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Analysis of Causes of Failure in High Emitting Cars

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ANALYSIS OF CAUSES OF FAILURE IN HIGH EMITTING CARS

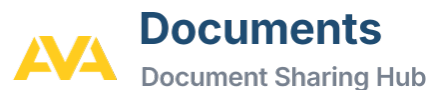
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PREFACE

by The American Petroleum Institute

Although new vehicles are designed to control exhaust emissions to specific levels for a significant portion of their useful lives, it is well known that these standards are substantially exceeded on average by vehicles in actual use. Inadequate maintenance, component failures, and tampering with emissions control systems are known to contribute to this problem.

In 1994 the American Petroleum Institute (API) sponsored a study to evaluate the primary causes of high emissions in the light-duty vehicle fleet. The effort focused on an analysis of emissions data from tests conducted both before and after the performance of repairs on 1981 and newer model vehicles. The data were compiled from five independently conducted programs which assessed the maintenance condition of vehicles representative of the in-use fleet. The compiled database was analyzed to: (1) assess the prevalence of different types of emission control system defects in the fleet; (2) classify the causes of those defects (e.g., malmaintenance, component failure, tampering, etc.) and (3) determine the contribution of those defects to fleet-average emissions.

Summary of fleet characteristics

The compiled database contained emissions and repair information on about 800 carbureted and fuel-injected automobiles representing a broad spectrum of geographic areas, maintenance histories and operating conditions. The carbureted cars were generally older models with higher odometer mileage (and thus higher emissions) than the fuel injected vehicles utilized in this study.

Results

This study produced the following results:

There are a substantial number of tampered or failed components, as well as normal maintenance items, on in-use light duty motor vehicles which are repairable. Large reductions in in-use emissions would accompany the repair of these components.

One EPA survey of vehicles that had not been exposed to any inspection/maintenance programs found that, on a fleet-wide basis, carbureted cars contained an average of 2.8 failed components in contrast to an average of 1.2 failed components for fuel injected automobiles. It was estimated that the repair of all failed components on this fleet of

vehicles would reduce composite (HC+NO_x+CO/10) exhaust emissions by 69% for carbureted automobiles and by 39% for fuel injected cars.

There are several classifications or categories of faults that cause excess emissions.

These faults are related to either 1) component failures (both mechanical and electrical); 2) need for replacement or adjustment of maintenance items (spark plugs, ignition timing, etc.); and 3) tampering of emissions control components. The percentage of overall failures seen in each of these categories was as follows:

Percent of Failures by Category

<u>Fuel System</u>	<u>Mechanical Failures</u>	<u>Electrical Failures</u>	<u>Maintenance</u>	<u>Tampering</u>
Carburetor	37	28	25	10
Fuel Injection	24	57	18	1

Failures of mechanical and electrical components are substantially more prevalent than tampering and maintenance related items - particularly in newer, fuel injected vehicles.

There are a few specific types of faults which have a significant effect on overall fleet emissions.

About 35% of the composite fleet emissions of carbureted vehicles is due to defective fuel metering systems. Defective oxygen sensors contribute an additional 10% of emissions. Ignition tune-up faults cause about 9% of the emissions.

Defective oxygen sensors cause from 22% to 15% of the emissions from light-duty fuel-injected vehicles. The variation in effect may be related to whether or not the fleet evaluated was subject to inspection and maintenance. Ignition tune-up was the only other fault that had a pronounced effect on the composite emissions from fuel-injected vehicles, ranging from 8% to 3%, depending on the test fleet.

Replacement of defective catalysts provides only small benefits for both carbureted and fuel injected vehicles.

Vehicle emissions warranty recalls provide only small reductions in fleet composite emissions.

Vehicle emissions warranty recalls are conducted regardless of the magnitude of the impact of the fault on emissions. In addition, the small emissions reductions from recall

repairs may be related to the fact that these benefits have been based on tests of well-maintained vehicles with under 50,000 odometer miles. Therefore, many recall repairs probably have negligible benefits. It also should be noted that the purpose of warranty recalls may not necessarily be to provide significant reductions of in-use emissions.

Conclusions

The results of this study can be helpful in focusing on productive, cost-effective strategies for reducing excessive in-use vehicle emissions. For instance, the following strategies are worth evaluating:

- The periodic replacement of oxygen sensors as a routine engine maintenance requirement, similar to current requirements for spark plug replacement.
- A greater emphasis on improvements in component durability. Recently instituted 10 year/100,000 mile emissions warranty requirements by the EPA and the California Air Resources Board should result in increased durability.
- Identification of high-effectiveness repair strategies for inspection and maintenance programs. Comprehensive evaluations to determine which repair items are most effective in reducing emissions will provide benefits to consumers, repair technicians and air quality.

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EXECUTIVE SUMMARY

Under contract to the American Petroleum Institute (API), Sierra Research, Inc. (Sierra) analyzed emissions and diagnostic data collected from vehicles recruited from customer service to determine the primary causes of excessive exhaust emissions in the motor vehicle fleet.* The primary data sources used for this study were two programs conducted by the U.S. Environmental Protection Agency (EPA), two programs conducted by the California Air Resources Board (CARB), and one joint EPA-Industry program. The focus of the effort was on 1981 and later model year passenger cars and light-duty trucks. In addition to analyzing emissions test data from those five programs, data presented in CARB's Technical Support Document prepared for on-board diagnostic system regulations were reviewed. That report contained emissions data for catalyst, oxygen sensor, and exhaust gas recirculation (EGR) system repairs. Finally, a limited review of EPA and CARB recall data was performed to determine the fraction of fleet-average emissions that is reduced through recall actions.

ANALYSIS OF IN-USE DATA

Data from five sources were evaluated for this project:

- EPA-Industry Cooperative Test Program (CTP);
- EPA Hammond, IN Test Program;
- EPA Phoenix, AZ Test Program;
- CARB Fuel-Injected Vehicles Study; and
- CARB Enhanced I/M Pilot Project.

The databases contained baseline (i.e., as-received) emission results conducted using the Federal Test Procedure (FTP) for over 1000 vehicles. Nearly 800 of those vehicles

*

Note that this study did not evaluate evaporative control system defects, which could be a significant source of excessive hydrocarbon emissions.

also received repair to the emission control system (in some cases multiple repairs were performed) and were tested again over the FTP before being released to the owner. The repair information was used to identify the types of defects corrected and to determine the emission reductions from repair. Because of the large number of individual emission control components that can be repaired on a vehicle (i.e., well over 200), the repairs were classified according to the following categories:

- Carburetor replacement/rebuild (for carbureted vehicles);
- Carburetor/fuel metering system adjustment/repair (carbureted vehicles);
- Fuel injector replacement (for fuel-injected vehicles);
- Fuel injection/fuel metering system adjustment/repair (fuel-injected vehicles);
- Ignition system tune-up repair (i.e., spark plugs, ignition wires, distributor);
- Other ignition system component repair (e.g., coil, knock sensor, etc.);
- EGR system repair;
- Air injection system repair;
- Catalyst replacement;
- Electronic control unit replacement (i.e., the vehicle computer);
- Oxygen sensor replacement; and
- Other sensor replacement/repair.

The emissions impact associated with repairing defects in the above categories was estimated on a per-repair basis, and estimates were extrapolated to the fleet based on the fraction of defects observed in the in-use fleet. Those estimates were prepared

independently for carbureted and fuel-injected vehicles. A summary of the results of the analysis follows.

Emission Reductions from Repair of Defective Components

Estimating the effects of emission reductions from repair of individual components was complicated by the fact that most of the databases analyzed in this effort contained before- and after-repair data on vehicles receiving more than one repair between tests.

For that reason, a regression technique was developed to estimate the FTP emissions reductions from individual system/component repairs. A summary of that analysis for fuel-injected vehicles is contained in Table ES-1. As shown in the table, the electronic control unit (ECU) and the oxygen sensor are the two most important categories of emission control component repairs in terms of the magnitude of FTP emissions reductions. Note that Table ES-1 includes only the repairs that resulted in a decrease in the weighted FTP "score" (defined in this analysis as $HC + NO_x + CO/10$) of more than 0.2 g/mi,^{*} and only results that were significant at the 90% confidence level are included.

Comparing the results presented in Table ES-1 to a similar analysis prepared for carbureted vehicles indicated that the emissions effect associated with the repair of ECU and oxygen sensor failures is less severe for carbureted vehicles, and that repairs of fuel system metering failures have a greater impact.

Excess Emissions Versus Nature of Defect

In addition to identifying which components were repaired, this analysis classified defects according to the type of failure, i.e., mechanical failure, electrical failure, malmaintenance, and tampering. The assignment of failure type was based on the

* An exception to this criterion was made when EGR system repairs were performed. In those cases, the repair was included in the analysis if NO_x emissions decreased by at least 0.2 g/mi, regardless of the effect on HC and CO emissions.

Table ES-1. Emission Reductions Associated with the Repair of Fuel-Injected Vehicles.

Category	Reduction in FTP Emissions (g/mi)			
	HC	CO	NOx	Score ^a
Injector Replacement	0.68	10.08	-0.24	1.41
Fuel Metering System Repair	0.56	7.93	0.22	1.36
Ignition System Tune-up Repair	ns ^b	ns	ns	1.00
Other Ignition System Repair	0.94	ns	ns	ns
EGR Repair	ns	ns	0.85	ns
Air Injection Repair	ns	ns	ns	1.96
Catalyst Replacement	ns	ns	1.27	1.59
ECU Replacement	3.48	34.83	ns	6.91
Oxygen Sensor Replacement	1.46	29.87	ns	4.11
Other Sensor Replacement/Repair	ns	ns	ns	ns

^a Score = HC + NOx + CO/10. Score values and individual HC, CO, and Nox values were computed in independent regression analyses, and therefore may not be equal.

^b Not significant at the 90% level. Regression statistics are included in Appendix A.

available mechanic comments, and therefore was somewhat subjective. In general, the following approach was used to determine defect type: replacement of spark plugs and ignition wires, timing adjustments, etc., were considered maintenance repairs; carburetor rebuilds/replacements, EGR system failures, air injection system failures, etc., were considered mechanical failures; and defective sensors and other electronic or wiring defects were labeled electrical failures. Repairs were labeled as tampering if there was a clear indication in the mechanic comments that the component had been tampered, or if a critical emission control component was missing (e.g., the air pump).

Based on the above assignments, it was possible to estimate the fraction of excess emissions that are the result of each of these failure modes. Although there is a moderate amount of uncertainty associated with these estimates, the analysis indicates

that 48-63% of the excessive emissions* from fuel-injected vehicles are related to electrical component failure, while only 25-32% of the excessive emissions from carbureted vehicles are related to electrical component failures. Malmaintenance contributed 11-22% and 22-32% to excessive exhaust emissions for fuel-injected and carbureted vehicles, respectively. Finally, the contribution of mechanical failures ranges from 18-28% for fuel-injected vehicles and 31-46% for carbureted vehicles. It is also interesting to note that the contribution of tampering to excess emissions from fuel-injected vehicles is $\leq 2\%$, while it ranges from 7-16% for carbureted vehicles, depending upon which database was analyzed.

Incidence of Defects in the Motor Vehicle Fleet

In addition to the increase in FTP emissions associated with individual component defects, the frequency with which those defects occur in the vehicle fleet is important in determining the total excess emissions produced by motor vehicles. A specific defect may cause a ten-fold increase in emissions on a single vehicle, but if there are few of those defects in the fleet, the overall impact could be relatively insignificant. Thus, there was interest in identifying the frequency of component/system defects in the fleets being analyzed for this study. This was complicated by the fact that vehicles recruited for laboratory testing were not randomly selected in most cases. In general, the laboratory databases contained a larger proportion of high emitting vehicles than was characteristic of the in-use fleet. Thus, the incidence of component failures observed in the laboratory databases had to be re-weighted to reflect the fleet of vehicles from which they were selected. This weighting procedure was based on results of IM240 tests, which were performed on a large sample of randomly selected vehicles in the Hammond and Phoenix fleets (i.e., component failure rates for the laboratory fleets

* In the context of this discussion, excessive emissions refer to the difference in the average emission rate of a fleet of vehicles in their baseline (i.e., before-repair) configuration and after identification and repair of defects.

were calculated for both IM240 passing and failing vehicles, and those results were weighted by the fraction of IM240 passing and failing vehicles in the in-use fleet).

The results for the Hammond fleet are contained in Table ES-2. (Refer to the body of the report for similar results for the Phoenix and CARB Enhanced I/M Pilot Project fleets. Only the Hammond results are presented in this summary because that is the largest of the databases analyzed in this effort, and readers are likely to be most familiar with that test program.) As seen in the table, there is a higher fraction of failures in carbureted vehicles, particularly for the fuel management system. This is not unexpected, since the carbureted vehicles are, on average, older than the fuel-injected vehicles (i.e., 6.7 versus 3.8 years), and the fuel control system is not as durable. Thus, the results presented in Table ES-2 do not reflect carbureted and fuel-injected vehicles at equal mileage intervals, but rather in their then-current state (i.e., in the 1990 to 1992 time period).

The effects of vehicle age on component failure rates were assessed by analyzing data from only 1983 to 1985 model year vehicles. That evaluation revealed similar failure rates for carbureted and fuel-injected vehicles for most components. For example, there was a 17% catalyst failure rate for both carbureted and fuel-injected vehicles, oxygen sensor failures occurred on 25% of the carbureted vehicles and 31% of the fuel-injected vehicles, and EGR failures occurred on 38% of the carbureted vehicles and 31% of the fuel-injected vehicles. However, the fuel metering system failure rate (e.g., idle speed, idle CO, choke adjustments, MAP sensor, etc.) for 1983 to 1985 model year carbureted vehicles was more than double that of the same model year fuel-injected vehicles (69% versus 30%).

Table ES-2. Baseline Component Failure Rates for the Hammond Fleet, Including Vehicles Passing and Failing the IM240 Test.

Fuel System	System/Component	Failure Rate ^a
Carbureted ^b	Carburetor	23.1%
	Fuel Metering System	67.0%
	Ignition Tune-up	65.0%
	Other Ignition	13.3%
	EGR System	40.4%
	Air Injection System	27.6%
	Catalyst	11.3%
	Electronic Control Unit	6.1%
	Oxygen Sensor	23.0%
	Other Sensors	3.6%
Fuel-Injected	Fuel Injector(s)	9.5%
	Fuel Metering System	14.2%
	Ignition Tune-up	41.3%
	Other Ignition	6.2%
	EGR System	15.0%
	Air Injection System	2.3%
	Catalyst	7.0%
	Electronic Control Unit	1.4%
	Oxygen Sensor	26.0%
	Other Sensors	1.8%

^a Failure rates shown have been adjusted to account for over-sampling of IM240 failures in the subset of vehicles receiving repairs and retests.

^b Note that the carbureted fleet is older; therefore, the higher component failure rates were not unexpected.

As Table ES-2 shows, ignition-related defects occur frequently in both the carbureted (78%) and fuel-injected (47%) vehicles. Although not as great, the incidence of oxygen sensor failures (approximately 25%) is more important, considering the significant emissions impact of defective oxygen sensors shown in Table ES-1.

Impacts of Defects on Fleet-Average Emissions

The overall impact of defective components on the fleet-average emission rate was calculated by combining the FTP increase as a result of those defects and the fraction of those defects observed in the fleet. The analysis treated fuel injected and carbureted vehicles independently. The results of that analysis are presented in Table ES-3 for the Hammond fleet. Note that the contribution of component defects to fleet average emissions does not sum to 100% in Table ES-3 because emissions remain after repair. The estimates in this table again indicate that the defects of significance differ between fuel-injected and carbureted vehicles. Failures leading to high emissions in carbureted vehicles are generally related to mechanical failure and malmaintenance (as observed by the large influence that carburetor/fuel system defects have on the fleet average emission rate), while failures leading to high emissions in fuel-injected vehicles are often related to sensors or electrical problems.

Another point to be made in reference to Table ES-3 is the relatively small impact that catalyst malfunctions have on the fleet-average emission rate. Two factors contribute to this: the incidence of catalyst failures is low, and the effect of repair of defective catalysts is not as large as one might imagine. This can be explained by noting that engine-out emissions for a properly functioning late-model vehicle are on the order of 2 g/mi HC, 20 g/mi CO, and 2 g/mi NO_x. A catalyst with a 90% efficiency for HC and CO and a 70% efficiency for NO_x would result in an emission reduction of 1.8 g/mi HC, 18 g/mi CO, and 1.4 g/mi NO_x. On the other hand, a vehicle with a malfunctioning closed-loop fuel control system (e.g., having a bad ECU or oxygen sensor) can have before-repair emissions as high as 10 g/mi HC and 150 g/mi CO, and the repair of those defects can bring emission rates down to certification levels (i.e., 0.41 g/mi HC and 3.4 g/mi CO). Thus, repairing those defects has a much larger effect on the reduction in FTP emissions than does repairing what might be considered the "heart" of the emission control system - the catalyst.

ES-8

The results presented in Table ES-3 were combined for the two fuel systems and for all components to calculate the overall effect on FTP emissions of repairing identifiable defects in the Hammond fleet. Repair of all identified defects is projected to reduce emissions of 1981 and later model year vehicles by 63% HC, 72% CO, and 16% NO_x, which reflects an upper limit of achievable emission reductions from this fleet of vehicles. For fuel-injected vehicles (which are, on average, newer than the carbureted vehicles in this fleet), the overall benefits of repair are considerably less for HC and CO (41% HC, 47% CO), while NO_x is similar (20%). The fuel-injected vehicle reductions are generally consistent with the benefits that EPA has estimated for "enhanced" vehicle inspection and maintenance (I/M) programs. There are two reasons why the actual emission reductions achieved in an I/M program would be somewhat less than the reductions achieved in these test programs. First, the cost of the diagnoses and repairs to correct all defects would sometimes exceed the repair cost limits applicable to an I/M program. Second, the quality of the repairs performed under these test programs is higher than what could be expected for the typical commercial repair.

Although not part of the scope of work for this project (because it is not an exhaust emission control component), a rough estimate of the effect that defective positive crankcase ventilation (PCV) valves have on fleet-average HC emissions was also made. Assuming that a defective PCV valve results in an increase of 1.2 g/mi HC (from MOBILE5a), defective PCV valves would contribute an additional 8% of the fuel-injected exhaust HC emission rate and 6% of the carbureted HC emission rate.

Table ES-3. Contribution of Defective Components to the Fleet-Average Emission Rate for the Hammond Database.

Fuel System	System/Component	Contribution to FTP Emissions			
		HC	CO	NOx	Score
Carbureted	Carb Rebuild/Replacement	ns ^a	11%	2%	7%
	Fuel Metering System Repair	34%	42%	-13%	29%
	Ignition Tune-up	24%	ns	ns	13%
	Other Ignition Repair	ns	ns	ns	ns
	EGR System	ns	ns	21%	ns
	Air Injection System	< 1%	8%	ns	< 1%
	Catalyst	5%	< 1%	8%	4%
	ECU	5%	8%	-3%	5%
	Oxygen Sensor	8%	17%	-5%	10%
	Other Sensors	ns	ns	1%	ns
Fuel-Injected	Injector Replacement	5%	5%	-2%	3%
	Fuel Metering System Repair	< 1%	< 1%	2%	< 1%
	Ignition Tune-up	2%	2%	ns	8%
	Other Ignition Repair	3%	-1%	ns	ns
	EGR System	ns	ns	11%	< 1%
	Air Injection System	< 1%	< 1%	ns	< 1%
	Catalyst	< 1%	< 1%	9%	3%
	ECU	4%	3%	ns	2%
	Oxygen Sensor	25%	37%	-1%	22%
	Other Sensors	ns	ns	< 1%	< 1%

^a Repair effects were not significant for these systems/components.

REVIEW OF CARB'S OBDII ANALYSIS

Data contained in CARB's Technical Support Document prepared for the September 1989 Board hearing regarding revised on-board diagnostic regulations (i.e., "OBDII") were analyzed as part of this project. The purpose of this effort was to provide

alternative estimates of the effect of component failure on fleet-average emissions. Three components were considered in the CARB report: catalyst, EGR, and oxygen sensor. For fuel-injected vehicles, defective catalysts were estimated to contribute 3% to the fleet-average FTP-weighted emission rate (i.e., "score," as defined above), which is consistent with the results of our analysis of repair data described above. In contrast, defective oxygen sensors were estimated to contribute 7% to the fleet-average FTP score, while our analysis indicates a 22% effect. Finally, EGR failures were projected to contribute 5% to the fuel-injected vehicle NOx fleet-average emission rate using the CARB OBDII database and 11% using the Hammond database. The difference between the results was expected, as the data used in CARB's analysis were collected seven to eight years ago. Because all of our analyses are focused on 1981 and later model year vehicles, lower defect rates would be expected for datasets with a lower average vehicle age. In fact, the average age of the vehicles in the OBDII database was 4.4 years, while the average age of the Hammond vehicles was 4.8 years. More importantly, the fraction of high-mileage vehicles (i.e., over 100,000 miles) was much higher in the Hammond database (12.4%) compared to the OBDII database (3.9%).

REVIEW OF RECALL DATA

Recall data from EPA and CARB were reviewed and a rough estimate of the impacts of recall actions on fleet-average emissions was prepared. That analysis revealed that actual vehicle recalls have a very small impact on in-use emissions, amounting to reductions of 1.3%, 2.1%, and 1.5% for HC, CO, and NOx, respectively. Since vehicles selected for recall testing are well-maintained vehicles with less than 50,000 miles, this suggests that the majority of excess emissions in the fleet result from maintenance problems or defects that occur beyond the "useful life" of the vehicle. As an example, data from the Hammond program indicated that fuel-injected vehicles had an 11% oxygen sensor failure rate for vehicles with less than 50,000 miles. For vehicles with more than 50,000 miles, the oxygen sensor failure rate increased to 40%.

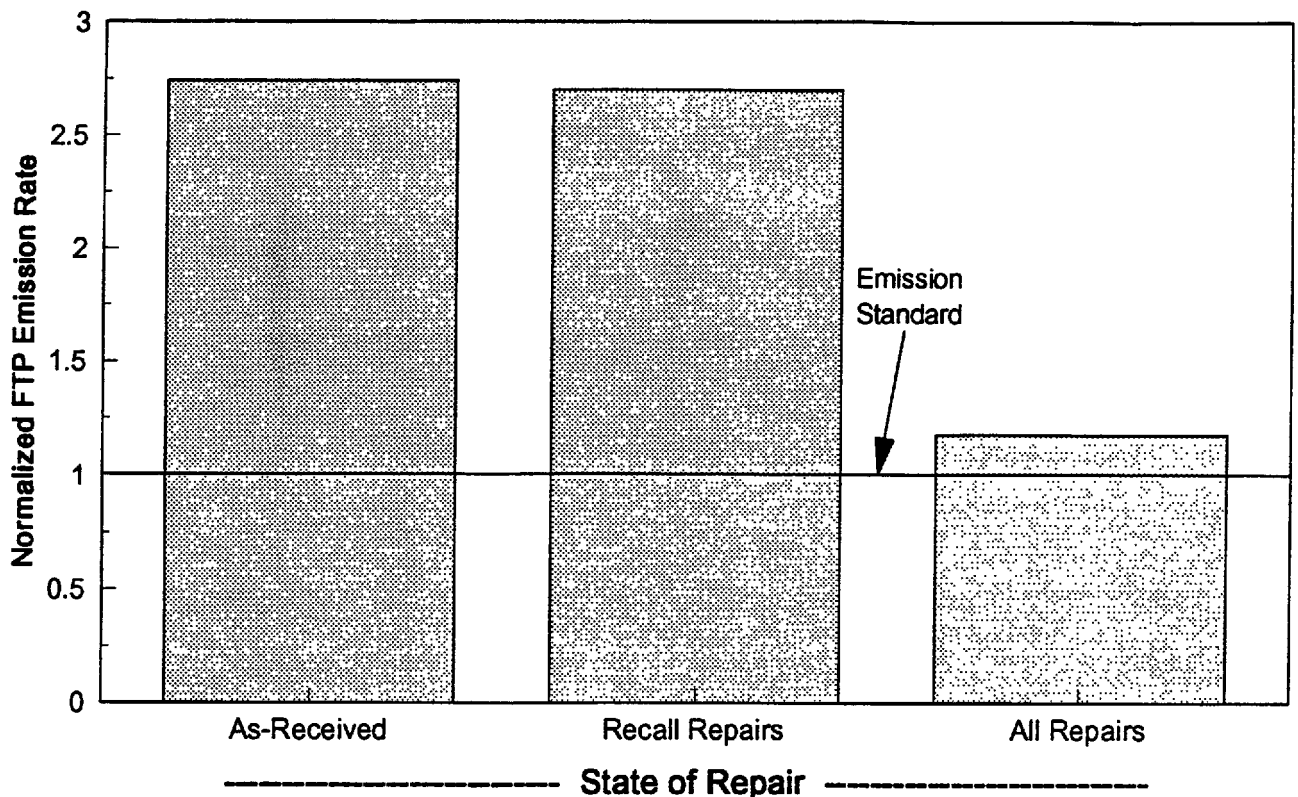


Figure ES-1. Contribution of Repairable Defects Relative to the Fleet-Average Emission Standard (HC + NO_x + CO/10) for the Hammond Database.

Figure ES-1 illustrates the contribution to the fleet-average weighted FTP "score" of recall repairs versus the non-recall repairs described above for vehicles in the Hammond database. The emission levels have been normalized by the emission standard to which these vehicles were certified (i.e., 0.41 HC + 1.0 NO_x + 3.4 CO/10), which is also shown in the figure. Figure ES-1 indicates that recall actions have a small impact on fleet-average emissions, but that if all identifiable defects are repaired, emissions are within 25% of the certification standard. The level of emissions remaining above the standards can be attributed to general aging and deterioration of emission control components that would not necessarily be positively identified as a defect.

Section 1

INTRODUCTION

Under contract to the American Petroleum Institute (API), Sierra Research, Inc. (Sierra) conducted a study of on-road motor vehicle emissions data to determine the primary causes of excessive exhaust emissions in the in-use motor vehicle fleet.* That topic is important from the perspective of how to craft motor vehicle control programs to effectively reduce in-use emissions. The analyses performed in this effort attempted to quantify the emissions impacts of individual emission control system component defects, the prevalence of those defects in the in-use motor vehicle fleet, and the overall contribution of those defects to fleet-average emissions. In addition, the primary causes of defective emission control system components were categorized according to whether the defect was the result of a mechanical component failure, electrical component failure, poor maintenance, or tampering. Estimates of the magnitude of each of these failure modes on excessive emissions were then made.

The primary data sources used for this study were two programs conducted by the U.S. Environmental Protection Agency (EPA), two programs conducted by the California Air Resources Board (CARB), and one joint EPA-Industry program. The focus of the effort was on 1981 and later model year light-duty cars and trucks. In addition to analyzing emissions test data from those five programs, data presented in CARB's Technical Support Document prepared for on-board diagnostic system regulations were reviewed. That report contained emissions data for catalyst, oxygen sensor, and exhaust gas recirculation (EGR) system repairs. Finally, a limited review of EPA and CARB recall data was performed to determine the fraction of fleet-average emissions that are reduced through recall actions.

* Note that this study did not evaluate evaporative control systems defects, which could be a significant source of excessive hydrocarbon emissions.

ORGANIZATION OF THE REPORT

Immediately following this introduction, Section 2 presents the results of the analysis of the five databases referenced above and contains the majority of the results from this study. The analysis of data from CARB's OBDII Technical Support Document is contained in Section 3, while the overview of EPA and CARB recall data is provided in Section 4. Finally, a list of references cited in the report is provided.

Section 2

ANALYSIS OF DIAGNOSTIC DATA

Determination of the causes and magnitude of excessive exhaust emissions in the vehicle fleet was a multi-step process involving the analysis of many different data sources. The first step in that process was the acquisition of data not already in-house and reformatting all databases to a common structure for subsequent analysis. Once reformatted, the data were evaluated (both collectively and for each individual database) for the following:

- the types of emission control system defects in each fleet (e.g., catalyst system, fuel delivery system, etc.);
- the prevalence of emission control system defects in each fleet (i.e., what fraction of vehicles contain specific types of defects);
- the primary causes of those defects (e.g., tampering, malmaintenance, mechanical component failure, electrical component failure);* and
- the contribution that those defects have on excessive exhaust emissions in the vehicle fleet.

The last item above is complicated by the fact that each database analyzed in this study used different vehicle selection criteria, which generally resulted in a larger proportion of high emitting vehicles in the sample than in the corresponding fleet from which that sample was drawn. Thus, analysis of inspection and maintenance short

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The primary cause of individual defects was determined by evaluating mechanic comments in conjunction with the type of repair. For example, replacement of spark plugs and/or ignition wires was considered a maintenance repair, carburetor rebuilds or replacements were considered mechanical failures, and oxygen sensor replacements were considered electrical failures. Repairs were categorized as tampering if there was a clear indication in the mechanic comment field that the component had been tampered.

test data (i.e., IM240) was also performed so that results from the databases could be extrapolated to the fleet.

This section of the report presents a description of the databases used in the analysis (with summary statistics from those databases), the types and prevalence of defects observed in the fleets analyzed, the primary causes of those defects, and the effect that those defects have on the fleet-average emission rate.

DATABASE DESCRIPTION

Emissions data collected on 1981 and later model year light-duty cars and trucks from five separate databases were analyzed in this study to determine the primary causes of excessive exhaust emissions in the in-use vehicle fleet. Two databases were compiled by the U.S. Environmental Protection Agency (EPA), two were compiled by the California Air Resources Board (CARB), and one was compiled as part of a cooperative test program conducted by EPA and automobile manufacturers. A brief description of each database is contained below.

Cooperative Test Program (CTP) Data

Under the CTP, data were collected on a sample of 265 vehicles by EPA and participating vehicle manufacturers. Vehicles included in the program were 1981 and later passenger cars and light trucks that had failed the Michigan I/M short test. These vehicles were procured for detailed diagnosis, emission testing and repair. Specific elements of the program included those listed below.

- Characterizing the as-received emission rates of each vehicle (on commercial fuel) according to a variety of I/M procedures, including extensive loaded pretest operation, extended idle pretest operation and a cold start;
- Measuring the as-received emissions using the Federal Test Procedure (FTP) (commercial and certification fuel);

- Conducting a complete and detailed engine and emissions system diagnosis on each vehicle for causes of the observed FTP and/or I/M failures;
- Ordering the repairs indicated by the diagnosis by their anticipated FTP emissions benefit (from highest to lowest);
- Conducting incremental remedial maintenance (based on the ranked repair items) to reduce FTP HC and CO emissions within the following mileage-dependent levels:

150% of cert standards for vehicles < 50,000 miles

200% of cert standards for vehicles > 50,000 miles

and verifying the emission reductions by additional FTP and I/M tests performed after each significant repair; and

- Conducting additional remedial maintenance on vehicles already repaired to acceptable FTP levels to achieve acceptable short test response (i.e., I/M pass), again verifying emission reductions with I/M testing performed after each significant repair.

A copy of the CTP data was obtained from EPA on magnetic tape. Hardcopy descriptions of the record format and field descriptions were also provided by EPA.

Although the CTP data can be used to estimate the emission reduction from repair, it is not possible to use this database to determine a fleet-average component failure rate. That is because the vehicle selection criteria (i.e., I/M short test failures) resulted in a larger proportion of high emitting vehicles in the database than would be expected in the fleet from which they were selected. In some of the other databases analyzed for this project (i.e., Hammond and Phoenix), IM240 scores were used to translate the sample results to the fleet. However, the CTP database does not contain sufficient information (e.g., I/M scores) on the Michigan fleet to be able to extrapolate the results to the fleet. In addition, this database does not contain diagnostic information on vehicles passing an I/M test, which could contain defects resulting in excessive FTP emissions.

EPA Indiana Data

The base emission rate equations and I/M benefits developed for MOBILE5a were based on data collected in a program sponsored by EPA in Hammond, IN. Although most of the vehicles included in the Hammond program were tested at an I/M lane over the IM240 cycle, a subset of vehicles was recruited for more extensive FTP testing at a local laboratory. Vehicles tested at the lane using IM240 were chosen at random (within specific model-year groups), while those recruited for FTP testing were intentionally selected to result in an approximate 50/50 mix of passing and failing vehicles. The FTP results from those vehicles were used to develop IM240-to-FTP correlations, I/M identification rates, and after-repair emission rates for MOBILE5a. Because the lab FTP data did not reflect the in-use fleet (i.e., they were more heavily weighted with high emitters), the ratio of IM240 pass and fail rates observed at the lane was used to re-weight the lab sample when EPA developed the I/M identification rate matrices for MOBILE5a.

The lab FTP data from the Hammond program were used in this effort by analyzing the FTP results in conjunction with the "narrative" (NARR) and "component" (ECOMP) files acquired from EPA's "MICRO" database.* The narrative file contains a comment field describing the vehicle's condition and any repairs that may have been performed for each test conducted. The component file contains a coded listing of defective emission control components for the as-received case. The as-received information was used to identify the malfunctioning components leading to high emissions, and the after-repair FTP information was used to quantify those malfunctions. These results were translated to the fleet by re-weighting the lab sample by the ratio of IM240 pass

* The MICRO database is maintained at Wayne State University and contains data from a variety of EPA emissions test programs.

and fail rates observed at the lane. The lane IM240 data had been received from EPA in a previous study conducted by Sierra for API (Sierra, 1994).

EPA Arizona Data

An EPA contractor (Automotive Testing Laboratories) has been performing IM240 tests in conjunction with the existing I/M program in Mesa, AZ (a suburb of Phoenix) since 1992. Some of the data collected in that program were used by EPA in a comparison of IM240 and "Acceleration Simulation Mode" (ASM) testing (EPA, 1993), and additional data have been collected since the publication of that report. As with the Hammond program, a subset of the IM240 tested vehicles were recruited for FTP testing at a local laboratory. The focus of testing has been on 1983 and later fuel-injected vehicles (only a small number of carbureted vehicles were tested in that program), and an approximate 50/50 mix of IM240 passing and failing vehicles was selected for FTP testing.

This database was evaluated in a similar fashion to that described above for the Hammond data. The FTP data were obtained from EPA's MICRO database, along with narrative and component files for this test program, and the sample results were extrapolated to the fleet by comparing IM240 failure rates for vehicles tested at the lab to the larger sample of vehicles receiving IM240 tests at the I/M lane. The Arizona lane IM240 results had also been received from EPA in a previous study conducted by Sierra for API (Sierra, 1994).

CARB Fuel-Injected (CARBFI) Vehicle Study

Under this program, Radian Corporation, under contract to CARB, obtained a sample of 58 high-mileage, fuel-injected vehicles that were tested at CARB's El Monte laboratory. The CARBFI database contains diagnostic, emission testing and repair