maintenance) was performed to manufacturers' specifications

Table 2

Fuel Economy Before and After Maintenance[1/]
1975-77 Model Year Failed Vehicles in the Portland Study

		Urban			Highway			Combined		
	N	Before Maintenance	After Maintenance	Percent Change	Before Maintenance	After Maintenance	Percent Change	Before Maintenance	After Maintenance	Percent Change
All 1975-77 Models	110	15.55	15.55	0.0	21.90	21.51	-1.8	17.88	17.76	-0.7
1975 Models	36	14.96	15.20	1.6 2/	21.27	21.36	0.4	17.26	17.47	1.2 2/
1976 Models	36	16.21	16.56	2.2 2/	22.70	22.46	-1.1	18.61	18.78	0.9
1977 Models	38	15.53	15.01	-3.3	21.78	20.80	-4.5 2/	17.83	17.16	-3.7 2/
Highest Idle HC Emitters	22	14.92	14.15	-5.2	20.88	19.70	-5.7 2/	17.12	16.20	-5.4
Highest Idle CO Emitters	22	14.85	14.98	0.9	20.81	20.23	-2.8	17.05	16.96	-0.5
Highest Idle HC and CO Emitters	12	15.40	15.09	-2.0	21.54	20.36	-5.5	17.67	17.08	-3.3

1/ Fuel economy is measured in miles per gallon.

2/ This change was statistically significant at the 0.05 level through the application of a paired t-test. Groups with less than 20 vehicles were not evaluated for statistical significance due to small sample size.

in progressive steps by skilled mechanics. For the I/M analysis, the "after maintenance" fuel economy was taken at the maintenance step where the idle standards would be met regardless of whether further maintenance was actually performed in the RM sequence. The observed fuel economy improvement was significant in the statistical sense. Fuel economy improved from 15.6 MPG to 16.2 MPG, or approximately 4%. These data, which are summarized in Tables 3 and 4, suggest that up to a 4% improvement in fuel economy is possible with an emission-oriented mechanic training program in place.

The California Air Resources Board (CARB) tested 150 1975-77 model year cars in its Light Duty Vehicle Surveillance Testing Program (LDVSP-II). Because of more stringent emission standards for California vehicles, these vehicles also closely represent non-California cars which will be sold in the 49 states in model year 1980. Of the vehicles tested by CARB, 31 failed the proposed California idle test standards of 50 ppm HC and 0.5% CO. Following an I/M-type repair to manufacturer's specifications by skilled CARB mechanics, fuel economy improved 1.8%, but this improvement was not significant in the statistical sense.

Applying the 0.5% CO and 50 ppm HC idle test standards to the sample of 100 1975-76 model year California cars tested in EPA's Restorative Maintenance Program in San Francisco, 14 vehicles were failed initially and met the standards following maintenance. An average combined city/highway fuel economy of 13.22 MPG before maintenance and 13.20 MPG after maintenance was observed on these vehicles. This result corroborates the CARB result of no fuel economy improvement for 1980 model year Federal cars. Since emission control technology is not expected to change dramatically in 1980, this result is somewhat puzzling and requires further investigation once 1980 model year Federal car data become available.

Table 3

Fuel Economy Before and After Maintenance
1975-76 Model Year Federal Failed Vehicles Tested in EPA's
Restorative Maintenance Program[1/]
(97 Cars)

	Urban	Highway	Combined
Before Maintenance	13.39	19.40	15.56
After Maintenance	14.10	19.69	16.17
Percent Change	5.3 [2/]	1.5 [2/]	3.9 [2/]

1/ Harmonic means are used to calculate mean fuel economy, which is presented in miles per gallon.

2/ This change was statistically significant at the 0.05 level through the application of a paired t-test. Groups with less than 20 vehicles were not evaluated for statistical significance due to small sample size.

Table 4

Fuel Economy Before and After Maintenance
Eleven 1977 Model Year Failed Vehicles Tested in
EPA's Restorative Maintenance Program[1/]

	Urban	Highway	Combined
Before Maintenance	13.71	18.58	15.54
After Maintenance	14.39	19.05	16.17
Percent Change	5.0 [2/]	2.5	4.1 [2/]

1/ Harmonic means are used to calculate mean fuel economy, which is presented in miles per gallon.

2/ This change was statistically significant at the 0.05 level through the application of a paired t-test. Groups with less than 20 vehicles were not evaluated for statistical significance due to small sample size.

It appears that 1975-80 model year cars' fuel economy, on the average, is unaffected by I/M if minimal maintenance is performed strictly in response to an idle test failure. However, EPA concludes on the basis of RM data that a strong emission-oriented mechanic training program could result in fuel economy improvements for 1975-79 model year failed vehicles, estimated at up to 4%. EPA refrains from making a conclusion with respect to 1980 models until data on 1980 model year Federal cars become available.

Post-1980 Model Year Cars

The majority of I/M failures of current technology (1975-80) vehicles results from the improper adjustment of the carburetor idle air-fuel mixture. The proper adjustment reduces the fuel used at idle, however idle fuel usage is only a small portion of the fuel used during typical vehicle operation. Thus, maintenance specific to the idle system usually results in a small improvement to fuel economy in everyday driving. This is reflected in the fuel economy changes presented in the sections above on pre-1981 model year cars in the Portland Study.

Beginning in 1981 there will be two types of changes in emission control systems. Some smaller cars will retain essentially their current systems, but their manufacturers will limit the adjustable range of the idle air/fuel mixture. EPA hopes this will reduce the frequency of improper carburetor adjustments among these vehicles. If it does, idle mixture maintenance in I/M programs and the small improvement it gives in fuel economy will also be less frequent for these cars.

The second type of change will affect the remaining smaller cars and virtually all larger cars (excepting those which convert to Diesel engines). These cars will also have reduced adjustability, but more importantly they will have new emission control systems. In addition, the new emission control systems will commonly incorporate three-way catalysts with feedback carburetion which will, through the input from an oxygen sensor in the exhaust, select the proper air-fuel mixture for all operating conditions, including idle. Failure of the oxygen sensor, the mini-computer, and many of its other input signals, will likely cause the carburetor to supply much more fuel than is required for best fuel economy and emissions at operating conditions such as acceleration and cruise, as well as at idle. Maintenance performed on these systems can thus be expected to increase fuel economy much more than with current technology cars.

EPA has tested several vehicles which are equipped with feedback carburetion systems. These data are summarized in Table 5. It is anticipated that these vehicles will be representative of 1981 and later production Federal vehicles (1980 and later in California). The results, although based on only a few vehicles, indicate about a 9 to 30 percent potential improvement in fuel economy when repairs to the engine control system are made. The fleetwide fuel savings cannot be estimated until experience with the frequency of failures and improper maintenance is obtained.

Table 5

Repaired Vehicle Fuel Economy Benefit
Expected for 1981 and Later Model Year Vehicles 1/

Vehicle	Description	Fuel Economy before Maintenance	Fuel Economy after Maintenance 3/	Percent Change
1	1978 Pontiac Sunbird	21.6 MPG 2/	25.4 MPG	17.6%
2	1978 Ford Pinto	21.9 MPG 2/	24.6 MPG	12.3%
3	1978 Pontiac Sunbird	19.9 MPG 2/	23.6 MPG	18.6%
4	1978 Pontiac Sunbird	18.9 MPG 2/	20.6 MPG	9.0%
5	1978 Ford Pinto	21.3 MPG 2/	24.2 MPG	13.6%
6	1979 Mercury Marquis	13.4 MPG 4/	17.4 MPG	29.9%
7	1981 GM prototype 5/	16.2 MPG 6/	18.6 MPG	14.8%

1/ Each vehicle was tested first in tuned-up condition, and then with the failure modes noted below. Testing was performed by EPA, except as noted.

2/ In tuned-up condition except with oxygen sensor disconnected; combined city/highway fuel economy. The oxygen sensor is a maintainable item, requiring periodic replacement.

3/ In tuned-up condition; combined city/highway fuel economy.

4/ In the "before maintenance" test, the vehicle was in a tunedup condition except that the "limited operating strategy," which can occur following failure of the on-board computer, was in effect.

5/ Testing was performed by GM. Data are preliminary.

6/ In the "before maintenance" test, the vehicle was in a tuned-up condition except that the carburetor was operating as rich as possible. This mode closely approximates that which would be caused by a disconnected oxygen sensor.

Attachment 1

Summary of Studies on Fuel Economy Benefit Due to Inspection and Maintenance

Study	Sample 1/	Screening Test Used to Determine Failure	Level of Mechanic Skill/Training 2/	Relevance to I/M 3/	Repaired Vehicles Average Fuel Economy Benefit 4/
1. EPA's Portland Study	93 1972-74 Models 11C 1975-77 Models	Oregon State Inspection Test (30% failure rate) (Idle Test + Brief Phy.Insp)	Average	High	1972-74: 0.6% 5/ 1975-77:-0.7% 5/
2. I/M-Oriented Analysis of EPA's RM 76 Program	97 1975-76 Models	Idle Test (30% failure rate)	High	High	3.9% 5/
3. I/M-Oriented Analysis of EPA's RM77 Program	11 Very Low Mileage 1977 Models	Idle Test (25% failure rate)	High	Medium	4.0% 5/
4. EPA's Analysis of Data from CARB's LDVSP-II	31 1975-77 Models	Idle Test (20% failure rate)	High	High	1.8% 5/
5. EPA's Analysis of Data on 3-Way Catalyst Equipped Vehicles	7 Feedback Carburetion Vehicles	Visual Inspection of Oxygen Sensor or Spark Timing	High	High	9%-30% 5/
6. EPA's Analysis of Data from CARB's Riverside Program	349 1955-74 Models	Idle Test (35% failure rate)	Average-High	Low	Pre-71: 3.1% 6/ 1971-74: 2.0% 6/
7. NHTSA 322-Car Study	322 1968-73 Models	Loaded or Idle Test	Average	Low	4.7% 7/
8. NHTSA 57-Car Study	57 1969-72 Models	Loaded Test	High	Low	3.5% 5/
9. Champion Spark Plug Co. Studies	310 pre-68 to 1975 Models (mostly pre-75s)	Extensive Diagnostic Inspection	High	Low	11.4% 8/
10. CARB Degradation Study	59 1968-74 Models	Idle Test (40% failure rate)	High	Low	3.1% 9/
11. Private Vehicle Fleet I/M	U.S. Postal Service, Baltimore Cty.Trans., & A.T.& T. fleets	Emission Tests	High	Low	4% - 10% 10/
12. EPA's I/M Information Document (EPA-400/2-78-001)	Mathematical Model	-	-	Low	4% - 10% 11/
13. J. Panzer's Model of Fuel Economy Benefit	Mathematical Model	Idle Test (varying failure rate)	-	Low	8% - 14%

1/ All vehicles described here have undergone maintenance due to failure of screening test.
2/ "Average" means that maintenance was performed by mechanics who have not been specially trained in emission-oriented maintenance techniques.
"High" means that maintenance was performed, usually to manufacturer's specifications, by skilled mechanics or technicians.
3/ Relevance to I/M is determined on the basis of how well the study's design represents anticipated I/M situations, and also on how well the technology of fleet of vehicles studied represents the early 1980's I/M target populations.
4/ As measured immediately after maintenance; except as noted.
5/ EPA city/highway combined fuel economy (55% city driving, 45% highway driving).
6/ As measured over the 75 FTP (EPA's city driving cycle).
7/ As reported by vehicle owners.
8/ After full tune-up to manufacturer's specification, plus mandatory replacement of spark plugs. Fuel economy is measured over a transient cycle representative of the Toledo metropolitan area's driving patterns.
9/ As measured over the 72 FTP (bag 1 and 2 of the 75 FTP) This assumes that all vehicle start-ups are from a cold engine condition
10/ No standard test procedure was used to determine fuel economy benefit; not necessarily as measured immediately after maintenance.
11/ Estimated annual fuel economy benefit.

Attachment 2

Bibliography of Studies Related to
the Effects of Inspection and Maintenance
Programs on Fuel Economy

Portland Study Interim Analysis: Observations on Six Months of Vehicle Operation; I/M Staff, Emission Control Technology Division, Office of Mobile Source Air Pollution Control, U.S. EPA; January 1979.

An Evaluation of Restorative Maintenance on Exhaust Emissions from In-Use Automobiles; White, J.T.; SAE Paper 780082; March 1978.

Vehicle Inspection and Maintenance - The California Program; Rubenstein, G., Ingels, R., Weis, R., Wong, A.; California Air Resources Board; SAE Paper 760557; June 7-10, 1976.

Motor Vehicle Diagnostic Inspection Demonstration Program - Summary Report; Innes, J. and Eder, L.; NHTSA Technical Report, DOT HS-802 760; October 1977.

Fuel Economy Improvements through Diagnostic Inspection; Bayler, T. and Eder, L.; NHTSA Technical Report DOT HS-802 284; March 1977.

How Passenger Car Maintenance Affects Fuel Economy and Emissions: A Nationwide Survey; Walker, D.L., Boord, J.O., Pigott, J.S., and Sutton, E.R.; Champion Spark Plug Company; SAE Paper 780032; February 27-March 3, 1978.

Car Maintenance Around the World; Champion Spark Plug Company; August 1978.

Final Report - Degradation Effects on Motor Vehicle Exhaust Emission; Olson Laboratories, Inc., Anaheim, California; March 1976.

Information Document on Automobile Emission Inspection and Maintenance Programs; Kincannon, B. and Castaline, A., pp. 15-17; EPA-400/2-78-001, February 1978.

Fuel Economy Improvements through Emissions Inspection/Maintenance; Panzer, J., Exxon Research and Engineering Company; SAE Paper 760003; February 23-27, 1976.