

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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PREPARED UNDER CONTRACT BY:

Philip L. Heirigs, Thomas C. Austin, Lawrence S. Caretto, Thomas R. Carlson, and Robert L. Hughes Sierra Research, Inc. 1801 J Street Sacramento, California 95814

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API STAFF CONTACT

David Lax, Health and Environmental Sciences Department

MEMBERS OF THE VEHICLE EMISSIONS TASK FORCE

Steve Welstand, Chairperson, Chevron Research and Technology Bill Bandy, Amoco Research Center Helen Doherty, Sun Refining and Marketing Company Dennis Feist, Shell Development Company Frank S. Gerry, BP America, Inc. Peter Jessup, Unocal Corporation George S. Musser, Exxon Research and Engineering Company Michael Payne, Arco Products Company Robert M. Reuter, Texaco, Inc. Rick Riley, Phillips Petroleum Charles Schleyer, Mobil Research and Development

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+NOx+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

Fuel <u>System</u>	Mechanical <u>Failures</u>	Electrical <u>Failures</u>	Malmaint- <u>enance</u>	Tampering
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 fuelinjected 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 wellmaintained 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 onboard 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

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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 + NOx + 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

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

	Reduction in FTP Emissions (g/mi)			
Category	НС	со	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

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

^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

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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

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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.

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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. 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%).

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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%

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

^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 NOx. A catalyst with a 90% efficiency for HC and CO and a 70% efficiency for NOx would result in an emission reduction of 1.8 g/mi HC, 18 g/mi CO, and 1.4 g/mi NOx. 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.

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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% NOx, 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 NOx 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 fuelinjected exhaust HC emission rate and 6% of the carbureted HC emission rate.

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Table ES-3. Contribution of Defective Components to the Fleet-Average Emission Rate	2
for the Hammond Database.	

Fuel System	System/Component	Contribution to FTP Emissions			
		HC	СО	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 API PUBL*4637 96 🎟 0732290 0551717 621 🎟

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%.

ES-11

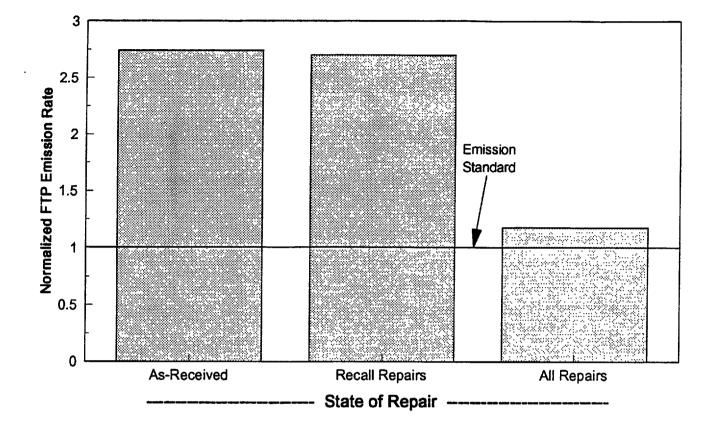


Figure ES-1. Contribution of Repairable Defects Relative to the Fleet-Average Emission Standard (HC + NOx + CO/10) for the Hammond Database.

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 NOx + 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.

ES-12

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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.

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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.

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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

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.

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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);

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- 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

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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 fuelinjected 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

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information for these vehicles, which cover model years 1980 through 1985. All the vehicles appear to be either "moderate" FTP emitters or higher.

Similar to the CTP database, CARBFI follows a procedure of baseline diagnosis (with a diagnostic coding scheme that is an expanded version of that used in-house by CARB), followed by incremental repair and retesting. The emission tests performed consist of a baseline (i.e., before repair) FTP followed by Hot-505s after each incremental repair. A final FTP was also conducted after all repairs had been performed. As with the CTP database, extrapolation of these data to the fleet is not possible. This database represents a subset of the 1980 to 1985 model year fleet, and the baseline emission characteristics are not reflective of the entire fleet. Nonetheless, the baseline and after-repair emissions data were used in this analysis to estimate the emission reductions from repairing specific emission control components.

CARB I/M Pilot Project Data

During the latter half of 1994, the California Bureau of Automotive Repair (BAR) and CARB conducted an "Enhanced Inspection and Maintenance Pilot Project" to investigate the feasibility of meeting EPA's enhanced I/M performance standard using a "hybrid" program design. Under the proposed program, vehicles suspected of having the highest emissions would be required to be tested at centralized (i.e., "test-only") I/M facilities, while other vehicles could be tested at decentralized (i.e., "test and repair") facilities.

As part of the Pilot Project, CARB recruited over 600 vehicles selected at random from Department of Motor Vehicle registration records for vehicles soon to be due for an I/M test. The owners of the vehicles were required to participate; failure to cooperate resulted in denial of registration renewal. As a result, the "capture rate" for the selected vehicles was very high. Each of the vehicles was tested in an "as received"

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condition at CARB's laboratory using both the IM240 and ASM tests. Most of the failing vehicles received a full FTP and then were repaired by BAR mechanics at Clayton Industries' facilities near the CARB laboratory. The IM240 standards were used as the after-repair target for about half of the vehicles and the ASM standards were used as the target for the rest of the vehicles. Diagnosis and repair work continued until the vehicles either passed the target test or additional repairs would cause total expenditures to exceed about \$500-\$600.[•] At the completion of the repair work, another FTP was conducted. Some of the passing vehicles also received an FTP. FTP emissions for other passing vehicles can be estimated from the IM240 test results (using a regression equation), which is the approach used in some of the analyses presented in this report. Because the vehicles in the Pilot Project were selected at random, regardless of emission level, there was no need to re-weight results to reflect the fleet of vehicles from which they were selected.

SUMMARY STATISTICS

As discussed above, the databases used for this project varied considerably in terms of how the vehicles were selected for each program. This can be seen from the baseline HC, CO, and NOx FTP scores summarized in Table 2-1. As observed in that table, the mean emission rates for the CTP, Hammond, and CARBFI databases are very similar, particularly when fuel technologies (i.e., carbureted and fuel-injected) are combined. When the data are compared by fuel delivery technology, similarities are observed for all of the databases that had carbureted vehicles included in them; there is more variability when the fuel-injected results are compared. Reasons for this distribution of emission levels among the databases include those listed below.

Based on discussions with CARB staff, the repair cost criteria used were somewhat vague and not precisely consistent with the \$450 repair cost minimum for waivers specified in the federal Clean Air Act.

• The CTP and CARBFI databases contain only vehicles that were likely to fail an I/M short test. Thus, average emission rates from those databases are expected to be higher than the other databases.

Fuel System	Database	(n)	Mean Mileage	Mean Emis	sion Rate	e (g/mi)
				НС	со	NOx
All	CTP Hammond Phoenix CARBFI CA I/M Pilot ^a	237 678 243 43 504	54,800 69,600 76,100 60,200 78,200	1.86 1.72 1.19 2.03 1.00	26.32 24.75 14.17 28.76 15.06	1.14 1.16 1.18 2.18 1.10
Carbureted	CTP Hammond Phoenix CARBFI CA I/M Pilot	114 154 - - 146	65,500 85,500 - - 99,600	2.06 2.67 - 1.92	28.79 36.23 - - 28.60	1.39 1.41 - - 1.50
Fuel-Injected	CTP Hammond Phoenix CARBFI CA I/M Pilot	123 524 243 43 358	44,900 64,900 76,100 60,200 69,500	1.68 1.44 1.19 2.03 0.62	24.03 21.37 14.17 28.76 9.54	0.91 1.09 1.18 2.18 0.94

Table 2-1.	Baseline FTP Emission Levels of the CTP, Hammond, Arizona, CARBFI,
	and California I/M Pilot Project Databases.

^a FTP scores for the California I/M Pilot Project database were estimated for some vehicles based on IM240-to-FTP correlation equations.

• Although the Hammond and Pilot Project databases include I/M passing vehicles, the average emission level of carbureted vehicles in those databases is similar to the CTP database. That can be explained by noting the mean mileage level for each database and considering when the programs were conducted. The CTP data were collected primarily in the latter half of 1987, which resulted in a lower mean mileage than the Hammond database (in which vehicles were tested primarily from 1990 to 1992) and the California I/M Pilot Project database (where vehicles were tested in the latter half of 1994). It would be expected that because of the higher mean mileage level of the Hammond and Pilot Project databases, there would be a higher proportion of higher emitting vehicles in those data sets which may be causing the mean emission levels to be elevated. (In fact, nearly 75% of the carbureted vehicles in the Hammond database failed 0.8 g/mi HC, 15 g/mi CO, and 2.0 g/mi NOx IM240 cutpoints, and nearly

65% of the carbureted vehicles in the Pilot Project database failed those cutpoints.)

Comparing the fuel-injected results, there appears to be a more easily explainable pattern of emission rates. Both the CTP database and the CARBFI database have the highest emissions (for HC and CO), but those programs targeted high emitting vehicles only. The Hammond and Phoenix databases, which consist of a nominal 50/50 mix of IM240 passing and failing vehicles, have mean emission levels between the CTP and CARBFI databases and the Pilot Project database. The California I/M Pilot Project database has the lowest emission levels because it was randomly selected and represents the California fleet. (Only 25% of the Pilot Project fuel-injected vehicles fail 0.8/15/2.0 HC/CO/NOx IM240 cutpoints.)

Because of the differing proportion of high emitting vehicles in each database, and because each program applied different criteria to determine whether a vehicle was to receive repair, there is a different proportion of vehicles that received repair and retesting in each program. For example, all vehicles received repairs in the CARBFI database, while 22% of the vehicles in the California I/M Pilot Project database received repairs. In addition, the level of repair differed in each program. As noted above, vehicles in the CTP study were repaired to meet 1.5 to 2.0 times their certification levels (depending on vehicle mileage), whereas vehicles in the California I/M Pilot Project were repaired to meet IM240 or ASM cutpoints. As might be expected, these differences in repair criteria resulted in different mean after-repair levels for each database. This is observed in Figures 2-1a and 2-1b, which show the mean baseline and after-repair FTP emission rates (for vehicles that received repairs) for carbureted and fuel-injected vehicles, respectively. Finally, each of the databases considered in this study contained vehicles subject to different I/M histories, which could have had an impact on the average before-repair emission rates observed in Figures 2-1a and 2-1b (e.g., most of the vehicles tested in the Hammond program had never been subject to an I/M program prior to testing (or had only been through a

single "cycle"), while vehicles in the Phoenix database had been subject to a fairly stringent I/M program for most of their lives).

DATABASE REFORMATTING

Because the databases analyzed in this study were compiled at different times by two different organizations, the format of the data varies considerably, particularly with respect to how repairs are coded. The CTP, CARBFI, and Pilot Project databases contain coded repair information, but the coding scheme is not consistent. At the other extreme, the Hammond and Phoenix databases contain a coded description of the vehicles' baseline condition (i.e., the ECOMP files described above), but do not have coded information for each repair cycle. The only information describing repairs in the Hammond and Phoenix databases is contained in the narrative files.

Before analysis of the repair data could proceed, it was necessary to reformat all databases into a common structure. This was accomplished by merging the mechanic comments with emission results for each vehicle. The comments regarding repairs were then manually translated into a coding scheme that (1) identified the system and component subject to repair; (2) identified the type of repair; and (3) identified the likely reason for component failure. This was a time-consuming process involving nearly 800 vehicles among the five databases, but consistent coding was necessary before analysis of the repair actions could proceed.

2-10

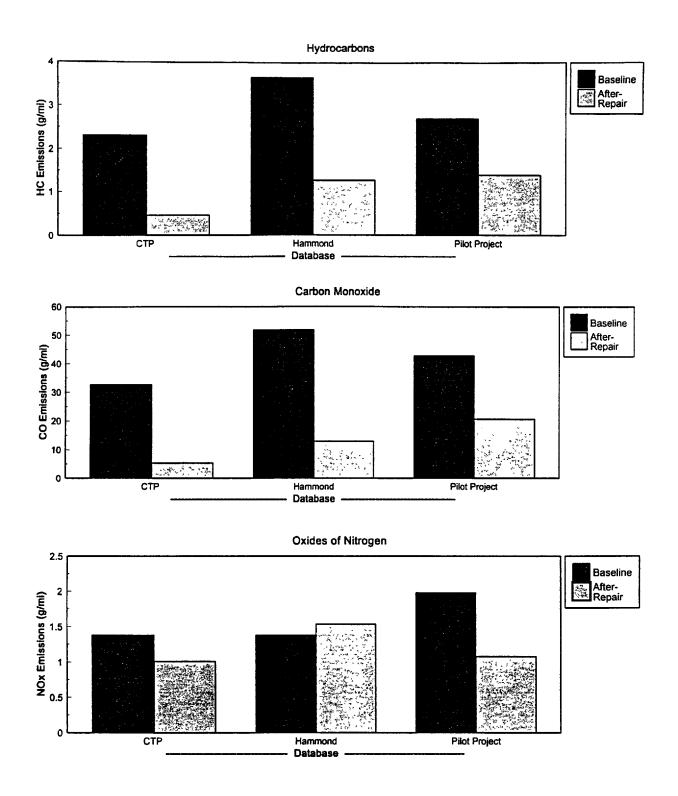


Figure 2-1a. Comparison of Mean Baseline and After-Repair FTP Emission Rates from 1981 and Later Model Year Carbureted Vehicles Receiving Repair in the CTP, Hammond, and California I/M Pilot Project Databases.

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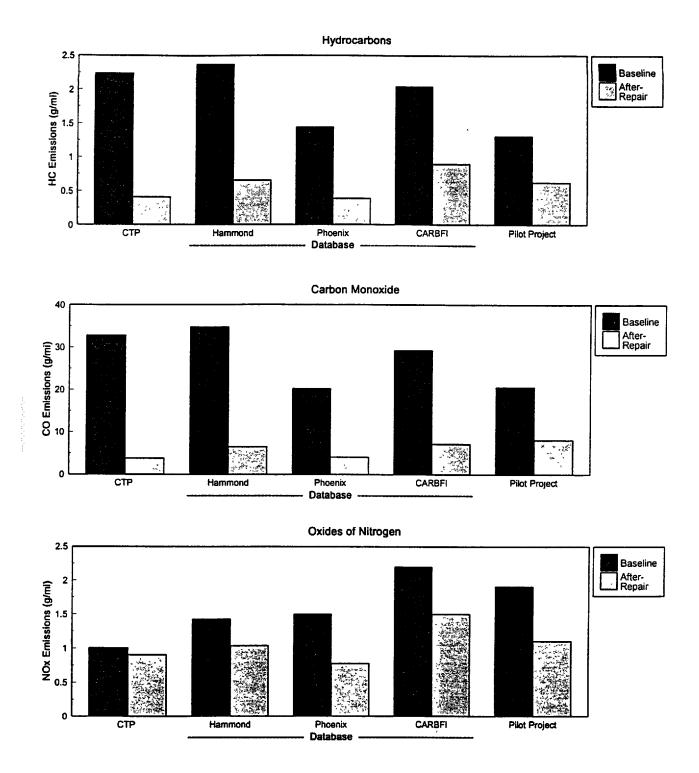


Figure 2-1b. Comparison of Mean Baseline and After-Repair FTP Emission Rates from 1981 and Later Model Year Fuel-Injected Vehicles Receiving Repair in the CTP, Hammond, Phoenix, CARBFI, and California I/M Pilot Project Databases.

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The system and component codes used in this analysis followed a structure proposed by Sierra in a study performed for EPA in 1989 (Sierra, 1989), and a summary of those codes is shown in Table 2-2. Because of the large number of individual codes, repairs were classified by major components and systems according to the following definitions, based on the codes contained in Table 2-2:

- Carburetor replacement/rebuild (system 2, component 2);
- Carburetor adjustment/fuel metering system repair (system 2, components 2-25; system 11, component 9);
- Fuel injector replacement (system 3, component 3);
- Fuel injection/fuel metering system adjustment/repair (system 3, components 2, 6-43; system 11, component 9);
- Ignition system "tune-up" repair (system 4, components 2-3, 5-6);
- Other ignition system repairs (system 4, components 4, 7-23);
- EGR system repair (system 5, components 2-14);
- Air injection system repair (system 8, components 2-15);
- Catalyst replacement (system 9, components 3-7);
- Electronic control unit replacement or repair (system 10, component 2);
- Oxygen sensor replacement (system 11, component 2); and
- Other sensor replacement or repair (system 11, components 10-21).

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Table 2-2. System and Component Codes Used to Standardize Repair Data from the CTP, Hammond, Phoenix, CARBFI, and California I/M Pilot Project Databases.

1 Air Induction

- 2 air door
- 3 air filter
- 4 air cleaner housing ach
- 5 cold air duct
- 6 hot air duct
- 7 intake manifold
- 8 turbocharger tc
- 9 charge air cooler cac
- 10 supercharger sc
- 11 sensor / switch / solenoid
- 12 hoses / vacuum lines
- 13 gasket / seal
- 14 wire / harness / fuse
- 15 other

2 Carburetion

- 2 carburetor assembly
- 3 idle mixture adj. limiting device
- 4 idle mixture
- 5 idle speed
- 6 idle speed control isc
- 7 throttle/throttle controls
- 8 throttle position sensor tps
- 9 mixture control solenoid mcs
- 10 mixture control solenoid mcs, cmds
- 11 choke adjustment (notches)
- 12 choke adjustment (vacuum break)
- 13 choke adjustment limiting device
- 14 choke heater
- 15 choke (misc.)
- 16 early fuel evaporation efe (electric)
- 17 engine coolant temp. sensor ects
- 18 intake air temperature sensor iats
- 19 vacuum diaphragms
- 20 fuel pump
- 21 fuel filter
- 22 hoses
- 23 gasket / seai
- 24 wire / harness / fuse
- 25 other

3 Fuel-Injection

- 2 air flow sensor
- 3 injector(s)
- 4 diesel injector(s)
- 5 diesel fuel supply pump
- 6 throttle body tb
- 7 throttle controls
- 8 throttle position sensor tps
- 9 fuel pump
- 10 fuel filter

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- 11 fuel distributor
- 12 fuel pressure regulator
- 13 fuel delivery/return line

3 Fuel-Injection (Continued)

- 14 fuel pump relay fpr
- 15 diesel fuel injection pump
- 16 diesel fuel heater
- 17 diesel speed governor
- 18 diesel smoke puff limiter spl
- 19 diesel glow plugs
- 20 diesel water separator
- 21 inertia fuel shutoff switch ifss
- 22 idle speed control isc
- 23 idle air control valve iacv
- 24 iacv hoses
- 25 cold start valve
- 26 early fuel evaporation efe (electrical)
- 27 engine coolant temp. sensor ects
- 28 cam position sensor (smpi)
- 29 crankshaft position sensor cps
- 30 manifold surface temp. sensor msts
- 31 intake air temperature sensor iats
- 32 diesel fast idle solenoid
- 33 diesel cold start solenoid
- 34 diesel altitude control solenoid
- 35 hoses
- 36 hoses (air flow sensor & throttle body)
- 37 hoses (vac hoses, pressure regulator, ect
- 38 gasket / seal
- 39 wire / harness / fuse
- 40 other
- 41 idle CO
- 42 idle speed
- 43 aux, air regulator
- 4 Ignition
 - 2 distributor assembly (cap & rotor)
 - 3 ignition timing
 - 4 ignition timing limiting device
 - 5 spark plugs and / or wires
 - 6 spark plugs and / or wires
 - 7 breakerless pickup (all types)
 - 8 ignition module
 - 9 spark timing control module
 - 10 coil/coil pack
 - 11 dwell / points

20 hoses 21 gasket / seal

23 other

2 - 14

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12 vacuum advance assembly

16 camshaft position sensor

19 thermal vacuum switch - tvs

17 crankshaft position sensor - cps

18 engine coolant temperature sensor - ects

- 13 spark delay devices
- 14 knock sensors ks 15 engine speed sensor

22 wire / harness / fuse

Table 2-2. System and Component Codes Used to Standardize Repair Data from the CTP, Hammond, Phoenix, CARBFI, and California I/M Pilot Project Databases (Continued).

5 EGR

- 2 egr valve assembly
- 3 egr filter
- 4 egr spacer plate
- 5 egr function sensor egrs
- 6 egr function control egrc
- 7 delay solenoid/valve
- 8 vacuum amplifier
- 9 vacuum reservoir
- 10 engine coolant temperature sensor ects
- 11 thermal vacuum switch tvs
- 12 hoses / vacuum lines
- 13 wire/hamess/fuse
- 14 other

6 PCV

- 2 pcv valve or orifice
- 3 pcv filter
- 4 oil filler cap
- 5 hoses
- 6 wire / harness / fuse
- 7 other

7 Evaporative Control

- 2 canister
- 3 canister filter
- 4 canister purge solenoid / valve
- 5 fuel filler cap
- 6 fuel restrictor
- 7 fuel tank
- 8 fuel line (supply/return)
- 9 vapor separator
- 10 pressure relief valve
- 11 rollover valve
- 12 anti siphon valve 13 hoses / vacuum lines
- 13 HUSES / Val
- 14 gasket / seal 15 wire / harness / fuse
- 15 wire / namess / iu
- 16 other

8 Secondary Air Injection

- 2 secondary air injection filter
- 3 secondary air injection pump
- 4 secondary air bypass valve sabv
- 5 secondary air anti-backfire valve sabfv
- 6 secondary air anti-backfire valve sabfv
- 7 secondary air switching valve sasv
- 8 secondary air pulse valve sapv
- 9 drive belt
- 10 upstream injection tube(s)
- 11 downstream injection tube(s)
- 12 hoses / vacuum lines
- 13 gasket / seal
- 14 wire / harness / fuse
- 15 other

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9 Exhaust After-Treatment

- 2 thermal reactor
- 3 warm-up oxidation catalyst wuoc

9 Exhaust After-Treatment (Continued)

- 4 warm-up three way catalyst wutwc
- 5 oxidation catalyst oc
- 6 three way catalyst
- 7 three way catalyst
- 8 trap oxidizer, continuous toc
- 9 trap oxidixer, periodic top

10 Engine Control

- 2 powertrain control module pcme
- 3 powertrain control module (trans.) pcmt
- 4 body control module bcm

11 Sensor/Solenoid/Valve

- 2 oxygen sensor o2s
- 3 oxygen sensor heated o2sh
- 4 air conditioner sensor acs
- 5 barometric absolute pressure sensor
- 6 coolant level sensor cols
- 7 engine coolant temperature sensor ects
- 8 fuel temperature sensor
- 9 manifold air pressure sensor map
- 10 manifold vacuum sensor mvs
- 11 manifold vacuum zone switch mvzs
- 12 wide open throttle switch wots
- 13 engine speed sensor
- 14 torque sensor
- 15 cylinder chamber temperature sensor
- 16 catalyst temperature sensor
- 17 thermal vacuum switch tvs
- 18 vehicle speed sensor vss
- 19 wire / harness / fuse / vacuum line
- 20 gasket / seal
- 21 other

12 On-Board Diagnostics

- 2 malfunction indicator light mil
- 3 mil bulb check
- 4 obd system
- 5 diagnostic trouble codes dtc
- 6 service reminder
- 7 data link connector dlc
- 8 wire / harness / fuse

13 Engine/Exhaust

- 2 engine block
- 3 cooling system 4 coolant fan control

7 belt tension

10 mufflers

12 tailpipe 13 other

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2-15

8 exhaust manifold

5 intake/exhaust valves

6 auxiliary vacuum pump

16 vacuum lines (general)

9 early fuel evaporation - efe (heat riser)

14 cylinder compression pressure (psi - xxx.)

11 exhaust port liner/double walled pipe

15 cylinder leak down (percent - xx.x)

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Not all of the components listed in Table 2-2 are included in the repair categories defined above. For the air induction system, the effects of repair were generally found to be insignificant (when analyzed according to the methodology described below), and those repairs were not considered in this analysis. Evaporative control system defects were not analyzed since the focus of this effort was on exhaust emission reductions. Although repair effects of PCV system defects were not analyzed (due to lack of data), that system is discussed later in this section. Finally, several specific components from system 13 were analyzed independently (i.e., repairs to the cooling system, intake/exhaust valves, and exhaust manifold), and the effects of repair were found to be insignificant. When components 2 to 12 in system 13 were combined, there was a calculated effect from repair for carbureted vehicles only. However, because those repairs encompassed so many different subsystems, it was unclear how those results could be extrapolated to the fleet with any confidence, and they were neglected.

Each repair was also classified according to the type of repair action taken by the mechanic, i.e., adjust, replace, reconnect, clean, rebuild, or restore continuity. Finally, the repairs were designated as electrical component failures, mechanical component failures, malmaintenance, or tampering. The data were compiled in a series of Excel spreadsheets, which were then converted to ASCII files for subsequent analysis. A sample of the spreadsheet for the CTP database is illustrated in Table 2-3.

EMISSION REDUCTIONS FROM REPAIR

During the initial phases of this project, it was hoped that sufficient emissions data on individual component repair would be available so that the change in emissions as a result of repair could be calculated on a component-specific basis. Unfortunately, a large fraction of the vehicles included in the repair database received multiple repairs between FTP tests, even though the test protocol in some cases (e.g., CTP) called for

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Vehicle	Repair	Model	Fuel	FTP		FTP Res	ults (g/mi)		System	· Component	Repair	
Number	Number	Year	System	Test	нс		NOx	Score	Code	Code	Action	Reason
											Roton	ricason
1	0	81	Carb	в	1.94	71.61	0.12	9.216				
	1			Ā	0.39	6.64	0.50	1.550	10	2	6	E
	•			R	1.55	64.97	-0.38	7.666		2	l °	
					1.55	04.97	-0.30	7.000				
2	0	83	Carb	в	4.84	49.00	0.54	10.280				
-	1		Guid	Ā	5.14	89.10	0.30	14.350	4	2	2	
				^	0.14	00.10	0.00	14.000	4	23		M M
	•			R	-0.30	-40.10	0.24	-4.070	4	3		111
				l	-0.50		0.24	-4.070				
2	1	83	Carb	в	5.14	89.10	0.30	14,350				
4	2	55	Carb	Ā	2.19	21.60	0.30					-
	2			~	2.19	21.00	0.94	5.290	1	16	2	T
	2				0.05	07.00			1	13	2	Т
				R	2.95	67.50	-0.64	9.060				
~	•					0.00						
2	2	83	Carb	В	2.19	21.60	0.94	5.290				
	3			A	0.72	9.70	1.05	2.740	2	4	1	м
	3								2	5	1	м
				R	1.47	11.90	-0.11	2.550				
3	0	85	TBI	В	1.08	21.87	0.17	3.433	!			
	1			A	0.32	6.36	0.16	1.120	10	2	2	E
				R	0.75	15.51	0.01	2.313	1			
3	1	85	TBI	В	0.32	6.36	0.16	1.120				
	2			A	0.31	6.22	0.15	1.084	3	40	2	F
-				R	0.01	0.14	0.01	0.036				
	. 1											
3	2	85	TBI	В	0.31	6.22	0.15	1.084				
	3			A	0.19	2.71	0.35	0.806	11	2	2	Е
				R	0.13	3.51	-0.20	0.278		-	-	-
4	0	82	Carb	в	8.32	81.26	1.88	18.322				
	1			A	1.65	12.16	2.87	5.736	2	2	2	м
				R	6.67	69.10	-0.99	12.586	-	-	-	
4	1	82	Carb	в	1.65	12.16	2.87	5.736				
	2			Ā	1,47	10.84	2.79	5.340	8	8	2	F
	-			R	0.18	1.32	0.08	0.396	Ň	v	۲	'
				· ·	0.10	1.02	0,00	0.030				
4	2	82	Carb	в	1.47	10.84	2.79	5.340				
• 1	3			Ă	1.53	10.08	3.24	5.778	1	3	4	м
	3				1.00	10.00	0.67	5.775	2	5	2	M
	3	i							4	5 12		F
	3								4	12 3	2	
	3										4	м
	3								6	3	2	м
	3								13	5	1	M
	°			R	-0.06	0.76	-0.45	-0.438	13	13	1	м
				ri,	-0.00	0.70	-0.40	-0.438				

Sample Spreadsheet Identifying Repair Actions in a Common Format -Table 2-3. CTP Database.

NOTES

FTP Test Codes :

B = Baseline

A = After-repair R = Reduction from repair

Repair Action Codes: 1 = Adjusted 2 = Replaced

3 = Reconnected

4 = Cleaned

5 = Rebuilt

6 = Continuity Restored

Reason Codes:

E = Electrical component failure

F = Mechanical component failure M = Maintenance

T = Tampering

FTP Results:

Score = HC + NOx + CO/10

FTPs after each repair. Because of the large number of multiple repairs and because of a desire to use FTP values to assign emission reductions, a methodology had to be

developed to estimate FTP improvements for individual repairs. This was accomplished with the regression technique described below.

Methodology to Estimate the Effects of Individual Component Repair From the databases analyzed in this project, it is possible to determine the improvement in FTP emissions due to component repairs. In some cases, FTP improvement data exist for individual repairs; however, a large fraction of the FTP tests were conducted after multiple component repairs. It was desired to identify the emission benefit from an individual component repair based on the average of the entire data set. This was accomplished by casting the problem according to the following linear equation:

$$\sum_{i=1}^{N_{\epsilon}} \delta_{ij} \quad B_i = (\Delta FTP)_j \qquad j = 1, N,$$

where:

i is an index specifying individual components;

 N_c is the total number of components that could be repaired;

j is an index specifying a particular repair action (i.e. a particular set of repairs) for which FTP improvement data are available (one or more components may be repaired in a single repair action);

- N_r is the total number of repair actions for which FTP data are available;
- B_i is the average benefit of repairing component i stated as an improvement in FTP emissions (this is the unknown that is being determined); and

 $(\Delta FTP)_i$ is the observed improvement in FTP emissions from repair action j.

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The above terms define the existing data. To analyze these data, the term δ_{ij} is defined as having the value 1 if component i is repaired in repair action j and having the value 0 otherwise; i.e.,

 $\delta_{ij} \left\{ \begin{array}{ll} 1 & \text{if component } i \text{ is repaired in action } j \\ 0 & \text{if component } i \text{ is NOT repaired in action } j \end{array} \right.$

The values of B_i can be found by using a linear regression analysis (with zero intercept) where the input data are the values of δ_{ij} and (Δ FTP)_j for each data point.

This approach assumes that the emission benefit of each component repair is independent of the benefits of other component repairs that take place in the same repair action. It also assumes that each component repair has the samimprovement in FTP emissions (i.e., B_i), regardless of the original state of the vehicle prior to repair. Although the first assumption can be argued, it was felt that the regression approach described above was more valid in this analysis than simply taking the mean FTP improvement of individual repairs because data points did not have to be discarded using the regression methodology. The second assumption is less of an issue in the final analysis of repair data, which segregated vehicles into normal and high emitter groups on the basis of before-repair emission levels.

Results of the Regression Analysis

To perform the regression analysis, it was necessary to create a repair array (i.e., δ_{ij}) for each FTP before- and after-repair couple. This was accomplished by analyzing the ASCII versions of the repair data files created from the FTP data and the mechanic comments (i.e., Table 2-3) in a FORTRAN post-processor and creating three sets of arrays based on:

- system codes (i.e., a series of 14 1s and 0s for each FTP before- and after-repair couple);
- component codes (i.e., a series of 224 1s and 0s for each FTP beforeand after-repair couple); and

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 repair type as defined above (i.e., a series of 10 1s and 0s for each FTP before- and after-repair couple).

The resulting data files were then processed in a SAS routine using a "backward elimination" regression procedure (with zero intercept) in which the user specifies which variables (i.e., components) to include in the regression and the program removes variables until those left are significant at the 90% level. A number of different runs were performed, both on individual components and on systems. That evaluation helped to define the 10 fuel-injected and 10 carbureted repair types ultimately chosen for analysis.

The repair data were segregated according to fuel system type (i.e., carbureted and fuel-injected) prior to analysis. Although it was desirable to also analyze the data according to model-year group (e.g., 1981-1985 and 1986+), there were concerns that doing so would compromise the sample size too severely. The results of the regression analysis are summarized in Tables 2-4a and 2-4b for carbureted and fuelinjected vehicles, respectively. (Appendix A contains the SAS output for those regressions. That appendix includes more detail of the regression statistics, and it contains the regression results for intermediate steps in the analysis, i.e., the regression results with the non-significant components included.) Note that those results are from all repair actions in the five databases where the diagnosis was considered accurate ("OK"). The decision as to whether a diagnosis was OK or faulty was based on the difference between the before-repair and after-repair FTP "score." (In this analysis, the FTP score was defined as HC + NOx + CO/10.) The cutoff used to distinguish between an OK and a faulty diagnosis was 0.2 g/mi for the FTP score, except in cases where there was an EGR repair aimed at NOx reductions. Those repairs were considered OK if the NOx emission rate decreased by more than

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0.2 g/mi, regardless of the effect that the repair may have had on HC and CO emissions.

Regressions were performed for each pollutant independently and for the composite FTP "score." It should be noted that the correlation coefficients (i.e., r^2 values) resulting from the regressions were poor, generally ranging from 0.2 to 0.5. However, it is not uncommon for vehicle emissions data to demonstrate significant scatter, resulting in poor correlations when regressions are performed.

Table 2-4a.Emission Reductions Associated with the Repair of Carbureted
Vehicles with "OK" Diagnoses.

System/	Reduction in FTP Emissions (g/mi)						
Component	HC	CO	NOx	Score			
Carb Rebuild/ Replacement	ns ^a	21.91±4.98	ns	2.77±0.78			
Fuel Metering System Repair	1.32±0.31	21.30±3.33	-0.27±0.11	3.13±0.56			
Ignition System Tune-up Repair	1.10±0.35	ns	ns	1.67±0.65			
Other Ignition System Repair ^b	ns	ns	ns	ns			
EGR Repair	ns	ns	0.66±0.13	ns			
Air Injection Repair	ns	9.44±4.43	ns	ns			
Catalyst Replacement	0.85±0.40	ns	0.78±0.14	2.31±0.70			
ECU Replacement	1.65±0.63	35.41±7.25	-0.51±0.23	4.85±1.11			
Oxygen Sensor Replacement	0.72±0.39	19.53±4.30	ns	2.42±0.69			
Other Sensor Replacement/Repair	ns	13.82±7.70	0.43±0.24	2.42±1.19			

^a Not significant at the 90% level.

^b Ignition system "tune-up" repairs include repairs to the distributor cap/rotor, timing, and plugs/wires. All other ignition system repairs were included in the "other" ignition system repair category.

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In comparing the results from Tables 2-4a and 2-4b, several interesting points can be made. First, the effect of ignition system defects was consistent in that only HC emissions were significantly affected. Likewise, EGR defects consistently affected only NOx emissions. Oxygen sensor defects had a significant effect on HC and CO emissions for both carbureted and fuel-injected vehicles. Another point to be made

Vehicl	es with "OK" D	iagnoses.	•	,			
System/	Reduction in FTP Emissions (g/mi)						
Component	НС	CO	NOx	Score			
Injector Replacement	0.68±0.34	10.08±4.66	-0.24±0.12	1.41±0.73			
Fuel Metering System Repair	0.56±0.27	7.93±3.68	0.22±0.09	1.36±0.60			
Ignition System Tune-up Repair ^b	nsª	ns	ns	1.00±0.53			
Other Ignition System Repair ^b	0.94±0.49	ns	ns	ns			
EGR Repair	ns	ns	0.85±0.10	ns			
Air Injection Repair	ns	ns	ns	1.96±1.19			
Catalyst Replacement	ns	ns	1.27±0.10	1.59±0.61			
ECU Replacement	3.48±0.61	34.83±8.42	ns	6.91±1.32			
Oxygen Sensor Replacement	1.46±0.19	29.87±2.61	ns	4.11±0.44			
Other Sensor Replacement/Repair	ns	ns	ns	ns			

Table 2-4b.Emission Reductions Associated with the Repair of Fuel-Injected
Vehicles with "OK" Diagnoses.

^a Not significant at the 90% level.

^b Ignition system "tune-up" repairs include repairs to the distributor cap/rotor, timing, and plugs/wires. All other ignition system repairs were included in the "other" ignition system repair category.

in reference to the tables is that catalyst replacements did not have as large of an effect on FTP reductions as some of the other repairs. 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 NOx. A catalyst with a 90% efficiency for HC and CO and a 70% efficiency for NOx would result in an emission reduction of

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1.8 g/mi HC, 18 g/mi CO, and 1.4 g/mi NOx. 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. (Note that in the test programs analyzed in this study, catalysts were generally not replaced until most other defects were identified and repaired.)

To serve as a check on how well the repairs that were statistically significant accounted for the total emission reduction from repairs, the emission reductions from all statistically significant repairs performed on the vehicles in the repair database were compared to the overall difference in emissions between the baseline and after-repair FTP results for those vehicles. This was done by first multiplying the number of significant repairs in each repair category by the average emission reduction from repair listed in Tables 2-4a and 2-4b. That product was then subtracted from the total before-repair emissions from the repaired vehicles. Dividing that result by the total number of vehicles (more correctly, "repair events," since a single vehicle may have been repaired and FTP tested more than once) gives the average g/mi value when only the significant repairs are considered. For example, there were 541 repair events (with "OK" diagnostics) in the fuel-injected repair database, and those had an average before-repair HC emission rate of 2.06 g/mi and an after-repair emission rate (considering all repairs) of 0.62 g/mi. When only the statistically significant repairs listed in Table 2-4b are considered (i.e., injector replacement, fuel metering system repair, other ignition system repair, ECU replacement, and oxygen sensor replacement), the estimated after-repair emission rate is 0.85 g/mi, based on the calculation shown below.

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$$\begin{array}{ll} HC_{After-Rep.} & = \left[(541 \ast 2.06 \text{ g/mi}) - (82 \ast 0.68 \text{ g/mi}) & \text{Injector Replacement} \\ & - (140 \ast 0.56 \text{ g/mi}) & \text{Fuel Metering System Repair} \\ & - (35 \ast 0.94 \text{ g/mi}) & \text{Other Ignition System Repair} \\ & - (23 \ast 3.48 \text{ g/mi}) & \text{ECU Replacement} \\ & - (280 \ast 1.46 \text{ g/mi}) \right] & \text{Oxygen Sensor Replacement} \\ & \div 541 = 0.85 \text{ g/mi} \end{array}$$

Thus, when only the statistically significant component repairs are considered, the calculated HC emission reduction from repair is 84% (i.e., (2.06-0.85)/(2.06-0.62)) of the reduction from <u>all</u> repairs. For CO emissions, the statistically significant component repairs account for 87% of the total emission reduction, and for NOx, the value rises to 92%.

The results presented in Tables 2-4a and 2-4b assume that the change in FTP emissions as a result of repair is independent of the original state of the vehicle. This assumption was tested by segregating vehicles by before-repair emission level prior to performing the regressions. Vehicles were considered "high" emitters if their before-repair FTP emission levels exceeded 1.0 g/mi HC, 15 g/mi CO, or 1.7 g/mi NOx; vehicles with emissions below those levels were considered "normal/moderate" emitters. These values were used because they approximate IM240 levels of 0.8 g/mi HC, 15 g/mi CO, and 2 g/mi NOx. (The FTP levels were calculated from EPA correlation equations developed for MOBILE5a, discussed in Sierra's report "Investigation of MOBILE5a Emission Factors - Evaluation of IM240-to-FTP Correlation and Base Emission Rate Equations" (Sierra, 1994) and from IM240-to-FTP correlations developed by Sierra from the CARB I/M Pilot Project data (Sierra, 1995).) The results of this analysis are summarized in Tables 2-5a and 2-5b for carbureted and fuel-injected vehicles, respectively.

As expected, the benefits from repair of high emitting vehicles are much greater than for normal/moderate emitting vehicles. In addition, it is clear that repair of high emitters drives the analysis when emitter groups are combined (i.e., Tables 2-4a and

2-4b). Finally, it is interesting to note that catalyst system repairs on normal/moderate emitting fuel-injected vehicles are significant for all pollutants, while those repairs are significant only for NOx and "Score" for the high emitting vehicles.

Emitter	System/Component		Reduction in FTF	P Emissions (g/m	i)
Category		HC	СО	NOx	Score
High	Carb Rebuild/ Replacement	nsª	21.73±5.47	ns	2.60±0.86
	Fuel Metering System Repair	1.42±0.36	23.81±3.75	-0.29±0.12	3.47±0.64
	Ignition System Tune-up Repair	1.11±0.40	ns	ns	1.80±0.73
	EGR Repair	ns	ns	0.79±0.15	ns
	Air Injection Repair	ns	9.61±4.82	ns	ns
	Catalyst Replacement	1.05±0.49	ns	0.98±0.17	2.87±0.86
	ECU Replacement	1.77±0.70	37.47±8.08	-0.52±0.25	5.20±1.23
	Oxygen Sensor Replacement	0.83±0.45	23.30±4.88	-0.27±0.15	2.92±0.78
	Other Sensor Replacement/Repair	ns	ns	0.45±0.26	ns
Normal/ Moderate	Carb Rebuild/ Replacement	ns	ns	0.53±0.18	0.81±0.28
	Fuel Metering System Repair	0.27±0.06	5.30±1.03	ns	0.93±0.13
	Air Injection Repair	ns	-5.46±2.28 ^b	ns	-0.50±0.28
	Catalyst Replacement	0.53±0.06	6.32±1.02	0.27±0.08	1.43±0.12
	Oxygen Sensor Replacement	-0.14±0.08	ns	0.23±0.11	ns

Table 2-5a.	Emission Reductions Associated with the Repair of Carbureted Vehicles with
	"OK" Diagnoses - Segregated into "High" and "Normal/Moderate" Emitters.

^a Not significant at the 90% level.

^b Due to the small sample size of normal/moderate emitters with air injection system repairs (3), this negative result is driven by a single vehicle. That vehicle had an EGR repair during the same repair event as the air injection repair, and its NOx emissions decreased by over 1 g/mi (thus, it was flagged as an "OK" repair). Its CO emissions increased by 17 g/mi, causing the negative repair effect shown in the table. For calculating the contribution of defective air injection systems to the fleet-average emission rate (presented later in this section), the normal/moderate emitter air injection repair reduction from fuel-injected vehicles (in Table 2-5b) was substituted for the carbureted results shown above. API PUBL*4637 96 🔳 0732290 0551746 422 🔳

Table 2-5b.	Emission Reductions Associated with the Repair of Fuel-Injected Vehicles with
	"OK" Diagnoses - Segregated into "High" and "Normal/Moderate" Emitters.

Emitter Category	System/ Component	Red	uction in FTP Er	nissions (g/m	i)
		HC	со	NOx	Score
High	Injector Replacement	0.92±0.42	12.70±5.64	0.34±0.15	1.90±0.90
	Fuel Metering System Repair	ns ^a	ns	0.33±0.12	ns
	Ignition System Tune-up Repair	ns	ns	ns	1.37±0.65
	Other Ignition System Repair	1.28±0.62	ns	ns	ns
	EGR System	ns	ns	1.01±0.12	ns
	Catalyst	ns	ns	1.53±0.13	1.30±0.77
	ECU	4.48±0.78	44.47±10.58	ns	8.80±1.66
	Oxygen Sensor Replacement	1.98±0.24	40.20±3.17	0.20±0.09	5.67±0.56
Normal/ Moderate	Injector Replacement	0.08±0.04	2.36±0.71	ns	0.27±0.12
	Fuel Metering System Repair	0.08±0.04	1.18±0.58	ns	0.23±0.10
	Ignition System Tune-up Repair	0.07±0.03	0.83±0.45	ns	0.20±0.08
	Other Ignition System Repair	-0.13±0.06	-2.34±1.02	ns	ns
	EGR System	ns	ns	0.38±0.06	0.29±0.09
	Air Injection	0.22±0.09	5.73±1.52	ns	0.84±0.27
	Catalyst	0.32±0.03	3.02±0.55	0.43±0.06	1.03±0.10
	Oxygen Sensor Replacement	0.08±0.02	2.14±0.36	0.11±0.04	0.38±0.06
	Other Sensor Replacement/Repair	ns	ns	0.31±0.11	0.31±0.18

^a Not significant at the 90% level.

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EXCESS EMISSIONS VERSUS NATURE OF DEFECT

This study also required an estimate of excess emissions versus the nature of the defects. As described above, the repair database included an assessment of the primary cause of each repaired defect: mechanical failure, electrical failure, malmaintenance, or tampering. These designations were arrived at by evaluating mechanic comments along with the type of repair. For example, replacement of spark plugs and/or wires was generally considered malmaintenance, carburetor rebuilds or replacements were considered mechanical failures, and oxygen sensor replacements were considered 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).

The methodology used to quantify the change in FTP emissions by type of defect is similar to the regression technique described above for the analysis of individual components. The arrays of 1s and 0s defined by the term δ_{ij} were constructed for each repair action, but rather than the subscript i referring to a particular component, it referred to the nature of the defect (i.e., mechanical failure, electrical failure, malmaintenance, and tampering). Once each δ_{ij} was matched with the change in FTP emissions from each repair, regressions were performed. The results of that analysis are shown in Table 2-6, which indicates that electrical component failures have the largest influence on the reduction in emissions as a result of repair, particularly for fuel-injected vehicles.

The results in Table 2-6 were combined with the frequency of each type of defect in each of the five databases analyzed in this study to arrive at the fraction of emissions reduced (according to defect type) in the fleet of vehicles receiving repairs. Although there is considerable uncertainty in some of the estimates contained in Table 2-6, this

gives a reasonable indication of the fraction of excess emissions that are a result of mechanical defects, electrical defects, malmaintenance, and tampering.

Fuel	Repair Reason	FTP Emission Reductions (g/mi)					
System		НС	CO	NOx	Score		
Carbureted	Mechanical Failure	0.79±0.42	9.16±3.18	0.49±0.10	2.20±0.48		
	Electrical Failure	0.92±0.34	23.58±3.95	-0.27±0.12	3.01±0.60		
	Malmaintenance	0.84±0.31	13.18±3.57	-0.13±0.11 ^a	2.03±0.54		
	Tampering	0.75±0.42	7.56±4.93 ^a	0.31±0.15	1.82±0.75		
Fuel-Injected	Mechanical Failure	0.41±0.20	3.13±2.81 ^a	0.72±0.21	1.46±0.44		
	Electrical Failure	1.23±0.21	25.26±2.86	-0.07±0.08ª	3.69±0.45		
	Malmaintenance	0.68±0.24	9.42±3.31	-0.04±0.09 ^a	1.58±0.52		
	Tampering	-0.21±0.56 ^a	-1.89±7.66ª	0.72±0.21	0.32±1.20 ^a		

Table 2-6. FTP Emission Reductions by Repair Reason.

^a Not significant at the 90% level.

The results of that analysis, which was performed for the combined FTP "score," are shown in Table 2-7. As seen in the table, the distribution of excessive emissions across the four defect types differs between carbureted and fuel-injected vehicles. This is not unexpected, since fuel-injected vehicles generally are more reliant on electrical components to control emissions than are carbureted vehicles. This is observed in Table 2-7, which indicates that 50-60% of excessive emissions from fuel-injected vehicles are related to electrical component failure, while only 25-30% of the excessive emissions from carbureted vehicles are related to electrical component failure. It is also interesting to note that the contribution of tampering to excessive emissions from fuel-injected vehicles is very small, but it is much larger for carbureted vehicles.

Fuel System	Database	Mechanical Failures	Electrical Failures	Malmaintenance	Tampering
Carb.	СТР	46%	25%	22%	7%
	Hammond	33%	28%	32%	7%
	CA I/M Pilot	31%	32%	22%	16%
Fuel- Injected	СТР	21%	63%	17%	0%
	Hammond	26%	55%	19%	0%
	Phoenix	28%	61%	11%	0%
	CARBFI	18%	60%	22%	1%
	CA I/M Pilot	28%	48%	22%	2%

 Table 2-7.
 Contribution of Mechanical Failures, Electrical Failures, Malmaintenance, and Tampering to Emission Reductions from Repair.

PREVALENCE OF EMISSION CONTROL SYSTEM DEFECTS IN THE FLEET

The <u>incidence</u> of emission control system defects in the fleet, coupled with the emissions impact of repairing those defects, gives an estimate of excessive emissions that can be attributed to specific component failures. The emission reductions associated with the repair of defects were presented previously; below is a description of how the fleet component failure rates were determined.

As discussed above, the manner in which vehicles were selected for each of the five databases analyzed in this section of the report has a bearing on how to translate the results to a fleet basis. The CTP database and the CARBFI database contain vehicles that should fail an I/M short test. However, transient short test data (i.e., IM240) are not available from the vehicles tested nor the fleets from which they were drawn. Thus, it is not possible to project component failure rates in those databases to a fleet basis. On the other hand, the Hammond and Phoenix databases contain IM240 scores that can be used to project the lab results to a fleet basis. Such an approach

was used by EPA in developing the base emission rate equations for MOBILE5a, and a similar approach was used in this study for projecting sample component failure rates to a fleet basis for both the Hammond and Phoenix databases. Finally, the Pilot Project database contains a randomly selected group of vehicles that reflects the California fleet without the need to re-weight the sample.

Hammond and Phoenix Component Failure Rates

The component failure rates for the Hammond and Phoenix databases were determined by analyzing the "ECOMP" files downloaded from EPA's MICRO database. Those files contain information regarding the baseline condition of each vehicle receiving an FTP. The codes "PASS", "FAIL", or "NA" are logged for 11 separate systems and 85 individual components. The systems and components contained in the ECOMP files were combined in a fashion similar to that described above for the analysis of repair effects so that a more manageable number of system/component combinations could be analyzed. These data were used in conjunction with IM240 scores to determine the fraction of component failures for vehicles passing and failing IM240 cutpoints of 0.8 g/mi HC, 15.0 g/mi CO, and 2.0 g/mi NOx. Failure rates were compiled in this manner so that the results could be extrapolated to the fleet on the basis of IM240 pass/fail rates observed at the I/M lanes in Hammond and Phoenix. The results of this analysis are contained in Tables 2-8a and 2-8b for the Hammond and Phoenix databases, respectively.

The component failure rates listed in Tables 2-8a and 2-8b are very similar for fuelinjected vehicles when the results are extrapolated to the fleet, with the Hammond fleet having slightly higher failure rates. This was expected, as the Hammond I/M lane data represented a non-I/M case (i.e., those data were collected during the initial two years of a biennial I/M program), and the Phoenix I/M data represented an I/M case. Also note that the component failure rates for the carbureted vehicles are much higher than

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for the fuel-injected vehicles. This is because the carbureted fleet is older and, in general, fuel management systems are not as durable on a carbureted vehicle as on a fuel-injected vehicle. Both databases indicate an approximate 25% failure rate for

			FTP Samp	FTP Sample - Component Failure Rate				
Fuel 1	System/	Percent	Ali	IM240	IM240	Failure		
System	Component	Equipped	Vehicles	Failures	Passes	Rate*		
Carbureted	Carburetor	100.0%	24.0%	25.7%	19.5%	23.1%		
	Fuel Metering System	100.0%	73.4%	84.1%	43.9%	67.0%		
	Ignition Tune-up	100.0%	69.5%	77.0%	48.8%	65.0%		
	Other Ignition	100.0%	14.9%	17.7%	7.3%	13.3%		
	EGR	98.7%	44.8%	52.2%	24.4%	40.4%		
	Air Injection	100.0%	31.2%	37.2%	14.6%	27.6%		
	Catalyst	100.0%	12.3%	14.2%	7.3%	11.3%		
	Electronic Control Unit	97.4%	7.8%	10.6%	0.0%	6.1%		
	Oxygen Sensors	83.8%	27.9%	36.3%	4.9%	23.0%		
	Other Sensors	97.4%	4.5%	6.2%	0.0%	3,6%		
Fuel-Injected	Fuel Injector(s)	100.0%	12.6%	20.9%	6.6%	9.5%		
	Fuel Metering System	100.0%	18.9%	31.4%	9.9%	14.2%		
	Ignition Tune-up	100.0%	48.9%	68.6%	34.5%	41,3%		
	Other Ignition System	100.0%	8.2%	13.6%	4.3%	6.2%		
	EGR	69.3%	20.2%	34.1%	10.2%	.15.0%		
	Air Injection	23.3%	3.8%	7.7%	1.0%	2,3%		
	Catalyst	100.0%	11.8%	24.6%	2.6%	7.0%		
	Electronic Control Unit	100.0%	2.1%	4.1%	0.7%	1,4%		
	Oxygen Sensor	100.0%	34.0%	55.0%	18.8%	26,0%		
	Other Sensors	99.8%	2.3%	3.6%	1.3%	1.8%		

Table 2-8a. Component Failure Rates for the Hammond Database.

 Since the FTP sample was skewed with high emitting vehicles, the fleet failure rates were calculated by weighting the IM240 passing and failing component failure rates by the IM240 pass and fail rates observed in the fleet.

Table 2-8b.	Component Failure	Rates for th	e Phoenix Database.
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			FTP Samp	Fleet		
Fuel	System/	Percent	Ali	IM240	IM240	Failure
System	Component	Equipped	Vehicles	Failures	Passes	Rate*
Fuel-Injected	Fuel Injector(s)	100.0%	14.4%	21.4%	7.9%	8.8%
	Fuel Metering System	100.0%	14.0%	17.9%	10.3%	10.8%
	Ignition Tune-up	100.0%	45.3%	53.9%	37.3%	38.4%
	Other Ignition System	100.0%	5.3%	9.4%	1.5%	2.0%
	EGR	86.4%	22.2%	34.2%	11.1%	- 12.6%
	Air Injection	25.9%	2.5%	4.3%	0.8%	1.0%
	Catalyst	100.0%	13.6%	23.9%	4.0%	5.3%
	Electronic Control Unit	100.0%	2.1%	3.4%	0.8%	1.0%
	Oxygen Sensor	100.0%	37.9%	53.0%	23.8%	25.8%
	Other Sensors	100.0%	6.6%	11.1%	2.3%	2.9%

Since the FTP sample was skewed with high emitting vehicles, the fleet failure rates were calculated by weighting the IM240 passing and failing component failure rates by the IM240 pass and fail rates observed in the fleet.

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oxygen sensors. This is important from the perspective that repair of oxygen sensor failures results in a large decrease in emissions.

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. 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%). This reflects, in large part, the greater number of components associated with carburetors relative to fuel injectors.

CARB I/M Pilot Project Component Failure Rates

The California I/M Pilot Project database was also analyzed to determine the fraction of specific component failures in the California fleet. Because the California I/M Pilot Project represents a randomly selected fleet, it was not necessary to re-weight the results to reflect the fleet. A summary of the system/component failure rates from the Pilot Project database is contained in Table 2-9. It is interesting to note that the component failure rates for the California fleet are considerably lower that the Hammond and Phoenix fleets. We believe vehicles in the EPA databases may have been subject to a more thorough inspection and repair protocol than the Pilot Project fleet, with more component failures discovered during the time in which the vehicles were being tested. The differences in failure rates between EPA and CARB data may reflect the thoroughness of the inspections more than real differences in the fleets.

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This can be better understood by noting the purpose of the programs. The CARB I/M Pilot Project was intended to evaluate vehicles under the same time and cost

		1	FTP Samp	ailure Rate	Fleet	
Fuel	System/	Percent	All	IM240	IM240	Failure
System	Component	Equipped	Vehicles	Failures	Passes	Rate*
Carbureted	Carburetor	**	14.4%	22.6%	0.0%	14.4%
	Fuel Metering System	**	48.6%	72.0%	7.6%	48.6%
	Ignition Tune-up	**	22.6%	33.3%	3.8%	22.6%
	Other Ignition System	**	4.8%	7.5%	0.0%	4.8%
	EGR	**	39.0%	51.6%	17.0%	39.0%
	Air Injection	**	17.1%	26.9%	0.0%	17.1%
	Catalyst	**	13.0%	20.4%	0.0%	13.0%
	Electronic Control Unit	**	2.1%	3.2%	0.0%	2.1%
	Oxygen Sensor	**	24.7%	36.6%	3.8%	24.7%
	Other Sensors	**	4.8%	7.5%	0.0%	4.8%
Fuel-Injected	Fuel Injector(s)	**	2.8%	7.9%	1.1%	2.8%
	Fuel Metering System	**	14.5%	42.2%	5.6%	14.5%
	Ignition Tune-up	**	8.1%	23.6%	3.0%	8.1%
	Other Ignition System	**	2.0%	5.6%	0.7%	2.0%
	EGR	**	8.1%	24.7%	2.6%	8.1%
	Air Injection	**	2.2%	5.6%	1.1%	2.2%
	Catalyst	**	5.6%	18.0%	1.5%	5.6%
	Electronic Control Unit	**	1.4%	4.5%	0.4%	1.4%
, ,	Oxygen Sensor	**	13.4%	39.3%	4.8%	13.4%
: 	Other Sensors	**	0.6%	2.3%	0.0%	0.6%

Table 2-9. Component Failure Rates for the California I/M Pilot Project Database.

Since the CARB Pilot Project fleet was randomly selected, there was no need to re-weight the sample; thus, columns 4 and 7 are equal.

** The percent of vehicles equipped with each system/component could not be determined from the Pilot Program database.

constraints as in an operating I/M program. On the other hand, although the vehicles in the EPA projects were selected from I/M fleets, those programs were more research oriented, and time and cost constraints were generally not imposed.

OVERALL IMPACT OF SPECIFIC DEFECTS ON FLEET-AVERAGE EMISSIONS

By combining the component failure rates calculated above with the FTP reductions from repair of those defects, it is possible to estimate the impact that defective components have on the fleet-average emission rate. This was performed for the Hammond, Phoenix, and Pilot Project databases by first determining the fraction of

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IM240 passing and failing vehicles (based on 0.8 g/mi HC, 15.0 g/mi CO, and 2.0 g/mi NOx cutpoints) in the fleet of vehicles from which the vehicles receiving FTPs were drawn. The system/component failure rates listed in Tables 2-8 and 2-9 were then used in combination with the IM240 pass/fail rates to arrive at the component failure rates for the fleet. The benefits of repairing the defects were then determined by multiplying the fraction of defects by the reduction in FTP emissions associated with the repair of those defects. This is best illustrated with an example, which is provided below.

Consider ECU defects in fuel-injected vehicles in the Hammond database. As noted in Tables 2-4b and 2-5b, repair of ECU failures results in the greatest FTP reduction of any component. However, because the fraction of ECU failures in the fleet is relatively low, the overall impact on fleet-average emissions is not as significant as the repair effects might indicate. To calculate the effects on the fleet-average emission rate of ECU defects, the first step was to estimate the baseline emission rate for the fleet being analyzed. As noted above, the sample selection process in Hammond was biased toward high emitting vehicles. The FTP data collected in Hammond were reweighted to a fleet basis by noting that 20% of the 1981 and later model year fuelinjected vehicles failed the 0.8/15/2 HC/CO/NOx IM240 cutpoints at the I/M lane. Since vehicles tested at the I/M lane were randomly selected, it is reasonable to assume that this is the failure rate for the Hammond fleet. The fleet-average FTP emission rate was then calculated by determining the average FTP levels for passing and failing IM240 vehicles in the sample that received FTPs, and weighting these results by 80/20. For HC emissions, passing vehicles averaged 0.42 g/mi, while failing vehicles averaged 2.84 g/mi. Combining these values resulted in a baseline fleetaverage HC level of 0.90 g/mi.

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From Table 2-8a, 4.1% of the IM240 failing vehicles had ECU failures, while only 0.7% of the IM240 passing vehicles had ECU failures. Since the Hammond fuel-injected fleet consists of 20% IM240 failures, the fleet contains 4.1% x 20%, or 0.82% high emitting vehicles with ECU failures. From Table 2-5b, repairing a defective ECU on high emitting vehicles results in an average HC decrease of 4.48 g/mi. (The effect of ECU repair is not significant for normal/moderate emitting vehicles.) Thus, the overall contribution to the fleet-average HC emission rate of defective ECUs is:

 $HC_{ECU} = 0.0082 * 4.48 = 0.04 \text{ g/mi}$ which is 0.04/0.90, or 4% of the fleet-average emission rate.

The above calculations were carried out for each database, system/component, and pollutant. The results are shown in Tables 2-10, 2-11, and 2-12 for the Hammond, Phoenix, and CARB I/M Pilot Project fleets, respectively. Several key points, detailed below, can be made in reference to the results presented in Tables 2-10 to 2-12.

- For carbureted vehicles, the primary contributor to excess emissions is defective fuel metering systems (including the carburetor and related components), which contribute 35-36% to the fleet-average emission rate (i.e., the FTP "score"). That is followed by defective oxygen sensors, which account for 10-11% of the fleetaverage emissions.
- For fuel-injected vehicles, defective oxygen sensors are the primary cause of excess emissions, contributing 22-23% to fleet-average emissions in the Hammond and Pilot Project fleets, and 15% to the Phoenix fleet. Other types of failures contribute less to the fleet-average emission rate, primarily because the frequency of failure is much lower than for oxygen sensors.
- The small contribution of defective catalysts to excess emissions is somewhat surprising. However, the fraction of defective catalysts in the fleet is relatively low and, as discussed previously, the benefit of repair is limited if all other systems on the vehicle are functioning properly. In addition, the regression analysis performed to determine the effects of repair indicated that catalyst system repairs of high emitters were significant only for NOx and the weighted FTP "score." Even if the HC value calculated by the regression analysis were used (i.e., 0.33 g/mi), the contribution to fleet-average HC emissions would go only from 1% to 2.5%. Under an optimistic scenario of a 1.5 g/mi HC reduction for each defective catalyst on

high-emitting vehicles,^{*} the contribution to the fleet-average emission rate only increases to 9%, less than half of the contribution due to defective oxygen sensors.

The overall impact on the fleet-average emissions of the repairs listed in Tables 2-10 to 2-12 is summarized in Table 2-13. That table shows that the baseline fleet-average emission rate for the fuel-injected vehicles is much lower than for carbureted vehicles, and that the fractional reduction from repair is larger for carbureted vehicles.

Fuel System	System/Component	Contri	bution to FT	P Emissio	ons
		НС	со	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 ECU		< 1%	9%	3%
			3%	ns	2%
	Oxygen Sensor	25%	37%	-1%	22%
	Other Sensors	ns	ns	< 1%	< 1%

Table 2-10.	Contribution of Defective Components to the Fleet-Average Emission Rate
	for the Hammond Database.

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

This is the approximate reduction in HC emissions associated with the replacement of a totally dead or missing catalyst on an otherwise properly functioning vehicle.

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Table 2-11.	Contribution of Defective Components to the Fleet-Average Emission Rate	te
	for the Phoenix Database.	

Fuel System	System/Component	Contribution to FTP Emissions			
		НС	СО	NOx	Score
Fuel Injected	Injector Replacement	4%	6%	-1%	3%
	Fuel Metering System Repair	2%	2%	< 1%	1%
	Ignition Tune-up	5%	5%	ns	6%
	Other Ignition Repair	1%	-1%	ns	ns
	EGR System	ns	ns	8%	2%
	Air Injection System	< 1%	< 1%	ns	< 1%
	Catalyst	2%	2%	5%	3%
	ECU	2%	2%	ns	1%
	Oxygen Sensor	18%	31%	2%	15%
	Other Sensors	ns	ns	< 1%	< 1%

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

 Table 2-12.
 Contribution of Defective Components to the Fleet-Average Emission

 Rate for the CARB I/M Pilot Project Database.

Fuel System	System/Component	Contri	bution to FTP	Emissions	\$
		HC	CO	NOx	Score
Carbureted	Carb Rebuild/Replacement	nsª	11%	< 1%	6%
	Fuel MeteringSystem Repair	34%	39%	-9%	29%
	Ignition Tune-up	12%	ns	ns	6%
	Other Ignition Repair	ns	ns	ns	ns
	EGR System	ns	ns	17%	ns
	Air Injection System	< 1%	6%	ns	< 1%
	Catalyst	7%	< 1%	9%	6%
	ECU Oxygen Sensor		3%	-1%	2%
			19%	-4%	11%
	Other Sensors	ns	ns	1%	ns
Fuel-Injected	Injector Replacement	3%	3%	-1%	2%
	Fuel Metering System Repair	< 1%	< 1%	4%	< 1%
	Ignition Tune-up	< 1%	< 1%	ns	3%
	Other Ignition Repair	3%	-1%	ns	ns
	EGR System	ns	ns	7%	< 1%
	Air Injection System	< 1%	< 1%	ns	< 1%
	Catalyst	< 1%	< 1%	8%	3%
	ECU	8%	5%	ns	4%
	Oxygen Sensor	32%	42%	-2%	23%
	Other Sensors	ns	ns	< 1%	< 1%

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

Table 2-13. Effect of Confecting All Repairable Defects of Freet-Average Emissions.							
Fleet	Fuel System	Repair Status	FTP Emissions (g/mi)				
			НС	со	NOx	Scoreª	
Hammond	Carbureted	As-Received After-Repair Reduction (%)	2.66 0.64 76%	36.08 4.73 87%	1.41 1.24 12%	7.67 2.36 69%	
	Fuel-Injected	As-Received After-Repair Reduction (%)	0.90 0.53 41%	12.99 6.89 47%	0.91 0.73 21%	3.12 1.89 39%	
Phoenix	Fuel-Injected	As-Received After-Repair Reduction (%)	0.50 0.33 34%	6.22 3.35 46%	0.80 0.67 16%	1.92 1.33 31%	
CA I/M Pilot	Carbureted	As-Received After-Repair Reduction (%)	1.93 0.67 66%	28.67 6.56 77%	1.50 1.30 14%	6.30 2.75 56%	
	Fuel-Injected	As-Received After-Repair Reduction (%)	0.62 0.33 47%	9.56 4.63 52%	0.94 0.79 17%	2.52 1.63 35%	

Table 2-13. Effect of Correcting All Repairable Defects on Fleet-Average Emissions.

^a Score = HC + NOx + CO/10

To put the estimates contained in Table 2-13 into perspective, it is useful to compare those results with the emission reductions expected in an enhanced I/M program. Based on MOBILE5a, an enhanced I/M program is expected to result in an approximate 35% reduction in HC and CO, and a 13% reduction in NOx. For the most part, the estimates presented in Table 2-13 are greater than the MOBILE5a estimates of enhanced I/M reductions. This is due to three factors: (1) the MOBILE5a enhanced I/M benefits are for the entire on-road fleet, while the results in Table 2-13 are just for light-duty cars and trucks (which would be subject to an enhanced I/M program); (2) the MOBILE5a estimates account for post-repair deterioration; and (3) the MOBILE5a estimates account for post-repair deterioration; and (3) the MOBILE5a estimates account participate in the program.

Another way to look at the results in Table 2-13 is to compare the after-repair emission levels to the emission standards, i.e., are there excess emissions remaining after repairing all of the significant defects. For example, assuming that the vehicles in the Hammond program were certified to 0.41 g/mi HC, 3.4 g/mi CO, and 1.0 g/mi NOx, Table 2-13 indicates that excess emissions remain after repair (i.e., the after-repair values are above the standard), except for NOx in the fuel-injected group. This is shown graphically in Figure 2-2, which shows the baseline and after-repair FTP emission rates (normalized by the emission standards) for the Hammond fuel-injected fleet. Although significant emission reductions occur as a result of repair, HC and CO emissions are still above the emission standards. The only fleet that was consistently below the emission standards after repair is the Phoenix fleet. That is primarily the result of its relatively low baseline (i.e., before-repair) emission rates.

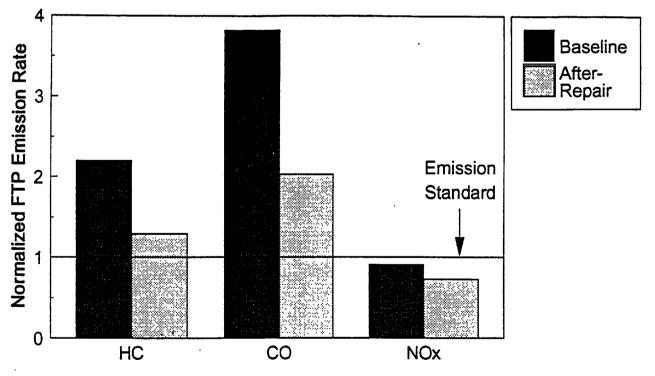


Figure 2-2. The Effect of Repairing Identified Defects in the Hammond Fuel-Injected Fleet Relative to the Emission Standards.

PCV SYSTEM DEFECTS

Although not part of the scope of work for this project, data were available from the EPA "ECOMP" files on the failure rates of PCV systems. Using those failure rates, coupled with an estimate of the emissions increase from PCV failures, it is possible to calculate the impact of PCV failures on fleet-average HC emissions. For the Hammond database, 5.8% of the fuel-injected vehicles were labeled as having defective PCV valve assemblies, and 13.8% of the carbureted vehicles had defective PCV valve assemblies. (These estimates include extrapolation of IM240 pass/fail vehicles to the fleet.) Assuming that a defective PCV valve causes a 1.2 g/mi HC emission increase (the MOBILE5a tampering offset for late-model, light-duty vehicles), the fleet-average HC emission rate would increase by 0.07 g/mi for fuel-injected vehicles and 0.17 g/mi for carbureted vehicles. This represents 8% and 6% of the baseline exhaust HC emission rate for fuel-injected and carbureted vehicles, respectively.

Section 3 REVIEW OF CARB'S OBDII ANALYSIS

In September 1989, the California Air Resources Board adopted regulations requiring more advanced emission control system monitoring capability to be incorporated into on-board diagnostic systems. Those regulations, termed "OBDII," contain specific requirements for monitoring of the catalyst, oxygen sensor, and EGR system, among others. The Technical Support Document prepared for that regulation contained a fairly detailed assessment of the effects of repairing defects in those components (CARB, 1989). However, because the data used to prepare that analysis were from one of CARB's standard in-use surveillance programs, they are subject to the biases normally experienced with surveillance programs (i.e., individuals with intentionally tampered or poorly maintained vehicles may be less likely to offer their vehicles for testing). Additionally, because the data used in CARB's OBDII analyses were collected seven to eight years ago, the 1981 and later model year vehicles were tested at a lower average age relative to the Hammond, Phoenix, and California I/M Pilot Project data sets analyzed in the previous section. Thus, a lower defect rate would be expected. Nonetheless, these data provide a lower bound on the frequency of emission control system component failure in the California fleet, and the after-repair data give an indication of the magnitude of excess emissions resulting from component failure.

The CARB OBDII analysis was limited in scope to three exhaust emission control components because those components were specifically required to be monitored by the OBDII system.^{*} Other components and systems, such as the ignition system, were not evaluated by CARB. Given the significance of other emission control systems in contributing to excessive exhaust emissions (as demonstrated in the previous section),

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^{*} An evaluation of the benefits of monitoring the evaporative emission control system was also included in CARB's OBDII analysis; however, issues related to evaporative emissions were not addressed in this study.

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this is a shortcoming of the OBDII analysis. However, the results obtained using the OBDII database and CARB's methodology provide a cross-check of the results obtained using the regression analysis presented in Section 2.

The discussion below summarizes the data presented by CARB in its evaluation of the emission reduction potential of identifying and repairing defective catalysts, oxygen sensors, and EGR systems.

DATABASE DESCRIPTION AND SUMMARY STATISTICS

The data used in CARB's analysis to support the OBDII regulations came from its ninth light-duty surveillance program. Only 1981 and later model year passenger cars equipped with three-way catalyst systems were used in the evaluation. A total of 494 vehicles were included in the final database - 260 carbureted and 234 fuel-injected. A summary of the baseline emission rates for that fleet is contained in Table 3-1. As shown in the table, the fleet used for the OBDII analysis is a relatively "clean" group of vehicles, particularly when compared to the databases analyzed in Section 2 of this report (see Table 2-1). It is interesting to note, however, that the fuel-injected vehicles in this database and in the California I/M Pilot Project database have nearly the same mean emission levels (the I/M Pilot Project fuel-injected vehicles averaged 0.62 g/mi HC, 9.54 g/mi CO, and 0.94 g/mi NOx). On the other hand, the Pilot Project carbureted vehicles have much higher mean FTP values than those observed in Table 3-1 (the I/M Pilot Project carbureted vehicles averaged 1.92 g/mi HC, 28.60 g/mi CO, and 1.50 g/mi NOx).

Fuel System	Sample Size	Mean Mileage	Mean FTP Emission Rate (g/mi)		
			HC CO NO		NOx
Carbureted	260	57,500	0.78	10.76	0.98
Fuel-Injected	234	51,800	0.64	8.77	0.94

Table 3-1. Baseline FTP Emission Levels of the CARB OBDII Database.

COMPONENT FAILURE RATES

Baseline component failure rates were calculated from data presented in the abovereferenced Technical Support Document. In that report, all vehicles with suspected catalyst failures, oxygen sensor failures, and EGR system failures are tabulated, and each failure is categorized according to whether it would have a high likelihood of detection by an OBDII system, a moderate likelihood of detection, or whether it would be unlikely to be detected by an OBDII system. In general, failures were classified as having a high or moderate likelihood of detection if there was a discernible decrease in emissions as a result of repair. For this analysis, the high and moderate likelihood failures were also considered to be true component failures. The failure rates observed in this fleet of vehicles are summarized in Table 3-2. Because surveillance vehicles are randomly selected, weighting factors to translate the sample results to a fleet basis are not necessary. In fact, as discussed above, surveillance data generally underrepresent the fraction of high emitting vehicles in the fleet. This is particularly evident when comparing the results of Table 3-2 to the CARB I/M Pilot Project database, which, for example, had oxygen sensor failure rates of 24.7% and 13.4% for carbureted and fuel-injected vehicles, respectively.

Fuel System	Component	Number Equipped	Number Fail	Mean Mileage	Failure F	Rate
-					Component	Fleet
Carb.	Catalyst	260	19	76,500	7.3%	7.3%
	O ₂ Sensor	212	10	77,900	4.7%	3.8%
	EGR System	258	17	67,700	6.6%	6.5%
Fuel- Injected	Catalyst	234	7	82,200	3.0%	3.0%
	O ₂ Sensor	234	24	64,100	10.3%	10.3%
	EGR System	178	7	71,000	4.1%	3.8%

Table 3-2.Baseline Component Failure Rates for 1981 and Later Model YearVehicles in the OBDII Database.

EFFECT OF COMPONENT REPAIR

The FTP emission reductions as a result of component repair were calculated in a manner much different than the analysis of the five databases presented in the previous section of this report. For this analysis of the OBDII database, CARB's methodology of classifying vehicles according to emitter regime was extended so that the baseline and after-repair emission results were estimated based on the distribution of vehicles among regimes before and after repair. In this way, the reductions from individual component repairs were calculated. A brief description of that methodology is contained below, followed by a summary of the reductions from repair of individual components and the effect on the fleet-average emission rate of repairing those failing components.

Methodology

The methodology used in CARB's OBDII analysis was based on several models developed to estimate the benefits of inspection and maintenance programs (Sierra, 1991; EPA, 1985). In that approach, vehicles are stratified by emitter category or

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"regime" (i.e., normals, moderates, highs, very highs, and supers), and vehicles migrate among regimes as a result of repair. For each of the vehicles listed as having a high or moderate likelihood of detection by an OBDII system, the before-repair and after-repair emitter categories (for HC, CO, and NOx) were tabulated. In addition, CARB listed the mean emission level of the emitter regimes, so it was possible to construct an estimate of the before- and after-repair mean emission level of those vehicles identified as having emission control system defects.

For vehicles receiving multiple repairs between FTP tests, CARB made a determination as to whether the full benefit of repair should be ascribed to the component repair of interest, or whether only partial benefit should be ascribed (e.g., by assigning the vehicle's after-repair status to one regime higher than it would normally be assigned solely on the basis of its FTP score). That determination was generally based on the results of intermediate Hot-505 test scores. For example, consider a vehicle in the high emitter regime that received an oxygen sensor repair and a fuel-injection system repair between FTPs, and the after-repair FTP placed the vehicle in the normal emitter regime. If intermediate Hot-505 test results indicated that both repairs had a significant effect on emissions, then that vehicle would be placed in the after-repair moderate emitter regime for the purposes of calculating the benefit of the oxygen sensor repair. In this way, CARB attempted to de-couple the effects of multiple repairs. This made it possible in this analysis to estimate the repair effects of individual component repairs by simply comparing the baseline and after-repair emissions calculated from the regime distributions presented by CARB.

Average Emission Reductions from Individual Repairs

Using the methodology described above, average FTP emission reductions from the repair of catalysts, oxygen sensors, and EGR systems were calculated. The results are presented in Table 3-3. For both carbureted and fuel-injected vehicles, catalyst system

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repairs are responsible for the largest FTP reductions. This is different from the results presented in Section 2, which indicated that ECU and oxygen sensor repairs had the greatest FTP reductions for fuel-injected vehicles and fuel system repairs had the greatest FTP reductions for carbureted vehicles. Several factors are likely responsible for these differences, but the one that has the most pronounced influence on the results is the way in which CARB "sequenced" catalyst system repairs when more than one repair was performed on a single vehicle. For example, vehicle 215 had before-repair HC emissions that put it in the super emitter category. After repair, which included an oxygen sensor replacement and an ignition system tune-up, it was in the very high emitter category for HC. A test of the catalyst revealed that it had low activity, so CARB assumed the catalyst benefit for that vehicle to be from the super category down to the high category, or a reduction of 5.14 g/mi (from 6.30 g/mi to 1.16 g/mi). It would have been more appropriate for CARB to assign the vehicle to the very high emitter group before catalyst repair and the moderate level after repair. This would have resulted in a reduction of 1.99 g/mi HC (from 2.58 g/mi to 0.59 g/mi), which is a much more reasonable estimate of the effects of catalyst replacement when other emission control and fuel system components are functioning properly.

Fuel System	Component	FTP Reduction (g/mi)				
		HC	со	NOx	Score ^a	
Carbureted	Catalyst	1.60	21.09	0.99	4.70	
	O ₂ Sensor	0.51	2.22	0.09	0.82	
	EGR System	-0.20	-1.95	1.18	0.79	
Fuel-Injected	Catalyst	0.73	9.40	1.07	2.74	
	O ₂ Sensor	0.59	9.74	0.09	1.65	
	EGR System	0.0	2.23	1.45	1.67	

 Table 3-3.
 Reduction in FTP Emissions as a Result of Repair Based on the CARB OBDII Database.

^a Score = HC + NOx + CO/10

Elect-Average Emission Reductions

The component failure rates in Table 3-2 were combined with the FTP reductions from repair listed in Table 3-3 to estimate the effect of component failure on the fleet-average emission rate. For example, the fuel-injected fleet is estimated to have an oxygen sensor failure rate of 10.3%; repairing those defects results in an average decrease in FTP HC emissions of 0.59 g/mi. Therefore, the overall impact of defective oxygen sensors on the fleet-average HC emission rate of the OBDII fleet is:

HC_{O2 Sensor} = 0.103 * 0.59 g/mi = 0.06 g/mi

Thus, oxygen sensor failures contribute 0.06/0.64 or 9.4% to the fleet-average HC emission rate of the OBDII fuel-injected fleet. The contribution of the remaining component failures to the fleet-average emission rates for HC, CO, NOx, and the weighted FTP "score" is summarized in Table 3-4.

Fuel System	Component	Contrik	oution to Flee	et-Average E	missions
		НС	со	NOx	Score ^a
Carbureted	Catalyst	15.1%	14.3%	7.3%	12.0%
	O ₂ Sensor	2.5%	0.8%	0.0%	1.1%
	EGR System	-1.7%	-1.2%	7.9%	1.8%
Fuel-Injected	Catalyst	3.4%	3.2%	3.4%	3.3%
	O ₂ Sensor	9.4%	11.4%	1.0%	6.9%
	EGR System	0.0%	0.8%	4.6%	2.0%

 Table 3-4.
 Contribution of Defective Components to the OBDII Fleet-Average Emission Rates.

^a Score = HC + NOx + CO/10

Comparing the results in Table 3-4 to the results computed in Section 2 of this report, defective catalysts were estimated to contribute approximately 3% to the fuel-injected vehicle, fleet-average FTP-weighted emission rate (i.e., "score," as defined above) for

both methodologies. In contrast, defective oxygen sensors were estimated to contribute 7% to the fleet-average FTP score using the OBDII database, while the regression 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 focussed on 1981 and later models, 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%).

Although the OBDII database provides an alternative estimate of the effect that catalyst, oxygen sensor, and EGR system failures have on fleet-average emissions, it likely underestimates their impact, and the results in the previous section are more reflective of the effect of component failure on fleet-average emissions.

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Section 4 REVIEW OF EPA AND CARB RECALL DATA

As part of this study, a limited review of EPA and CARB recall data was conducted to estimate the effects of recall actions on fleet-average emissions. EPA data were used to determine the number of vehicles subject to recalls each year, and the CARB data were used to provide a rough estimate of the average emission benefit from a recall repair. The discussion that follows describes the EPA and CARB data from which these estimates were made.

Beginning in 1983, EPA has compiled a list each year of vehicles that are subject to emission control system recall actions. Those lists contain the manufacturer, model year, engine family designation, affected models, the emission problem, and the number of vehicles recalled (based on production volume). A summary of the information contained in the 1994 calendar year recall list is shown in Table 4-1. Several points can be made in reference to the table. First, more than half of the recalls were voluntary, i.e., they were not required as a result of EPA or CARB recall testing. Voluntary recalls are generally initiated by vehicle manufacturers if a specific part or component is found to have a high percentage of warranty claims, or if a problem is found independently by the manufacturer. The effect on emissions of these voluntary recalls is likely to be less than EPA- or CARB-influenced recalls, which are based on the results of emissions testing of vehicles in customer service. Second, the recalled vehicles range in age from new to eight years of age. It is a little surprising that vehicles beyond the five-year/50,000-mile warranty period would be recalled, but these could be vehicles where the defect was identified before the warranty period ended and the resolution (which, for influenced recalls, is usually decided by mutual agreement between the manufacturer and EPA) was protracted. Finally, the most common types of defects and components on the 1994 recall list included oxygen sensors, catalysts, evaporative control systems, and the computer control system.

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F Many 2.	F Many 2:	F Many 23	2.2	Disp (Itr) 2.2L turbo		Family ocr2 5v5faax	ΗC		NOX,	Kecall Reason if not Exhaust Emissions	Number Recalled
F Jeep Wrangler	F Jeep Wrangler	Vrangler	Vrangler	4.2L High		lam4.212hea4		××	×		166,206
F Many	F Many	1	1	2.2L High		jcr2.5v5fbe6		: ×			1,400
	F Grand Cherokee			5.9L 2.21		pcr5.915fey4	-			Spark Plug Spec	3,204 4,855
Chrvsler C Grand Wassnoor E O				0.4L	_	pcr360t5thb2				Spark Plug Spec	
C Dodge Ram	C Dodge Ram			5.2 & 5.9L		lam5.912hlex			,	Carburetor	780
C Jeep many	C Jeep many	many	many	2.5L		kam150t5lad9			<	O Sensor/DCV	13,715
C Jeep many	C Jeep many			2.5L		lam 15015ladx					4,48/
C Jeep Wrangler	C Jeep Wrangler	Vrangler	Vrangler	4.2L		lam258t2hea8	×	×		PCV Solenoid	000,1
ster F Cher, Com, Wran	F Cher, Com, Wran	om, Wran	om, Wran	2.5L		kam2.5t5tad8				O2 Sensor	0.242
				2.0L		jfm2.0t2gmf2	_		×		27,612
				3.0L High	_	jfm3.0v5fegx		×			20,500
F Taurus/Sable 3.0L High	F Taurus/Sable 3.0L High	3.0L HIGN	3.0L HIGN			Kim3.Uv5teg0		×			
F T-bird,Car.XR4T) 2.3L turbo	F T-bird,Car.XR4T) 2.3L turbo	T-bird.Car.XR4T) 2.3L turbo	Car.XR4T) 2.3L turbo			afm2.3v5fnk3		×			
F T-bird,Cgr,XR4Ti 2.31, turbo	F T-bird,Cgr,XR4Ti 2.3L turbo	T-bird,Cgr,XR4TI 2.3L turbo	Cgr,XR4TI 2.3L turbo	urbo	_	nfm2.3v5fgk4		< ×			91,765
F IT-bird,Cgr,XR4TI	F IT-bird,Cgr,XR4TI	T-bird,Cgr,XR4TI	Cgr,XR4TI	2.3L turbo		jfm2.3v5fgk8		×			
T-bird,Cgr,XR4TI	F T-bird,Cgr,XR4TI	T-bird,Cgr,XR4TI	Cgr,XR4TI	2.3L turbo	_	kfm2.3v5fgk9		×			
F/C [16mpo, 10paz [2.3 & 3.0L]	F/C [16mpo, 10paz [2.3 & 3.0L]	1 empo, 1 opaz 2.3 & 3.0 L	2.3 & 3.0L	4 3.0L						Canister Hose	230
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B Lumina FY 3.1L	B Lumina FY 3.1L	Lumina FFV 3.1L	3.1L 3.1L			old3.1m8mphy	•=•	,		Circuit Board	1,265
B Lumina FFV 3.1L	B Lumina FFV 3.1L	Lumina FFV 3.1L	a FFV 3.1L			& p1g3.148mpbx		< ×			403
		LUI 4.3L	4.3L		-					PCV Line Freezes at Low Temp.	1 543
GM B SVT Trucks 4.3L B	B S/T Trucks 4.3L B S/T Trucks 4.3L	S/T Trucks 4.3L	4.3L			s3g4.319gfej	-			Misfire	837
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C Sonata	C Sonata	Sonata		4		Iny Custedo				Catalyst	16,000
lai C Sonata	C Sonata	Sonata		1.0L		lhy3.0v5fca3				Catalyst	
F Geo Storm	F Geo Storm	Geo Storm				lsz1.6v5fcb6		×			FA 734
F Montero 3.5L	F Montero 3.5L	3.5L	3.5L		_	rmt3.58jgaea				Tine-un lahel	102,40
C 3000GT, Stealth 3.0L	C 3000GT, Stealth 3.0L	3000GT, Stealth 3.0L	3.0L		_	mml3.0v5fc17		-		Hinh Evan Emissions	100'1
3.0L	C 3000GT, Stealth 3.0L	3000GT, Stealth 3.0L	3.0L		-	& mmt3.0v5fc28				High Evap Emissions	
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3.0	r 3.000GI, Stealth 3.0L	SUUGI, Stealth 3.0L	3.0		_	& mmt3.0v5ff23				High Evap Emissions	10010
			sta Eagle Summit [1.8L		<u> </u>	nm11.8v5ff45				Tune-up Label	24.458
			star Eagle Summit 1.8L		⊆	nmt1.8v5fc4x				Tune-up Label	
			sta, cagle Summit 1.8L		-	pmt1.8v5ff47				Tune-up Label	
		Colt Vista, Eagle Summit	sta, cagle summit	ਲ <u>਼</u> ;		pmt1.8v5fc41	_			Tune-up Label	
				10.1		lsk1.0v5ffc2		×		•	3.827
			33			rad2.8v8gfea				Tune-up Label	1.599
			2	8		rad2.8v8gbea				Tune-up Label	
				4	-	W/ Ahotes					

I = Influenced - Voluntary recall after EPA investigation.
 V = Voluntary - Voluntary recall without EPA investigation.

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To prepare an estimate of the direct effect of recalls on fleet-average emissions, it was first necessary to determine the total number of vehicles subject to recall. The recall lists from 1983 to 1994 were obtained from EPA, and the total number of vehicles recalled each calendar year was compiled. The results are shown in Table 4-2. Because it was desired to estimate the total VMT from those vehicles in 1995, several assumptions had to be made regarding the number left in the fleet in 1995 and their annual mileage accumulation rates. Although the age at which vehicles are recalled varies widely, this analysis assumed that, on average, vehicles were recalled at three years of age. (This is the timeframe when recall testing is normally conducted by EPA and CARB.) Thus, if the vehicles recalled in 1994 were three years old, there would be 96.4% of their original numbers remaining in the fleet, based on EPA's scrappage curve used in the MOBILE5a dynamic registration preprocessor (EPA, 1994). Similarly, vehicles recalled during 1993 were assumed to be four years old, and 94.5% of those were assumed to still be in the fleet. This calculation continued for all vehicles recalled back to the 1983 calendar year, and the results are also contained in Table 4-2. To determine the average mileage driven by recalled vehicles in 1995, the MOBILE5a annual mileage accumulation rates (which are a function of age) were applied to the remaining vehicles.

Recall	Vehicles	Fraction	Total	Average	
Year	Recalled	Remaining	Remaining	Annual VMT	Total VMT
1983	2,751,660	0.412	1,133,684	6,987	7.92E+09
1984	2,076,190	0.481	998,647	7,386	7.38E+09
1985	2,140,520	0.553	1,183,708	7,807	9.24E+09
1986	1,561,540	0.625	975,963	8,254	8.06E+09
1987	3,170,847	0.693	2,197,397	8,726	1.92E+10
1988	3,383,642	0.755	2,554,650	9,225	2.36E+10
1989	4,921,810	0.809	3,981,744	9,751	3.88E+10
1990	2,615,493	0.855	2,236,247	10,310	2.31E+10
1991	2,326,339	0.893	2,077,421	10,899	2.26E+10
1992	2,979,176	0.923	2,749,779	11,552	3.18E+10
1993	2,013,315	0.945	1,902,583	12,180	2.32E+10
1994	552,788	0.964	532,888	12,875	6.86E+09
Total:	30,493,320		22,524,709		2.22E+11

 Table 4-2.
 Number of Vehicles Subject to EPA Recall Action by Calendar Year (Including Voluntary Recalls).

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Summing across all recall calendar years, the total VMT driven by recalled vehicles in 1995 was estimated to be 2.2×10^{11} miles. However, this is an optimistic assessment because it assumes that recall repairs were performed on all vehicles.

The total mileage driven by the U.S. fleet was estimated by assuming a fleet-average annual mileage accumulation rate of 10,000 miles, and a light-duty fleet population of 176 million (based on 1993 and 1994 issues of AAMA Facts & Figures). The fraction of VMT traveled by recalled vehicles in 1995 was then calculated as $2.2 \times 10^{11}/(176 \text{ million} * 10,000) = 12.5\%$.

To determine the change in emissions from a typical recall action, the mean excess emission rates (i.e., the tested FTP value minus the certification standard) from 65 CARB recall tests were used. Those tests were conducted from 1983 to 1993 and covered model years from 1980 to 1991 (CARB, 1995). The results of that analysis yielded average excess emissions of 0.13 g/mi HC, 2.54 g/mi CO, and 0.19 g/mi NOx. Although those numbers at first appear low, it should be recognized that not all recalls are strictly for tailpipe emissions. Vehicles can be recalled for things such as incorrect information on tune-up labels, evaporative control system defects, etc. Also, not every emissions-related recall affects all three pollutants. Finally, those estimates are likely conservative (i.e., high) because they represent only vehicles that were subject to an influenced recall. As discussed above, voluntary recalls make up over half of the recall actions, and the effect on emissions of those recalls could be less than for an influenced recall because the recalled components do not necessarily result in vehicles exceeding emission standards. Unfortunately, emissions data on voluntary recalls were not identified in this project.

To determine the fleet-average baseline emission rate, the MOBILE5a model was run for January 1, 1995, under a "basic" I/M scenario at 750F. This resulted in light-duty

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gasoline vehicle emission rates of 1.22 g/mi HC, 14.8 g/mi CO, and 1.61 g/mi NOx. Assuming that (1) all vehicles subject to recall get repaired, (2) a recall repair results in a constant offset in emissions over the remaining life of the vehicle, and (3) the excess emissions calculated above are a reasonable representation of the benefit of a recall repair, the overall impact of those repairs on the fleet-average HC emission rate is:

Performing the same calculation for the other pollutants results in recall actions accounting for 2.1% of fleet-average CO emissions and 1.5% of fleet-average NOx emissions.

These results indicate that the direct impact of recalls on fleet-average emissions is very small. Since vehicles selected for recall testing are well-maintained vehicles with less than 50,000 miles, this indicates 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%.

The contribution to the fleet-average weighted FTP "score" of recall repairs versus nonrecall repairs (discussed in Section 2 of this report) is illustrated in Figure 4-1 for the Hammond database (carbureted and fuel-injected vehicles combined). The emission levels have been normalized by the emission standard to which these vehicles were certified (i.e., 0.41 g/mi HC + 1.0 g/mi NOx + 3.4 g/mi CO/10), which is also shown in the figure. Figure 4-1 indicates that recall actions have a small impact on fleet-average emissions, but if all identifiable defects are repaired, emissions are within 25% of the certification standard. The level of emissions remaining above the standards may be

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attributable to general aging and deterioration of emission control components that would not necessarily be positively identified as a defect.

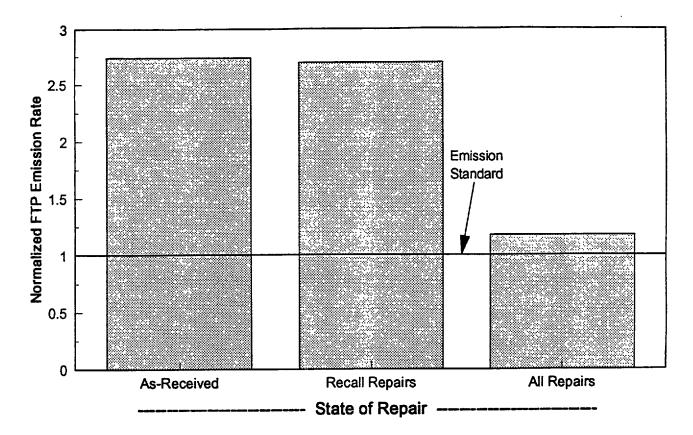


Figure 4-1. Contribution of Repairable Defects Relative to the Fleet-Average Emission Standard (HC + NOx + CO/10) for the Hammond Database.

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Appendix A

REGRESSION RESULTS FOR ANALYSIS OF FTP REDUCTIONS FROM REPAIRS

Components included in the regression variables (see the table on the next page for the system and component codes) were:

COM1 - Carburetor replacement/rebuild (system 2, component 2)

COM2 - Fuel metering system repairs for carbureted vehicles (system 2, components 2-25; system 11, component 9)

COM3 - Fuel injector replacement (system 3, component 3)

COM4 - Fuel metering system repairs for fuel-injected vehicles (system 3, components 2, 6-43; system 11, component 9)

COM5 - Ignition system tune-up repairs (system 4, components 2-3, 5-6)

IGN2 - Other ignition system repairs (system 4, components 4, 7-23)

COM6 - EGR system repairs (system 5, components 2-14)

COM7 - Air injection system repairs (system 8, components 2-15)

COM8 - Catalyst replacement (system 9, components 3-7)

COM9 - ECU replacement (system 10, component 2)

COM10 - Oxygen sensor replacement (system 11, component 2)

SENS2 - Other sensor replacement/repair (system 11, components 10-21)

A-1

Table A-1. System and Component Codes Used to Standardize Repair Data from the CTP, Hammond, Phoenix, CARBFI, and California I/M Pilot Project Databases.

1 Air Induction 2 air door

- 3 aur filter
- 4 air cleaner housing ach
- 5 cold air duct
- 6 hot air duct
- 7 intake manifold
- 8 turbocharger to
- 9 charge air cooler cac
- 10 supercharger sc
- 11 sensor / switch / solenoid 12 hoses / vacuum lines
- 13 gasket / seal 14 wire / hamess / fuse
- 15 other
- 2 Carburation
 - 2 carburetor assembly
 - 3 idle moture adj. limiting device
 - 4 idle moture
 - 5 idle speed 6 idle speed control isc
 - 7 throttle/throttle controls
 - 8 throttle position sensor tps
 - 9 mixture control solenoid mcs
 - 10 mixture control solenoid mcs, cmds
 - 11 choke adjustment (notches)
 - 12 choke adjustment (vacuum break)
 - 13 choke adjustment limiting device 14 choke heater
 - 15 choke (misc.)
 - 16 early fuel evaporation efe (electric)
 - 17 engine coolant temp, sensor acts
 - 18 intake air temperature sensor iats
 - 19 vacuum diaphragms
- 20 fuel pump
- 21 fuel filter 22 hoses
- 23 gasket / seal 24 wire / barness / fuse
- 25 other

3 Fuel-Injection

- 2 air flow sensor
- 3 injector(s)
- 4 diesel injector(s) 5 diesel fuel supply pump
- 6 throttle body tb
- 7 throttle controls
- 8 throttle position sensor tos
- 9 fuel pump
- 10 fuel filter
- 11 fuel distributor
- 12 fuel pressure regulator
- 13 fuel delivery/return line
- 14 fuel pump relay fpr
- 15 diesel fuel injection pump 16 diesel fuel heater
- 17 diesel speed governor
- 18 diesel smoke puff limiter spl
- 19 diesel glow plugs
- 20 diesel water separator 21 inertia fuel shutoff switch ifss
- 22 idle speed control isc
- 23 idle air control valve iacv
- 24 Jacv hoses 25 cold start valve
- 26 early fuel evaporation efe (electrical)
- 27 engine coolant temp. sensor ects
- 28 cam position sensor (smpi)
- 29 cranicshaft position sensor cps
- 30 manifold surface temp. sensor msts 31 intake air temperature sensor - iats
- 32 diesel fast idle solenoid
- 33 diesel cold start solenoid
- 34 diesel altitude control solenoid
- 35 hoses

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3 Fuel-Injection (Continued)

- 38 hoses (air flow sensor & throttle body)
- 37 hoses (vac hoses, pressure regulator, ect)

8 Secondary Air Injection (Continued)

4 secondary air bypess velve - sabv

5 secondary air anti-backfire valve - sabiy 6 secondary air anti-backfire valve - sabfv

7 secondary air switching valve - sasv

8 secondary air pulse valve - sapv

3 warm-up codation catalyst - wuoc

8 trap oxidizer, continuous - toc

2 powertrain control module - pome

5 barometric absolute pressure sensor

9 manifold air pressure sensor - map 10 manifold vacuum sensor - mvs 11 manifold vacuum zone switch - mvzs

15 cylinder chamber temperature sensor

19 wire / harness / fuse / vacuum line

2 malfunction indicator light - mil

5 diagnostic trouble codes - dtc

7 data link connector - dic 8 wire / harness / fuse

12 wide open throttle switch - wots

16 catalyst temperature sensor

17 thermal vacuum switch - tvs

18 vehicle speed sensor - vss

7 engine coolant temperature sensor - ects

3 powertrain control module (trans) - pcmt

9 trap oxidoxer, penodic - top

4 body control module - born

6 coolant level sensor - cols

8 fuel temperature sensor

13 engine speed sensor 14 torque sensor

20 gasket / seal

12 On-Board Diagnostics

4 obd system

13 Engine/Exhaust

2 engine block

7 belt tension 6 exhaust manifold

10 mufflers

12 tailpipe

3 cooling system

4 coolant fan control 5 intake/exhaust valves

6 audiliary vacuum pump

16 vacuum lines (general)

9 early fuel evaporation - efe (heat nser)

13 other 14 cylinder compression pressure (psi - xxx.)

11 exhaust port liner/double walled pipe

15 cylinder leak down (percent - xx.x)

3 mil bulb check

6. service reminder

21 other

4 warm-up three way catalyst - wutwo

10 upstream injection tube(s)

12 hoses / vacuum lines

14 wire / hamess / fuse

9 Exhaust After-Treatment

5 condition catalyst - oc

6 three way catalyst

7 three way catalyst

2 thermal reactor

11 downstream injection tube(s)

9 drive belt

13 gasket / seal

15 other

10 Engine Control

11 Sensor/Solenoid/Valve

2 oxygen sensor - c2s

3 oxygen sensor - o2s 4 air conditioner sensor - acs

- 38 gasket / seal
- 39 wire / harness / fuse
- 40 other
- 41 Idle CO
- 42 idle speed
- 43 aux air regulator

4 Ignition

- 2 distributor assembly (cap & rotor)
- 3 ignition traing
- 4 ignition timing limiting device
- 5 spark plugs and / or wires
- 6 spark plugs and / or wres
- 7 breakerless pickup (all types)
- 8 ignition module
- 9 spark timing control module
- 10 col/col pack
- 11 dweli / points
- 12 vacuum advance assembly
- 13 spark delay devices
- 14 knock sensors ks
- 15 engine speed sensor
- 16 camshaft position sensor
- 17 crankshaft position sensor cps
- 18 engine coolant temperature sensor ects
- 19 thermal vacuum switch Ms.
- 20 hoses

2 egr valve assembly

7 delay solenoid/valve

12 boses / vacuum lines 13 wre/hamess/fuse

2 pcv valve or onfice

6 wire / harness / fuse 7 other

4 canister purge solenoid / valve

8 fuel line (supply/return)

13 hoses / vacuum lines

15 wre / harness / fuse

2 secondary air injection filter

3 secondary air injection pump

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Not for Resale

8 vacuum amplifier

9 vacuum reservoir

5 egr function sensor - egrs

6 ear function control - earc

11 thermal vacuum switch - tvs

10 engine coolant temperature sensor - ects

4 egr spacer plate

21 gasket / seal 22 wire / hamess / fuse

23 other

3 egr filter

14 other

3 pcv filter

5 hoses

4 oil filler cap

7 Evaporative Control

5 fuel filler cap

6 fuel restrictor

9 vapor separator 10 pressure relief valve

11 rollover valve 12 anti siphon valve

14 gasket/seal

8 Secondary Air Injection

16 other

7 fuel tank

2 canister 3 canister filter

6 PCV

5 EGR

		1981+ CARSU	RETED VEH	ICLES - OK DIAG	NOSTICS - ALL SITE	S CONBINED	15:02	Tuesday, May 2, 199
		Backward E	liminatio	n Procedure for	Dependent Variabl	e R_HC		
Step 0	All Variables Entered	R-square	= 0.28197	7841 C(p) = 10	.00000000	-		
		DF		Sum of Squares	Mean Square	F	Prob>F	
	Regro	ession 10 r 314		1118.31162403 2847.63607597	111.83116240 9.06890470	12.33	0.0001	
	Tota			3965.94770000				
			rameter	Standard	Type 11			
	Varia	able E	stimate	Error	Sum of Squares	F	Prob>f	
	CON1		6282904	0.45126060	19,56604584	2.16	0.1429	
	COH2		7891116	0.32600452	162,24830751	17.89 7.14	0.0001	
	CONS		0097783 2549988	0.37454840 0.39263682	64.77208296 0.03825154	0.00	0.9483	
	CON7		4393537	0.39565955	1.20018055	0.13	0.7163	
	COHS		5710408	0.39901388	41.84522924	4.61	0.0325	
	COK9		4598952	0.64301855	59.42401044	6.55	0.0109	
	CON10		7853236	0.39635141	26.57878720	2.93	0.0879	
	I GN2 SENS		5519954 3302377	0.72718406 0.68919882	19.09568866 5.42449024	2.11 0.60	0.1478 0.4399	
					21-12			
Bounds o	on condition number:	1.825337,	131.6381					
		-						
Step 1	Variable COM6 Removed	R-square :	= 0.28196	876 C(p) = 8	.00421788			
		DF		Sum of Squares	Mean Square	F	Prob>F	
	Regro	ession 9		1118.27337249	124.25259694	13.74	0.0001	
	Erro			2847.67432751	9.04023596			
	Total	L 324		3965.94770000				
			rameter	Standard	Type II	_		
	Varia	sble E	stimate	Error	Sum of Squares	F	Prob>F	
	CONT		5897726	0.44663862	19.67922931	2.18	0.1411	
	COH2		7487048	0.31950633	167.39573894	18.52	0.0001	
	CONS CON7		9782623	0.37080399	65.46373872 1.25957627	7.24 0.14	0.0075 0.7092	
	CONS		4663683 5614640	0.39284454 0.39811056	41.80887096	4.62	0.0323	
	CON9	1.6	4231072	0.63950553	59.62135151	6.60	0.0107	
	CON9 CON10		4231072 7506678	0.63950553 0.39212163	26.79363562	6.60 2.96	0.0861	
	CON10 IGN2	0 0.6 -1.0	7506678 5754563	0.39212163 0.72513736	26.79363562 19.22814676	6.60 2.96 2.13	0.0861 0.1457	
	CON10	0 0.6 -1.0	7506678	0.39212163	26.79363562	6.60 2.96	0.0861	
lounds o	CON10 IGN2	0 0.6 -1.0	7506678 5754563	0.39212163 0.72513736 0.67914383	26.79363562 19.22814676	6.60 2.96 2.13	0.0861 0.1457	
	CON10 IGN2 SENS2 N condition number:	0 0.6 -1.0 2 0.5 1.794697,	7506678 5754563 2582217 103.3038	0.39212163 0.72513736 0.67914383	26.79363562 19.22814676 5.41918575	6.60 2.96 2.13	0.0861 0.1457	
	CON10 IGN2 SENS2	0 0.6 -1.0 2 0.5 1.794697, R-square :	7506678 5754563 2582217 103.3038 	0.39212163 0.72513736 0.67914383 117 C(p) = 6.	26.79363562 19.22814676 5.41918575 	6.60 2.96 2.13 0.60	0.0861 0.1457	
	CON10 IGN2 SENS2 Wariable CON7 Removed	0 0.6 -1.0 2 0.5 1.794697, R-square • DF	7506678 5754563 2582217 103.3038 	0.39212163 0.72513736 0.67914383 117 C(p) = 6. Sum of Squares	26.79363562 19.22814676 5.41918575 	6.60 2.96 2.13 0.60 F	0.0861 0.1457 0.4394 Prob>F	
	COM16 IGN2 SENS2 M condition number: Variable COM7 Removed Regre	0 0.6 -1.0 2 0.5 1.794697, R-square • DF ession 8	7506678 5754563 2582217 103.3038 • 0.28165	0.39212163 0.72513736 0.67914383 1117 C(p) = 6. Sum of Squares 1117.01379622	26.79363562 19.22814676 5.41918575 	6.60 2.96 2.13 0.60	0.0861 0.1457 0.4394 Prob>F	
	CON10 IGN2 SENS2 Wariable CON7 Removed	0 0.6 -1.0 2 0.5 1.794697, R-square = DF ession 8 r 316	7506678 5754563 2582217 103.3038 - 0.28165	0.39212163 0.72513736 0.67914383 117 C(p) = 6. Sum of Squares	26.79363562 19.22814676 5.41918575 	6.60 2.96 2.13 0.60 F	0.0861 0.1457 0.4394 Prob>F	
	COM1 IGN2 SENS2 Wi condition number: Variable COM7 Removed Regre Error	0 0.6 -1.0 2 0.5 1.794697, R-square - DF ession 8 r 316 1 324	7506678 5754563 2582217 103.3038 - 0.28165	0.39212163 0.72513736 0.67914383 117 C(p) = 6. Sum of Squares 1117.01379622 2848.93390378	26.79363562 19.22814676 5.41918575 	6.60 2.96 2.13 0.60 F	0.0861 0.1457 0.4394 Prob>F	
	COM1 IGN2 SENS2 Wi condition number: Variable COM7 Removed Regre Error	0 0.6 -1.0 2 0.5 1.794697, R-square • DF ession 8 r 316 1 324 Pai	7506678 5754563 2582217 103.3038 0.28165	0.39212163 0.72513736 0.67914383 117 C(p) = 6. Sum of Squares 1117.01379622 2848.93390378 3965.94770000	26.79363562 19.22814676 5.41918575 	6.60 2.96 2.13 0.60 F 15.49	0.0861 0.1457 0.4394 Prob>F	
	COM1 IGN2 SENS2 Wr condition number: Variable COM7 Removed Regre Error Total	0 0.6 -1.0 2 0.5 1.794697, R-square • DF ession 8 r 316 1 324 Pai uble Es	7506678 5754563 2582217 103.3038 • 0.28165	0.39212163 0.72513736 0.67914383 117 C(p) = 6. Sum of Squares 1117.01379622 2848.93390378 3965.94770000 Standard Error 0.44090638	26.79363562 19.22816676 5.41918575 .14310745 Nean Square 139.62672453 9.01561362 Type II	6.60 2.96 2.13 0.60 F 15.49	0.0861 0.1457 0.4394 Prob>F 0.0001 Prob>F 0.1516	
	CON1C IGN2 SENS2 Variable CON7 Removed Regre Error Total Varia	0 0.6 -1.0 2 0.5 1.794697, R-square • DF ession 8 r 316 1 324 uble Er 0.63 1.37	7506678 7754563 2582217 103.3038 	0.39212163 0.72513736 0.67914383 117 C(p) = 6. Sum of Squares 1117.01379622 284.9.93390378 3965.94770000 Standard Error 0.44090638 0.31894498	26.79363562 19.22816676 5.41918575 	6.60 2.96 2.13 0.60 F 15.49 F 2.07 18.49	0.0861 0.1457 0.4394 Prob>F 0.0001 Prob>F 0.1516 0.0001	
	COM16 IGN2 SENS2 Wariable COM7 Removed Regre Error Total Varia COM1 COM2 COM2 COM2 COM2	0 0.6 -1.0 2 0.5 1.794697, R-square 1 DF ession 8 r 316 L 324 Pai able Ei 0.6 1.3 0.90	7506678 7754563 2582217 103.3038 	0.39212163 0.72513736 0.67914383 117 C(p) = 6. Sum of Squares 1117.01379622 2848.93390378 3965.94770000 Standard Error 0.44090638 0.31896498 0.36813288	26.79363562 19.22814676 5.41918575 	6.60 2.96 2.13 0.60 F 15.49 F 2.07 18.49 7.13	0.0861 0.1457 0.4394 Prob>F 0.0001 Prob>F 0.1516 0.0001 0.0080	
	COM1 IGN2 SENS2 Wricondition number: Variable COM7 Removed Regre Error Total Varia COM1 COM2 COM2 COM2	0 0.6 -1.0 2 0.5 1.794697, R-square • DF ession 8 r 316 L 324 pai able Ei 0.6 1.3 0.94 0.6 0.6	7506678 575563 2582217 103.3038 • 0.28165 • 0.	0.39212163 0.72513736 0.67914383 117 C(p) = 6. Sum of Squares 1117.01379622 2848.93390378 3965.94770000 Standard Error 0.44090638 0.31894498 0.31894498 0.34813288 0.36813288	26.79363562 19.22814676 5.41918575 	6.60 2.96 2.13 0.60 F 15.49 F 2.07 18.49 7.13 4.54	0.0861 0.1457 0.4394 Prob>F 0.0001 Prob>F 0.1516 0.0001 0.0080 0.0339	
	COM16 IGN2 SENS2 Wariable COM7 Removed Regre Error Total Varia COM1 COM2 COM2 COM2 COM2	0 0.6 -1.0 2 0.5 1.794697, 	7506678 7754563 2582217 103.3038 	0.39212163 0.72513736 0.67914383 117 C(p) = 6. Sum of Squares 1117.01379622 284.9.93390378 3965.94770000 Standard Error 0.44090638 0.31894498 0.36813288 0.36813288 0.33629953 0.62905200	26.79363562 19.22814676 5.41918575 	6.60 2.96 2.13 0.60 F 15.49 F 2.07 18.49 7.13	0.0861 0.1457 0.4394 Prob>F 0.0001 Prob>F 0.1516 0.0001 0.0080 0.0339	
	CON1 IGN2 SENS2 Variable CON7 Removed Regre Error Total Varia CON1 CON2 CON9 CON9 CON9 CON9 CON9 CON9 CON9 CON9	0 0.6 -1.0 2 0.5 1.794697, R-square = DF ession 8 T 316 L 324 Pai able Ei 0.6 1.3 0.9 0.6 1.3 0.9 0.6 1.3 0.9 0.6 1.3 0.9 0.6 1.3 0.9 0.6 1.3 0.9 0.6 1.3 0.9 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6	7506678 575563 2582217 103.3038 • 0.28165 • 0.	0.39212163 0.72513736 0.67914383 117 C(p) = 6. Sum of Squares 1117.01379622 2848.93390378 3965.94770000 Standard Error 0.44090638 0.31894498 0.36813288 0.36813288 0.3689533 0.62905200 0.38942657 0.71960156	26.79363562 19.22816676 5.41918575 Nean Square 139.62672653 9.01561362 Type II Sum of Squares 18.62859245 166.71242381 64.26664765 40.91912644 58.4073381 25.87337193 20.60321909	6.60 2.96 2.13 0.60 F 15.49 F 2.07 18.49 7.13 4.54 6.48 2.87 2.29	0.0861 0.1457 0.4394 Prob>F 0.0001 Prob>F 0.1516 0.0001 0.0339 0.0114 0.0912 0.1316	
	CON10 IGN2 SENS2 Variable CON7 Removed Regre Error Total Varia CON1 CON2 CON3 CON9 CON9 CON9 CON9 CON9 CON9 CON9 CON9	0 0.6 -1.0 2 0.5 1.794697, R-square = DF ession 8 T 316 L 324 Pai able Ei 0.6 1.3 0.9 0.6 1.3 0.9 0.6 1.3 0.9 0.6 1.3 0.9 0.6 1.3 0.9 0.6 1.3 0.9 0.6 1.3 0.9 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6	7506678 7754563 2582217 103.3038 	0.39212163 0.72513736 0.67914383 117 C(p) = 6. Sum of Squares 1117.01379622 2848.93390378 3965.94770000 Standard Error 0.44090638 0.31894498 0.36813288 0.39629533 0.62905200 0.33942657	26.79363562 19.22814676 5.41918575 Nean Square 139.62672453 9.01561362 Type II Sum of Squares 18.62859245 166.71242381 64.26664765 40.91912644 58.40733381 25.87337193	6.60 2.96 2.13 0.60 F 15.49 F 2.07 18.49 7.13 4.54 6.48 2.87 2.29	0.0861 0.1457 0.4394 Prob>F 0.0001 Prob>F 0.1516 0.0001 0.0080 0.0339 0.0114 0.0912	
Step 2	CON10 IGN2 SENS2 Variable CON7 Removed Regre Error Total Varia CON1 CON2 CON3 CON3 CON4 CON4 CON4 CON4 CON4 CON4 CON4 CON4	0 0.6 -1.0 2 0.5 1.794697, R-square = DF ession 8 1 316 1 324 Pan able Es 0.63 1.37 0.94 0.84 1.45 0.65 1.45 0.65	7506678 575563 2582217 103.3038 • 0.28165 • 0.	0.39212163 0.72513736 0.67914383 117 C(p) = 6. Sum of Squares 1117.01379622 2848.93390378 3965.94770000 Standard Error 0.44090638 0.31894498 0.36813288 0.33629953 0.62965200 0.38942657 0.71960156 0.67766015	26.79363562 19.22816676 5.41918575 Nean Square 139.62672653 9.01561362 Type II Sum of Squares 18.62859245 166.71242381 64.26664765 40.91912644 58.4073381 25.87337193 20.60321909	6.60 2.96 2.13 0.60 F 15.49 F 2.07 18.49 7.13 4.54 6.48 2.87 2.29	0.0861 0.1457 0.4394 Prob>F 0.0001 Prob>F 0.1516 0.0001 0.0339 0.0114 0.0912 0.1316	

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Γ

1981+ CARBURETED VEHICLES - OK DIAGNOSTICS - ALL SITES COMBINED 15:02 Tuesday, May 2, 1995 R-square = 0.28033549 C(p) = 4.71846820 Step 3 Variable SENS2 Removed DF Sum of Squares Nean Square F Prob>F 7 1111.79590438 158.82798634 Regression 17.64 0.0001 2854.15179562 Frror 317 9.00363342 3965.94770000 Total 324 Standard Parameter Type II Variable Estimate Error Sum of Squares F Prob>F 0.61684310 0.44005126 17.69133821 COH1 1.96 0.1620 COK2 1.39770912 0.31687099 175.18077100 19.46 0.0001 7.79 CONS 0.36486897 70.18173159 41.31599564 0.0056 1.01868535 0.39600111 0.0329 COM8 0.84829443 COH9 1.60101543 0.62863390 58.40005319 6.49 0.0113 COH10 0.38746921 3.15 0.68736142 28.33438018 0.0770 -1.04586813 0.71700742 19.15686158 0.1456 IGN2 2.13 Bounds on condition number: 1.744769. 62.46968 R-square = 0.27587468 C(p) = 4.66923721 Step 4 Variable COM1 Removed DF Sum of Squares Mean Square F Prob>F 6 1094.10456617 182.35076103 20.19 0.0001 Regression Error 318 2871.84313383 3965.94770000 9.03095325 Total 324 Parameter Standard Type II Sum of Squares Variable Estimate Error F Prob>F 174.07388362 COM2 1.39321506 0.31733513 19.28 0.0001 1.14387792 0.35430577 0.39659949 94.13182889 41.48676041 10.42 0.0014 COH5 CON8 COH9 1.62098386 0.62942524 0.38749912 59.89666784 6.63 0.0105 COH10 0.71646459 30.87319739 0.0654 I GN2 -0.98618422 0.71682717 17.09309791 1.89 0.1699 Bounds on condition number: 1.64023. 46.02912 -----Step 5 Variable IGN2 Removed R-square = 0.27156472 C(p) = 4.55404011 DF Sum of Squares Mean Square F Prob>F 1077.01146827 215.40229365 0.0001 Regression 23.78 2888.93623173 Error 319 9.05622643 3965.94770000 Total 324 Parameter Standard Type II Variable Sum of Squares F Prob>F Estimate Error 17.71 COH2 1.31617203 0.31279162 160.34756820 0.0001 87.59282892 COHS 1.09867808 0.35327249 9.67 0.0020 CON8 0.84646850 0.39714553 41.14049547 4.54 0.0338 1.64558701 61.77854941 COH9 0.63005090 6.82 0.0094 COH10 0.72425488 0.38799952 31.55496934 3.48 0.0629 Bounds on condition number: 1.626127, 32,64309 All variables left in the model are significant at the 0.1000 level. Summary of Backward Elimination Procedure for Dependent Variable R_HC Variable Number Partial Model R##Z Step Removed In R**2 C(p) F Prob>F Label COH6 9 0.0000 0.2820 8.0042 0.0042 0.9483 EGR 6.1431 4.7185 0.7092 CON7 SENS2 8 7 0.0003 0.2817 0.1393 SECOND AIR 23 0.0013 0.5788 0.4474 4.6692 0.0045 0.2759 1.0640 0.1620 CARB RPL/RBLD COH1 6 5 0.0043 1.8927 0.1699 5 IGN2 0.2716

A-4

15:02 Tuesday, May 2, 1995 1981+ CARBURETED VEHICLES - OK DIAGNOSTICS - ALL SITES COMBINED Backward Elimination Procedure for Dependent Variable R CO Step 0 All Variables Entered R-square = 0.44871048 C(p) = 10.0000000 F Prob>F DF Sum of Squares Nean Square Regression 10 303165.75713329 30316.57571333 25.56 0.0001 1186.21668015 Error 314 372472.03756671 Total 324 675637.79470000 Parameter Standard Type 11 Variable Sum of Squares Estimate Error F Prob>F COH1 21.06603200 5.16097802 19763.57409824 0.0001 16.66 3.72844904 4.28363579 COH2 19.90441296 33806.97801877 28.50 0.0001 6.23135527 CONS 2510 17485371 2.12 0 1448 COH6 -4.24585148 4.49050948 1060,47977374 0.3451 COH7 COH8 8.89808350 5.80636667 4.52507982 4586.74389028 1920.38249930 3.87 0.0501 1.62 34.02746927 COH9 7.35407575 25396.10592226 21.41 0.0001 COH10 17.98271105 4.53299246 18668.28251181 15.74 0.0001 0.7818 IGNZ -2.30556978 8.31665996 91,16385475 0.08 SENS2 13.75331911 7.88223032 3611.44349585 0.0820 3.04 Bounds on condition number: 1.825337, 131.6381 R-square = 0.44857555 C(p) = 8.07685262 Step 1 Variable IGH2 Removed **DF** Sum of Squares Nean Square F Prob>F Regression 9 303074.59327854 33674.95480873 28.47 0.0001 315 372563,20142146 675637,79470000 Error 1182,74032197 Total 324 Parameter Standard Type II Variable Sum of Squares Estimate F Prob>F Error 19690.12111804 COH1 21.01165938 5.14968731 16.65 0.0001 34048.46993310 2472.47576661 3.68085845 28.79 COH2 19.74936859 0.0001 COHS 6.17818280 4.27306436 2.09 0.1492 4.47838858 1094.29713878 CON6 -4.30769260 0.93 0.3368 COH7 8.76521787 4.49302894 4501.28386910 3.81 0.0520 1925.04530605 25626.23472246 1.63 21.67 COM8 5.81332361 4.55668202 0.2030 COH9 34.13431712 7.33319985 0.0001 COH10 18.03616102 4.52224914 18813.45854579 15.91 0.0001 SENS2 13.61661837 7.85525518 3553.91747186 3.00 0.0840 Bounds on condition number: 1.821677, 107.8856 Step 2 Variable CON6 Removed R-square = 0.44695590 C(p) = 6.99936294 DF Sum of Squares Mean Souare F Prob>f 301980.29613976 37747.53701747 31.92 0.0001 Regression 8 316 373657.49856024 1182,46043848 Error Total 324 675637,79470000 Parameter Standard Type 11 Sum of Squares Variable Prob>f Estimate Error £ CON1 20.34999922 5.10293429 18805.09197011 15.90 0.0001 20102 19.03837130 3.60544977 32970.63453563 2093.57474975 27.88 0.0001 5.63530344 4.23512643 0.1843 CON5 4.46465806 4.55306865 7.30534907 COH7 8.28483444 4071.71978363 3.44 0.0644 CONS 5.65234064 1.54 0.2154 1822.36294153 33.52973391 24909.49301835 17944.08485574 21.07 COH9 00110 17.45848344 4.48166271 15.18 0.0001 12.37348671 3016.27431339 SENS2 7.74729313 2.55 0.1112 Bounds on condition number: 1.789897, 82.40099

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T 1	Wastable cout (VEHICLES - OK DIA		SITES COMBINED	10:02	Tuesday, May	2, 1995
Step 5	Variable COM8 8	lemoved	R-square = 0.444 DF	425865 C(p) =					
		Permentia		Sum of Squares			Prob>f		
		Regressio Error Total	317 324	300157.93319823 375479.86150177 675637.79470000	1184.4790583		0.0001		
		Variable	Parameter Estimate				Prob>F		
		COH1 COH2	20.29628701	3.59529425	34563.3708607	75 29.18	0.0001		
		COH5 COH7	5.79968731 8.72774871				0.1720 0.0509		
		COH9	34.30396756	7.28488955	26264.5612029	22.17	0.0001		
		COM10 SENS2	17.80610172 12.46745230		18738.9246150 3062.5524137		0.0001 0.1088		
	condition numb		8148, 64.377	02					
	ariable COM5 R		-square = 0.440	197336 C(p) = (5.40685983				
			DF	Sum of Squares	Mean Squar	e F	Prob>F		
		Regression Error Total	n 6 318 324	297938.26649142 377699.52820858 675637.79470000			0.0001		
		Variable	Parameter Estimate				Prob>F		
		CON1	21.91139426		23032.3052532				
		COH2 COH7	21.29614414 9.44473185		48612.6297364 5400.3076384		0.0001 0.0337		
		COH9	35.41282323	7.24965753	28340.3652724	6 23.8 6	0.0001		
		CON10 SENS2	19.52814621 13.81744728		24470.93577471 3823.55084643		0.0001 0.0737		
ounds on (condition numb	er: 1.250	137, 41.8863	\$8		*			•••••
ll variab	les left in the	e model are s	ignificant at th	he 0.1000 level.					
Sur				r Dependent Varia	ble R_CO				
Step	Variable N Removed	Number Part In R	ial Model **2 R**2	C(p)	F Prob>F	Label			
1 2	IGN2 COH6	9 0.0 8 0.0			.0769 0.7818 .9252 0.3368	EGR	•		
34	COH8 COH5	7 0.0	027 0.4443	6.5356 1	.5412 0.2154 .8740 0.1720	CATALYST			

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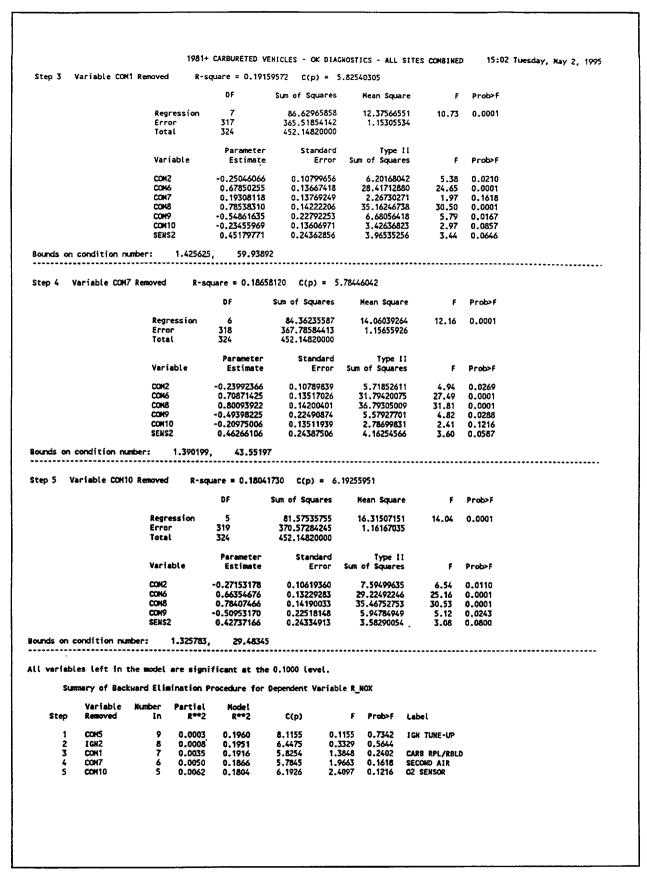
Not for Resale

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		1981+ CAKBOKETED A	FRICLES - OK DIAG	WOSTICS - ALL SITE	S COMBINED	15:02 Tuesday, May	/ 2, 1995
		Backward Eliminat	tion Procedure for	Dependent Variabl	e R_NOX		
tep 0	All Variables Entered	R-square = 0.196	626812 C(p) = 10	.00000000			
		DF	Sum of Squares	Mean Square	F	Prob>F	
	Regre	ssion 10	88.74227730	8.87422773	7.67	0.0001	
	Error Total	314	363.40592270 452.14820000	1.15734370		••••	
	Varia	Parameter ble Estimate		Type 11 Sum of Squares	F	Prod>f	
	CON1	-0.16914326		1.27411724		0.2949	
	COH2 COH5	-0.22048752 -0.04548019		4.14835229 0.13371606	3.58 0.12	0.0592 0.7342	
	CON6	0.71628400		30, 18167185		0.0001	
	CON7	0.23362516	0.14134336	3.16191919	2.73	0.0994	
	CONS	0.78496387		35.09765949		0.0001	
	CON9 CON10	-0.54671408 -0.21201095		6.55583996 2.59484010	2.24	0.0179 0.1353	
	IGN2	-0.14555842		0.36336311	0.31	0.5757	
	SENS2			3.93821443		0.0660	
ounds o	on condition number:	1.825337, 131.63	.81	••••••		••••••	
tep 1	Variable COM5 Removed	R-square = 0.195	97239 C(p) = 8	.11553704			
		DF	Sum of Squares	Mean Square		Prob>F	
	Regres Error Total	315	88.60856124 363.53963876 453.14830000	9.84539569 1.15409409	8.53	0.0001	
	tv.a.	324 Parameter	452.14820000 Standard	Type 11			
	Varia			Sum of Squares	F	Prob>F	
	CONT	-0.18050654		1.51626973	1.31		
	COH2	-0.23348554		5.21401923		0.0343	
	CON6 CON7	0.71010695		30.16979371		0.0001	
	COM/	0.22916323 0.78368770		3.06876462 35.00791833	2.66 30.33	0.1040 0.0001	
	COH9	-0.55432845		6.80443661	5.90	0.0157	
	CON10	-0.22439669	0,13662921	3.11305632	2.70	0.1015	
	IGN2 SENS2	-0.14951212 0.44587006		0.38414089 3.83330706	0.33 3.32	0.5644 0.0693	
				4 + Gy 444 (Vo	J.J.	0,6372	
unds o	n condition number: 1	1.470814, 98.706	49				
ep 2	Variable IGN2 Removed	·			-		
		DF	Sum of Squares	Mean Square	F		
	Regres		88.22442034	11.02805254	9.58	0.0001	
	Error Totel	316 324	363.92377966 452.14820000	1.15165753			
		Parameter		Type II Sum of Squares	F	Prob>f	
	Variab	e Estimate				0 2402	
	CON1	-0.18490285	0.15712937	1.59476176	1.38		
	COH1 COH2	-0.18490285 -0.24454754	0.15712937 0.10804798	5.89951896	5.12	0.0243	
	COH1 COH2 COH6	-0.18490285 -0.24454754 0.70561934	0.15712937 0.10804798 0.13852147	5.89951896 29.88340868	5.12 25.95	0.0243 0.0001	
	COH1 COH2	-0.18490285 -0.24454754	0.15712937 0.10804798 0.13852147 0.13952409	5.89951896	5.12	0.0243 0.0001 0.1155	
	COH1 COH2 COH6 COH6 COH7 COH8 COH9	-0.18490285 -0.24454754 0.2019086 0.70561934 0.22019086 0.78404280 -0.54796408	0.15712937 0.10804798 0.13852147 0.13952409 0.14214039 0.22778501	5.89951896 29.88340868 2.86829299 35.04030655 6.66464884	5.12 25.95 2.49 30.43 5.79	0.0243 0.0001 0.1155 0.0001 0.0167	
	C0H1 C0H2 C0H6 C0H7 C0H7 C0H7 C0H9 C0H9 C0H10	-0.18490285 -0.24454754 0.22454754 0.70561934 0.22019086 0.78404280 -0.54796408 -0.22186452	0.15712937 0.10804798 0.13852147 0.13952409 0.14214039 0.22778501 0.13641447	5.89951896 29.88340868 2.86829299 35.04030655 6.66464884 3.04633867	5.12 25.95 2.49 30.43 5.79 2.65	0.0243 0.0001 0.1155 0.0001 0.0167 0.1049	
	COH1 COH2 COH6 COH6 COH7 COH8 COH9	-0.18490285 -0.24454754 0.2019086 0.70561934 0.22019086 0.78404280 -0.54796408	0.15712937 0.10804798 0.13852147 0.13952409 0.14214039 0.22778501 0.13641447	5.89951896 29.88340868 2.86829299 35.04030655 6.66464884	5.12 25.95 2.49 30.43 5.79	0.0243 0.0001 0.1155 0.0001 0.0167 0.1049	
unds of	COH1 COH2 COH6 COH7 COH8 COH9 COH9 COH10 SENS2	-0.18490285 -0.24454754 0.22454754 0.70561934 0.22019086 0.78404280 -0.54796408 -0.22186452	0.15712937 0.10804798 0.13852147 0.13952409 0.14214039 0.22778501 0.13641447 0.24383415	5.89951896 29.88340868 2.86829299 35.04030655 6.66464884 3.04633867 3.68823247	5.12 25.95 2.49 30.43 5.79 2.65 3.20	0.0243 0.0001 0.1155 0.0001 0.0167 0.1049	
unds or	COH1 COH2 COH6 COH7 COH8 COH9 COH9 COH10 SENS2	-0.18490285 -0.24454754 0.70561934 0.22019086 0.78464280 -0.54796408 -0.22186452 0.43635705	0.15712937 0.10804798 0.13852147 0.13952409 0.14214039 0.22778501 0.13641447 0.24383415	5.89951896 29.88340868 2.86829299 35.04030655 6.66464884 3.04633867 3.68823247	5.12 25.95 2.49 30.43 5.79 2.65 3.20	0.0243 0.0001 0.1155 0.0001 0.0167 0.1049 0.0745	
unds or	COH1 COH2 COH6 COH7 COH8 COH9 COH9 COH10 SENS2	-0.18490285 -0.24454754 0.70561934 0.22019086 0.78464280 -0.54796408 -0.22186452 0.43635705	0.15712937 0.10804798 0.13852147 0.13952409 0.14214039 0.22778501 0.13641447 0.24383415	5.89951896 29.88340868 2.86829299 35.04030655 6.66464884 3.04633867 3.68823247	5.12 25.95 2.49 30.43 5.79 2.65 3.20	0.0243 0.0001 0.1155 0.0001 0.0167 0.1049 0.0745	
unds or	COH1 COH2 COH6 COH7 COH8 COH9 COH9 COH10 SENS2	-0.18490285 -0.24454754 0.70561934 0.22019086 0.78464280 -0.54796408 -0.22186452 0.43635705	0.15712937 0.10804798 0.13852147 0.13952409 0.14214039 0.22778501 0.13641447 0.24383415	5.89951896 29.88340868 2.86829299 35.04030655 6.66464884 3.04633867 3.68823247	5.12 25.95 2.49 30.43 5.79 2.65 3.20	0.0243 0.0001 0.1155 0.0001 0.0167 0.1049 0.0745	
unds or	COH1 COH2 COH6 COH7 COH8 COH9 COH9 COH10 SENS2	-0.18490285 -0.24454754 0.70561934 0.22019086 0.78464280 -0.54796408 -0.22186452 0.43635705	0.15712937 0.10804798 0.13852147 0.13952409 0.14214039 0.22778501 0.13641447 0.24383415	5.89951896 29.88340868 2.86829299 35.04030655 6.66464884 3.04633867 3.68823247	5.12 25.95 2.49 30.43 5.79 2.65 3.20	0.0243 0.0001 0.1155 0.0001 0.0167 0.1049 0.0745	
unds or	COH1 COH2 COH6 COH7 COH8 COH9 COH9 COH10 SENS2	-0.18490285 -0.24454754 0.70561934 0.22019086 0.78464280 -0.54796408 -0.22186452 0.43635705	0.15712937 0.10804798 0.13852147 0.13952409 0.14214039 0.22778501 0.13641447 0.24383415	5.89951896 29.88340868 2.86829299 35.04030655 6.66464884 3.04633867 3.68823247	5.12 25.95 2.49 30.43 5.79 2.65 3.20	0.0243 0.0001 0.1155 0.0001 0.0167 0.1049 0.0745	

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Backward Elimination Procedure for Dependent Variable E_SCORE Step 0 All Variables Entered R-sparse 0.47510784 C(p) = 10.0000000 Variable Step 0 Step		1981+	CARBURETED VE	EHICLES - OK DIAG	NOSTICS - ALL SITE	S COMBINED	15:02 Tuesday, May 2, 19
DF Sum of Squares Hean Square F ProbPF Begression 10 BD29, 074/0755 BD2, 064/0777 BD2, 074/0755 BD2, 064/0777 BD2, 074/0755 BD2, 064/0777 BD2, 074/0755 BD2, 074/0757 BD2, 075/074 BD2		Back	ward Eliminati	ion Procedure for	Dependent Variabl	e R_SCORE	
tegression 10 8020,974/6705 802,974/6705 28.54 0.0001 Error 314 18000,1972/2000 758.01 758.000 759.000 Wariable Error Sun of Squares F Prob/F 0.0012 0.0012 COM 2.60024/000 0.7702004 301.136/77023 10,70 0.4012 COM 2.60024/010 0.7702004 305.57783 30.70 0.6012 COM 2.60024/010 0.7702004 301.136/77033 10.70 0.4012 COM 0.597795164 0.6995537 55.6346385 1.08 0.1017 COM 0.597795164 0.6995537 55.6346285 10.16207 1.120 COM 1.52537 131.6351 1.1220744 44.5005640 11.8.07 0.0017 COM 1.52537 131.6351 100.62607037 3.79 0.6255 Bounds on condition number: 1.825337 131.6351 31.78 0.0001 Variable CoMS Removed R-square = 0.47586193 C(p) = \$.14738630 50.00	Step 0 All Variables	Entered R-s	quare = 0.4761	10784 C(p) = 10	.00000000		
Frier 314 8835.69911145 28.139886099 Veriable Parameter Standard Type II Front Standard Type II COR1 2.60034104 0.74659433 301.13557953 10.70 0.0012 COR2 3.14659922 0.5742576 65.945473 10.670 0.0012 COR2 0.5742576 0.6977021 10.67070021 7.200371 10.70 0.0012 COR4 0.697795104 0.6997771 10.69770021 1.530 0.0011 COR7 0.697951104 0.6997772 10.701 1.001 0.0017 COR7 0.69795102 1.132678434 0.101 0.0017 0.0011 COR7 0.697772 10.7728373 10.701 0.2011 0.0011 Stand 5 1.42208 1.80284342 1.804280777 1.25 0.2001 Stand 7 1.24044517 1.24034513 31.07280771 1.25 0.2001 Stap 1 Veriable COM5 Removed R-standrd Type II F Pr			DF	Sum of Squares	Kean Square	F	Prob>f
Frier 314 at35, 59911145 28, 13980609 Veriable Parameter Standard Type II COM1 2,60054104 0,74059643 301,13457953 10,70 0,0012 COM2 3,14659922 0,57425760 65,945473 16,105710027 5,72 0,0712 COM2 1,57501464 0,6997971 16,105770017 15,004270 16,0017 COM2 2,5253442 0,59979710 15,9042897 15,011,001 0,0017 COM7 0,99795710 0,59979710 15,9042897 15,011,001 0,0017 COM7 0,99795710 1,22,023317 31,07205070 1,23 0,2001 COM7 1,2204357 124,142206 10,0017 0,001 0,0017 COM7 1,2203517 31,0205070 1,23 0,2001 0,001 Step1 Veriable CoM6 Removed R-squares = 0,47364097 1,0203618 31,78 0,0001 Step1 Veriable DF Sum of Squares F Prob>F Step1<		Regression	10	8029 97467055	802.99746706	28.54	0,0001
Variable Parameter Estimate Standard Estimate Type II Estimate F Prob/F CMI 2.0031104 0.0702304 0.11457953 0.00 0.0001 CMI 2.14657922 0.7928943 0.511457953 0.00 0.0001 CMI 2.14657922 0.7928144 0.6990597 161.0970083 0.70 0.0001 CMI 2.2231462 0.7928147 251.546774 151.09700 0.0017 CMI 2.2231462 0.7928347 251.5468295 10.01 0.0011 CMI 1.2327542 4.1472817 15.20 0.0001 CMI 1.2327542 4.14728451 3.5028078 1.25 0.2263 Stard 1.4253377 131.6351 31.78 0.0001 Stard Regression 9 5025.5272455 691.7355318 31.78 0.0001 Tratal 2.21 10665.5772405 691.7355318 31.78 0.0001 CMI 2.4604458 0.7362314 315.9531287 11.26 0.0001		Error	314	8835.89911145		2013 1	•••••
Variable Estimate Error Sun of Squares F ProbeF CM1 2.60034104 0.79459643 301.13457923 10.70 0.0012 CM2 3.1435922 0.57135764 85.9547783 10.70 0.0012 CM4 1.2255233 0.67133 4.17472197 5.15 0.7713 CM4 2.2235424 2.0699597 5.311388 1.80 0.0001 CM4 2.2235424 0.6999597 3.531388 1.80 0.0001 CM4 2.23517502 1.1257744 44.5005520 10.31 2.2 0.2001 E02 1.12304547 1.21807261 5.020177 2.9.372833 10.33 0.0001 Step 1 Variable CM4 Removed R-square = 0.47386193 C(p) = 8.14738630 JL 0.0001 DF Sun of Squares F ProbF Error Sun of Squares F ProbF CM1 2.4604535 0.7865314 31.76 0.0001 0.001 CM2 3.1002757 0.54		Total	324	16865.87378200			
Cont 2.40034104 0.70489643 301.13457953 10.70 0.0012 Cont 3.14259022 0.5742776 85.96457755 30.06 0.0001 Cont 0.20353314 0.6916937 4.16153885 1.72 0.0017 Cont 0.20353314 0.6916937 4.16153885 1.78 0.001 Cont 0.20353314 0.6917573 2.5646252 15.80 0.0017 Cont 0.20353314 0.6917573 2.603532835 0.0001 0.0017 Cont 0.2058125 0.6917573 2.60353285 1.25 0.2050 Bounds on condition number: 1.25337 151.6351 1.226 0.2053372 3.178 0.0001 Step 1 Variable Regression 9 8025.82776353 31.78 0.0001 Total 324 16653.67578200 1795 11 2.12 0.0001 Cont 1.26406458 0.78925741 315.9531287 31.78 0.0001 Cont 1.264064585 0.78927814 31		Vaciable				F	ProbaF
Cox2 3.14257922 0.57/23750 85.965735 30.00 0.0001 CCX5 1.57860146 0.65976771 61.0570703 CCX6 0.2253333 0.69126333 4.1472117 6.15 0.7013 CCX6 0.2253333 0.69126333 4.1472117 6.15 0.7013 CCX6 0.2253334 0.69126333 4.1472117 6.15 0.7013 CCX6 0.2253334 0.70228374 281.5564925 10.01 0.0017 CCX6 1.2254324 0.70228374 281.5564925 10.01 0.0017 CCX6 1.2254324 0.70228374 281.5564925 10.01 0.0013 CCX7 0.725492 0.757515 33.02285778 11.23 0.2050 SENS2 2.3331092 1.21402508 106.6267037 31.23 0.2050 SENS2 2.3331092 1.21402508 106.6267037 31.23 0.2050 SENS2 2.3331092 1.21402508 106.6267037 31.75 0.0021 SENS 1 Variable COX6 Removed R-square = 0.47586193 C(p) = 8.14738630 DF Sum of Squares Mean Square F Prob>F Regression 9 8025.82726358 001.7553318 31.78 0.0001 Error 315 8840.04633324 28.033379 Total 324 16865.8737820 Parameter Standard Type II Error 4.141821 0.6333204 280.0633372 28.0030379 Total 324 16865.8737820 CCX7 1.000000606 0.6923781 0.315.95312297 11.26 0.0007 CCX8 2.39047387 0.7839731 0.35093731 0.000 CCX8 2.39047387 0.7839731 0.35093731 0.02 0.0014 CCX9 1.00000606 0.69215417 59.5297312 00.11.0 0.0007 CCX8 2.39047387 0.7839738 0.378904260 2.212 0.0001 CCX9 4.54046559 1.1274702 455.53719456 10.42 0.0001 CCX9 4.5404657 1.12674702 455.53719456 11.570 0.0016 CCX9 4.5404657 1.12674702 455.53719456 11.50 0.0027 CCX9 4.5404657 1.12674702 455.53719456 11.50 0.0016 CCX9 4.5404657 1.12674702 455.53719456 11.50 0.0027 CCX9 4.5406457 1.12674702 455.53719456 11.50 0.0016 CCX9 4.5406457 1.12674702 455.53719456 11.50 0.0016 CCX9 5.1214322 1.1665.57778200 1.121 0.2720 Step 2 Variable IGU2 Removed R-square 8.047384676 C(p) = 7.3551966 DF Sun of Squares F Prob>F Regression 8 7991.5396477 998.7759601 11.10 0.0016 CCX9 5.0499775 0.7846073 3.0285277 988.7759601 11.10 0.0016 CCX9 5.0499775 0.7846073 3.73519032 10.94 0.0010 CCX9 5.0499775 0.7846073 3.73519032 10.94 0.0010 CCX9 5.0499775 0.7846073 3.055526275 30.0001 CCX9 5.0499775 0.63264771 70.156 0.0010 CCX9 5.0499775 0.63264771 70.156 0.0010 CCX9 5.049							
Cox6 1.37860146 0.65970774 161.00570083 5.7.0 0.0173 COX6 0.2555233 0.09705104 0.6909597 35.6313885 1.98 0.1607 COX7 0.97795104 0.6909597 35.6313885 1.98 0.1607 COX7 0.97795104 0.6909597 35.6313885 1.98 0.1607 COX7 0.9795702 1.13267744 444.5005240 15.80 0.0001 COX7 0.236125 4.0691773 2.02.0572353 10.53 0.0001 COX7 0.236125 4.0691773 2.02.07528353 10.53 0.0001 COX7 0.236125 4.0691773 2.02.07528353 10.53 0.02013 Exercise on condition number: 1.425337, 131.6381 Step 1 Variable COM6 Removed R-sequere = 0.47586193 C(p) = 8.14738630 DF Sun of Squares Mean Square F ProbF Regression 0 8025.8272453 891.75558318 31.78 0.0001 Error 315 8840.0463342 22.0303979 3. Variable COM6 Removed R-sequere standard Type II Parameter Standard Type II Variable Estimate Error Sun of Squares F ProbF COX1 2.4604455 0.7586370 0.156293792 001.5412409 82.12 0.0001 COX2 3.190675367 0.56293793 001.5412409 82.12 0.0001 COX2 3.19067537 0.165320460 2.12 0.1463 COX7 1.00008066 0.69215417 39.5500420 2.12 0.1463 COX9 1.23440675 0.77142208 124.5164309 10.14 0.0016 COX9 2.4306327 0.12774220 1.12657755 4.15 0.0042 COX9 2.4304527 0.1714223 24.5164509 10.14 0.0016 COX9 2.4304527 1.1267772 453.6317452 4.15 0.0042 COX9 2.4304577 1.2772528 Step 2 Variable IGM2 Removed R-sequere = 0.47384676 C(p) = 7.35519566 DF Sun of Squares Mean Square F ProbFF Regression 8 7091.63849777 99.57795172 35.57 0.0001 Step 2 Variable IGM2 Removed R-sequere Standard Type II Error Sun of Squares F ProbFF Regression 8 7091.63849777 99.57795172 35.57 0.0001 COX9 1.5774200 307.3217423 28.506260 2.12 0.464 COX9 1.26045579 0.7864607 1.20 0.0220 Step 2 Variable IGM2 Removed R-sequere Standard Type II Variable Estimate Error Sun of Squares F ProbFF Regression 8 7091.63849777 99.57796172 35.57 0.0001 COX9 1.57742002 0.75846077 1.90.57364677 1.10.0.0001 COX9 1.577423040 0.05326477 1.90.57354656							
Conf 0.97995104 0.69695507 55.3143885 1.080 0.1607 Conf 2.2235424 22354542 281.59602595 10.01 0.0017 Conf 2.2255125 1.13267844 244.50056240 15.80 0.0001 IAU 2.2551125 0.6961777 290.5752307 10.33 0.0013 IAU 2.2551125 0.2650125 1.2162200 1.25 0.2552 Bounds on condition number: 1.825337 131.4381 1.25 0.2552 Step 1 Variable COK6 Removed R-square = 0.47586193 C(p) = 8.14738430 DF Sum of Squares Mean Square F ProbF Regression 9 8025.8272455 891.75858318 31.78 0.0001 Total 324 16663.57378200 Type II Color 0.0001 Variable Estimate Error Sun of Squares F ProbF Conf 1.61141821 0.6332302 101.512071 11.26 0.0000 Conf 2.64044558							
COMB 2.22334262 0.7026337 28.159665259 10.01 0.001 COMP 2.25631254 0.6981737 29.37528393 10.033 0.0031 Idi2 1.4304545 1.2809531 33.0705078 1.25 0.2553 Bounds on condition number: 1.425337 131.6381 100.62207037 3.77 0.0525 Bounds on condition number: 1.425337 131.6381 100.62207037 3.77 0.0525 Bounds on condition number: 1.425337 131.6381 100.62207037 3.77 0.0525 Bounds on condition number: 1.425337 131.6381 100.001 1.25 0.0517 Step 1 Variable CMA R-square = 0.47586193 C(p) = 8.14738430 177 0.0001 Fror 315 28.00.0453352 28.00.0453352 28.00.0453352 28.00.0453352 11.25 0.0001 COM1 2.46464538 0.7867378200 11.25 0.0001 2.23340673 0.71122003811 6.00142 COM2 2.49947451 0.48633204							
COMP 0 4.50175002 1.12267844 444.50056240 15.80 0.0001 IGN2 -1.63044547 1.28073615 33.070205078 1.25 0.2550 Bounds on condition number: 1.625337, 131.6381 1.25 0.2550 Step 1 Variable COM6 Removed R-square = 0.47586193 C(p) = 8.14738630 F ProboF Regression 9 B025.827(458) 691.7555338 31.78 0.0001 Total 324 16865.67378200 1.72 0.0001 Parameter Standard Type II 7 0.0001 CoN1 2.64044558 0.7865314 31.78 0.0001 CoN2 3.19067357 0.529737200 1.726 0.0001 CoN2 2.64044558 0.76653144 315.9531287 11.726 0.0							
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CON10 2.30189867 0.69088046 311.53767680 11.10 0.0010 IGN2 -1.40601631 1.27762205 33.9875480 1.21 0.2720 SENS2 2.43817921 1.19658588 116.51651765 4.15 0.0424 Bounds on condition number: 1.794697, 103.3038 Step 2 Variable IGN2 Removed R-square = 0.47384676 C(p) = 7.35519686 DF Sum of Squares Nean Square F Prob>F Regression 8 7991.83969379 998.97996172 35.57 0.0001 Error 316 8574.0340821 28.08238636 Total 326 1685.87378200 Variable CON1 2.60149759 0.78640030 307.32191032 10.94 0.0010 CON2 3.08989763 0.55562675 866.47216239 30.93 0.0001 CON2 3.08989763 0.55562675 866.47216239 30.93 0.0001 CON2 3.08989763 0.55562675 866.47216239 30.93 0.0001 CON2 3.08989763 0.55562675 866.47216239 30.93 0.0001 CON3 1.57723902 0.65264643 143.37861247 5.82 0.0164 CON7 0.92284687 0.68003717 50.52094695 1.80 0.18008 CON8 2.23623994 0.70166190 285.24301677 10.16 0.0016 CON9 4.59993183 1.22508287 468.82144070 16.69 0.0001 CON9 2.32943688 0.69065771 31.9453858 1.188 0.00188 SENS2 2.34393102 1.19391576 108.23713743 3.85 0.0505 Bounds on condition number: 1.789897, 82.40099							
SENS2 2.43817921 1.19658588 116.51651765 4.15 0.0424 Bounds on condition number: 1.794697, 103.3038 Step 2 Variable IGN2 Removed R-square = 0.47384676 C(p) = 7.35519686 DF Sum of Squares Mean Square F Prob>F Regression 8 7991.83569379 998.97996172 35.57 0.0001 Error 316 8874.0340821 28.08238636 7 0.0001 Total 324 16865.87378200 988.97996172 35.57 0.0001 Variable Parameter Standard Type II F Prob>F COM1 2.60149759 0.78640030 307.32191032 10.94 0.0010 COM2 3.08989763 0.55562675 868.47216239 30.93 0.0001 COM5 1.57423902 0.655562675 868.47216239 30.93 0.0001 COM5 1.57423902 0.65264633 143.37861247 5.82 0.0164 COM6 2.252623994 0.70166190 285.24301677 10.16 0.0016 COM9 4							
Bounds on condition number: 1.794697, 103.3038 Step 2 Variable IGN2 Removed R-square = 0.47384676 C(p) = 7.35519686 DF Sum of Squares Mean Square F Regression 8 7991.839697379 998.97996172 35.57 0.0001 Error 316 8874.03408821 28.08238636 35.57 0.0001 Variable Parameter Standard Type II F Prob>F CON1 2.60149759 0.78640030 307.32191032 10.94 0.0010 CON2 3.08989763 0.55562675 866.47216239 30.93 0.0011 CON3 1.57423902 0.65266463 163.37861247 5.82 0.0164 CON4 2.20149759 0.78640030 307.32191032 10.94 0.0010 CON4 2.60149759 0.78640030 307.32191032 10.94 0.0010 CON5 1.57423902 0.65266463 163.37861247 5.82 0.0164 CON6 1.57423902 0.652664643 163.37861247 18.0 0.0001 CON6 2.23423994							
Step 2 Variable IGN2 Removed R-square = 0.47384676 C(p) = 7.35519686 DF Sum of Squares Nean Square F Prob>F Regression 8 7991.83969379 998.97996172 35.57 0.0001 Error 316 6874.03408821 28.08238636 35.57 0.0001 Variable Parameter Standard Type II F Prob>F CON1 2.60149759 0.78640030 307.32191032 10.94 0.0010 CON2 3.08989763 0.65266463 163.77861247 5.82 0.0164 CON3 1.572423902 0.65266463 163.77861247 5.82 0.0164 CON4 2.23623994 0.63266463 163.77861247 5.82 0.0164 CON4 2.23623994 0.70166190 285.24301677 10.16 0.0016 CON4 2.32423994 0.606803717 50.52094693 1.80 0.1808 CON4 2.32423994 0.60669771 319.45535866 11.38 0.0006 CON4 2.3243393102 1.19391576 108.23713743 3.85 0.0505<	Paumda an eardition numb				110121021102	4115	0.0424
DF Sum of Squares Mean Square F Prob>F Regression 8 7991.83969379 998.97996172 35.57 0.0001 Error 316 8874.03408821 28.08238636 28.08238636 0.0001 Variable Parameter Standard Type II F Prob>F COM1 2.60149759 0.78640030 307.32191032 10.94 0.0010 COM2 3.08989763 0.55562675 864.47216239 30.93 0.0001 COM5 1.57423902 0.65266473 163.7861247 5.82 0.0164 COM7 0.92284897 0.66803717 50.52094693 1.80 0.1808 COM8 2.23623994 0.701646190 285.24301677 10.16 0.0016 COM9 4.5999993183 1.12580887 468.82144070 16.69 0.0001 COM10 2.32943688 0.69065771 319.45535866 11.38 0.0008 SENS2 2.34393102 1.19391576 108.23713743 3.85 0.0505		EFI 1./9409/	, 103.303				
Regression 8 7991.83969379 998.97996172 35.57 0.0001 Error 316 8874.03408821 28.08238636 28.08238636 28.08238636 Total 324 16865.87378200 28.08238636 7 Porb>F Variable Estimate Error Sum of Squares F Prob>F COM1 2.60149759 0.78640030 307.32191032 10.94 0.0010 COM2 3.05989763 0.55562675 868.47216239 3.093 0.0001 COM5 1.57623902 0.65266463 163.37861247 5.82 0.0164 COM7 0.92284897 0.68803717 50.52094693 1.80 0.1808 COM8 2.23623994 0.70166190 285.24301677 10.16 0.0016 COM9 4.599997183 1.12580887 468.82144070 16.69 0.0001 COM10 2.32943688 0.69065771 319.45535866 11.38 0.0008 SENS2 2.34393102 1.19391576 108.23713743	Step 2 Variable IGN2 R	emoved R-so	ware = 0.4738	4676 C(p) = 7.	.35519686		
Error Total 316 324 8874.03408821 16865.87378200 28.08238636 Variable Parameter Estimate Standard Error Type II Sum of Squares F Prob>F CON1 2.60149759 0.78640030 307.32191032 10.94 0.0010 CON2 3.08989763 0.5556475 868.47216239 30.93 0.0001 CON5 1.57423902 0.65266463 163.37861247 5.82 0.0164 CON7 0.92284897 0.66803717 50.52094693 1.80 0.1808 CON8 2.23623994 0.70166190 285.24301677 10.16 0.0016 CON9 4.59993183 1.12580887 468.82144070 16.69 0.0001 CON10 2.32943688 0.69065771 319.45535866 11.38 0.0008 SENS2 2.34393102 1.19391576 108.23713743 3.85 0.0505			DF	Sum of Squares	Hean Square	F	Prob>F
Total 324 16865.87378200 Variable Parameter Estimate Standard Error Type II Sum of Squares F Prob>F CON1 2.60149759 0.78640030 307.32191032 10.94 0.0010 CON2 3.06989763 0.55562675 868.47216239 30.95 0.0001 CON5 1.57423902 0.65266463 163.37861247 5.82 0.0164 CON7 0.92284897 0.68803717 50.52094693 1.80 0.1808 CON8 2.23623994 0.70166190 285.24301677 10.16 0.00016 CON9 4.59993183 1.12580887 468.82144070 16.69 0.0001 CON10 2.32943688 0.69065771 319.45535866 11.38 0.0008 SENS2 2.34393102 1.19391576 108.23713743 3.85 0.0505 Bounds on condition number: 1.789897, 82.40099 285 2.40059 285						35.57	0.0001
Parameter Variable Parameter Estimate Standard Error Type II Sum of Squares F Prob>F COM1 2.60149759 0.78640030 307.32191032 10.94 0.0010 COM2 3.08989763 0.55562675 868.47216239 30.93 0.0001 COM5 1.57423902 0.65266463 163.77861247 5.82 0.0164 COM7 0.92284897 0.68803717 50.52094693 1.80 0.1808 COM8 2.23623994 0.70166190 285.24301677 10.16 0.0016 COM9 4.5999978183 1.12580887 468.82144070 16.69 0.0001 COM10 2.32943688 0.69065771 319.45535866 11.38 0.0008 SENS2 2.34393102 1.19391576 108.23713743 3.85 0.0505	•				28.08238636		
Variable Estimate Error Sum of Squares F Prob>F CON1 2.60149759 0.78640030 307.32191032 10.94 0.0010 CON2 3.08989763 0.55562675 868.47216239 30.93 0.0001 CON5 1.57423902 0.65266463 163.37861247 5.82 0.0164 CON7 0.92284897 0.6803717 50.52094693 1.80 0.1808 CON8 2.23623994 0.70166190 285.24301677 10.16 0.0016 CON9 4.59993183 1.12580887 468.82144070 16.69 0.0001 CON10 2.32943688 0.69065771 319.45535866 11.38 0.0008 SENS2 2.34393102 1.19391576 108.23713743 3.85 0.0505 Bounds on condition number: 1.789897, 82.40099 50.505 50.505							
CON1 2.60149759 0.78640030 307.32191032 10.94 0.0010 CON2 3.08989763 0.55562675 868.47216239 30.95 0.0001 CON5 1.57423902 0.65266463 163.37861247 5.82 0.0164 CON7 0.92284897 0.68803717 50.52094693 1.80 0.1808 CON8 2.23623994 0.70166190 285.24301677 10.16 0.0016 CON9 4.59993183 1.12580887 468.82144070 16.69 0.0001 CON10 2.32943688 0.69065771 319.45535866 11.38 0.0008 SENS2 2.34393102 1.19391576 108.23713743 3.85 0.0505 Bounds on condition number: 1.789897, 82.40099		Variable				F	Prob>F
COM2 3.08989763 0.55562675 868.47216239 30.93 0.0001 COM5 1.57423902 0.65266463 163.37861247 5.82 0.0164 COM7 0.92284897 0.68803717 50.52094693 1.80 0.1808 COM8 2.235623994 0.70166190 285.24301677 10.16 0.0016 COM9 4.59993183 1.12580887 468.82144070 16.69 0.0001 COM10 2.32943688 0.69065771 319.45535866 11.38 0.0008 SEMS2 2.34393102 1.19391576 108.23713743 3.85 0.0505 Bounds on condition number: 1.789897, 82.40099		0001	2 601/0750	0 784/0070		10 0/	0.0010
CONS 1.57423902 0.65266463 163.37861247 5.82 0.0164 CON7 0.92284.897 0.68803717 50.52096695 1.80 0.1808 CON8 2.23623994 0.70166190 285.24301677 10.16 0.00016 CON9 4.59993183 1.12580887 468.82144070 16.69 0.0001 CON10 2.32943688 0.69065771 319.45535866 11.38 0.0008 SENS2 2.34393102 1.19391576 108.23713743 3.85 0.0505 Bounds on condition number: 1.789897, 82.40099							
COM8 2.23623994 0.70166190 285.24301677 10.16 0.0016 COM9 4.59993183 1.12580887 468.82144070 16.69 0.0001 COM10 2.32943688 0.69065771 319.45535866 11.38 0.0008 SENS2 2.34393102 1.19391576 108.23713743 3.85 0.0505 Bounds on condition number: 1.789897, 82.40099		CONS	1.57423902	0.65266463	163.37861247	5.82	0.0164
CON9 4.59993183 1.12580887 468.82144070 16.69 0.0001 CON10 2.32943688 0.69065771 319.45535866 11.38 0.0008 SENS2 2.34393102 1.19391576 108.23713743 3.85 0.0505 Bounds on condition number: 1.789897, 82.40099							
COM10 2.32943688 0.69065771 319.45535866 11.38 0.0008 SENS2 2.34393102 1.19391576 108.23713743 3.85 0.0505 Bounds on condition number: 1.789897, 82.40099							
SEXS2 2.34393102 1.19391576 108.23713743 3.85 0.0505 Bounds on condition number: 1.789897, 82.40099							
	Bounds on condition number	er: 1.789897	, 82.4009				
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			1981+ (CARBURETED VE	HICLES - OK DI	AGNOSTI	S - ALL SI	TES COMBINED	15:02	Tuesday, Hay 2, 1	995
Step 3 Va	ariable COH7	Removed	R-sq	uare = 0.4708	5131 C(p) =	7.15055	205				
				DF	Sum of Square	s I	lean Square	F F	Prob>F		
		Regr Erro Tota		7 317 324	7941.3187468 8924.5550351 16865.8737820	4 2	28.15317046		0.0001		
		Vari	able	Parameter Estimate	Standar Erro		Type II of Squares		Prob>f		
		COH1 COH2 COH5 COH8 COH9 COH9 SENS	0	2.76743075 3.12508672 1.67460914 2.31144620 4.85426116 2.42351521 2.42240449	0.7775865 0.5557060 0.6491771 0.7002988 1.1111233 0.6879522 1.1939833	4 89 0 18 9 30 1 53 3 34	6.60167443 0.35093154 67.33884450 6.71004936 7.33986926 9.38337771 5.88417344	31.63 6.65 10.89 19.09 12.41	0.0001 0.0103 0.0011 0.0001 0.0005		
Bounds on c	condition nu		- 1.766368,								
		•••••		•••••	•••••		••••				••••
					e 0.1000 level						
201	Wariable		Partial	Nodel	Dependent Var	Table K_	SLOKE				
Step	Removed	In	R**2	R**2	C(p)	F	Prob>f	Label			
1 2 3	COM6 I GN2 COM7	9 8 7		0.4759 0.4738 0.4709	8.1474 7.3552 7.1506	0.1474 1.2111 1.7990	0.2720	EGR SECOND AIR			
			,								

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						IED 15:02 Tuesday, May 2	2, 1995
	Back	ward Eliminat	ion Procedure for	Dependent Variabl	e R_HC		
Step 0 All Variables	Entered R-s	quare = 0.2597	74605 C(p) = 10	.00000000			
		DF	Sum of Squares	Mean Square	F	Prob>F	
	Regression	10	1526.68295603	152.66829560	18.63	0.0001	
	Error Total	531 541	4350.91544397 5877.59840000	8.19381440			
	10101	341	3677.39840000				
	Variable	Parameter Estimate		Type II Sum of Squares		Prob>F	
		CSCIMBLE	Error		r	Procer	
	COM3 COM4	0.61420862	0.34065590 0.27785591		3.25 2.57	0.0720 0.1096	
	CON5	0.35373155	0.24963137	16.45263184	2 01	0 1571	
	COH6	-0.30390386	0.28427083	16.45263184 9.36470221	1.14	0.2855	
	CON7 CONS	0.93014545 0.41217915		17 10518113	2 00	0.0918 0.1491	
	COH9	3.45762930	0.61177594	261.73282387	31.94	0.0001	
	COM10 IGN2	1.29358445	0.20619331 0.49955004	322.49764436 23.24457489	39.36	0.0001	
	SENS2	0.27290305		1.87578202		0.6325	
Bounds on condition numb	1.4087	3 110 777	7				
Step 1 Variable SENS2	temoved R-so	uare = 0.2594	2691 C(p) = 8	.22892659			
•						Probof	
			•	Mean Square			
	Regression	9 570	1524.80717401 4352.79122599 5877.59840000		20.71	0.0001	
	Error Total	541	5877.59840000	8.18193839			
	Variable	Parameter Estimate		Type II Sum of Squares	F	Prob>F	
				-			
	CON3 CON4		0.34038644 0.27760989	26.80338313 20.82708455		0.0709 0.1112	
	COHS	0.36572944		17.76692146 9.10983888		0.1412	
	CON6 CON7	-0.29958905	0.28392177	9,10983888 23,56822186		0.2918 0.0902	
	COM8	0.41305256	0.28506336 0.61045856	17.17845314		0.1479	
	CON9 CON10					0.0001	
	IGNZ	0.83904032	0.20589788 0.49916380	324.81144222 23.11722578		0.0001 0.0934	
Bounds on condition number	r: 1.483112	97.8993	7				
					•••••	*********************	•••••
Step 2 Variable COH6 Re	moved R-sq	uare = 0.2578	7698 C(p) = 7.	34072123			
		DF	Sum of Squares	Mean Square	F	Prob>F	
	Regression Error	8 533	1515.69733514 4361.90106486	189.46216689 8.18367930	23.15	0.0001	
	Total	541	5877.59840000	- · · · · / • = •			
		Parameter	Standard	Type II			
	Variable	Estimate	Error	Sum of Squares	F	Prob>F	
	2003	0.58401704	0.33906329	24.27940851	2.97	0.0856	
	COH4	0.42251939	0.27696558	19.04540835	2.33	0.1277	
	CONS CON7	0.33551978 0.88181236	0.24655806 0.54807350	15.15466897 21.18475083		0.1741 0.1082	
	COH8	0.37101993	0.28229645	14.13618634	1.73		
	COH9	3.41681488	0.60817377	258.30697676	31.56	0.0001	
	CON10 IGN2	1.27885773 0.80740806	0.20517679 0.49831580	317.93372214 21.48450990	38.85 2.63	0.0001 0.1058	
sounds on condition numbe							
		, ;0./0003	, 			*****	

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1981+ FUEL-INJECTED VEHICLES - OK DIAGNOSTICS - ALL SITES COMBINED 15:02 Tuesday, May 2, 1995 Step 3 Variable COM8 Removed R-square = 0.25547189 C(p) = 7.06594780 F Prob>F DF Sum of Squares Mean Square 214.50873554 7 26.18 0.0001 1501.56114880 Regression 8.19482631 534 Error 4376.03725120 Total 541 5877.59840000 Type 11 Parameter Standard Variable Sum of Squares Estimate Error £ Prob>F 0.60053578 0063 0.33906094 25.70762813 20.34800955 3.14 0.0771 0.43641129 COH4 2.48 0.1157 COH5 0.35877572 0.24608973 17.41802354 2.13 0.1455 COH7 0.90125995 0.54824672 22.14561888 261.23953843 2.70 0.1008 COH9 3.43524245 0.60842607 0.0001 CON10 .32558108 0.20221107 352.16198231 42.97 0.0001 LCN2 0.82953519 0.49837039 22,70413274 2.77 0.0966 Bounds on condition number: 1.455839, 59.0831 ······ Step 4 Variable COMS Removed R-square = 0.25250843 C(p) = 7.19170056 DF Sum of Squares Mean Souare F Prob>F 247.35718754 Regression * 1484 . 14312526 30.12 0.0001 8.21206593 535 4393.45527474 Error Total 541 5877.59840000 Standard Type 11 Parameter Variable Estimate Sum of Squares Error F Prob>F COH3 0.64411923 0.33809556 29.80616013 3.63 0.0573 COH4 0.55104209 0.26583584 0.54882282 35.28538870 22.10654636 4.30 0.0387 0.90046409 COH7 2.69 0.1014 COH9 3.46780767 0.60865512 266.57528028 CON10 1.42113183 0.19149634 452.27252879 55.07 0.0001 0.49323360 IGN2 0.93867747 29.74266663 3.62 0.0576 Sounds on condition number: 1.250335. 40.18764 Step 5 Variable CON7 Removed R-square = 0.24874727 C(p) = 7.88965603 DF Sum of Squares Nean Square F Prob>F 5 1462.03657890 292.40731578 Regression 35.49 0.0001 536 4415.56182110 8.23798847 Error Total 541 5877.59840000 Standard Parameter Type II Sum of Squares Variable Estimate Error F Prob>F 00163 0.67826076 0.33798678 33.17532242 4.03 0.0453 36.13901903 268.16410396 COH4 0.55760458 0.26622494 4.39 0.0367 COH9 3.47794732 0.60958359 32.55 0.0001 1.45557203 CON10 0.19064258 480.22940567 58.29 0.0001 29.83422625 1042 0.94011968 3.62 0.0576 Bounds on condition number: 1.235312, 28.25606 All variables left in the model are significant at the 0,1000 level. Summary of Backward Elimination Procedure for Dependent Variable R_HC Variable Number Partial Kodel Step Removed In R**2 R**2 C(p) F Prob>F Label SENS2 0.0003 8.2289 9 0.2594 0.2289 0.6325 COH6 COH8 0.0015 0.2918 8 7 0.2579 7.3407 1.1134 23 EGR 7.0659 0.2555 1.7274 CATALYST COHS 0.0030 0.2525 7.1917 2.1255 0.1455 4 6 IGN TUNE-UP 5 COH7 S 0.0038 0.2487 7.8897 2.6920 0.1014 SECONDARY AIR

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	1981	+ FUEL-INJECTED	VEHICLES - OK DI	AGNOSTICS - ALL SI	TES COMBIN	ED 15:02 Tuesday, May 2,	1995
	Ba	ckward Eliminat	ion Procedure for	Dependent Variabl	e R_CO		
Step 0	All Variables Entered R	-square = 0.322	94678 C(p) = 10	0.00000000			
		DF	Sum of Squares	Mean Square	F	Prob>F	
	Regression	10	400145.78720277	40014,57872028	25.33	0.0001	
	Error Total	531 541	838899.82609723 1239045.6133000	1579.84901337			
		Parameter		Туре П			
	Variable	Estimate	Error	Sum of Squares	F	Prob>f	
	C013	9.68804321		6627.14426459	4.19	0.0410 0.0760	
	CON4 CON5	6.86034238 4.74159235		4995.03382274 2956.21641616	3.16 1.87	0.1719	
	COH6	-4.09187022			1.07	0.3004	
	COM7	8.54440164		1972.62502418	1.25	0.2643	
	CONB	-1.61941298		264.04069029	0.17	0.6828	
	COM9 COM10	34.93443255 28.80442977		26718.29366389 159902.60563723	16.91 101.21	0.0001 0.0001	
	IGN2	0.92382044		28.02226598	0.02	0.8941	
	SENS2	3.42204577		294.94239741	0.19		
Bounds	on condition number: 1.49	823, 119.32	32				
step 1	Variable IGN2 Removed R	-square = 0.322	92416 C(p) = 8 Sum of Squares		F	Prob>F	
	Regression		400117.76493678	Mean Square	28.19	0.0001	
	Error Total	532 541	838927.84836322 1239045.6133000	1576.93204580	20.17		
	Variable	Parameter Estimate		Type II Sum of Squares	F	Prob>F	
				-			
	CON3	9.71363211		6673.20892254	4.23	0.0402	
	C014 C015	6.84039598 4.80595388		4973.52439222 3097.21710322	3.15 1.96	0.0763 0.1617	
	COHÓ	-4.06015186		1677.60587165	1.06	0.3028	
	COH7	8.54007086		1970.66149784	1.25	0.2641	
	CONS	-1.60619100		259.90993636	0.16	0.6849	
	CON9 CON10	34.96461718		26783.54983022 160768.16454340	16.98 101.95	0.0001 0.0001	
	SENS2	28.82783326 3.41168160	7.91229982	293.18685518	0.19	0.6665	
ounds o	on condition number: 1.4691	08, 97.397	55				
tep 2	Variable COM8 Removed R-	square = 0.322	71439 C(p) = 6	.18225299			
		DF	Sum of Squares	Mean Square	F	Prob>F	
	Regression Error Total	8 533 541	399857.85500043 839187.75829957 1239045.6133000	49982.23187505 1574.46108499	31.75	0.0001	
	1000	Parameter		Type II			
	Variable	Estimate		Sum of Squares	F	Prob>f	
	0013	9.66560399	4.71676146	6611.53192706	4.20		
	CON4 CON5	6.79796773 4.72572912	3.84729211 3.42087730	4915.63699881 3004.65480441	3.12 1.91	0.0778 0.1677	
	CONG	-4.28592870	3.89390518	1907.44081546	1.21		
	COH7	8.49694224	7.63272173	1951.18480220	1.24	0.2661	
	COH9	34.92738213	8.47686557	26729.65853010	16.98	0.0001	
	CON10 SENS2	28.64165543 3.39191075	2.81580220 7.90594858	162901.04696833 289.80961674	103.46 0.18		
ounds a		23, 77.0584					
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1981+ FUEL-INJECTED VEHICLES - OK DIAGNOSTICS - ALL SITES COMBINED 15:02 Tuesday, May 2, 1995 Step 3 Variable SENS2 Removed R-square = 0.32248050 C(p) = 4.36569433 ÐF Sum of Squares Mean Square F Prob>F 36.31 0.0001 399568.04538369 57081.14934053 7 Regression 534 839477.56791631 1572.05537063 541 1239045.6133000 Total Parameter Standard Type II Variable Sum of Squares F Prob>F Error Estimate 4.71285745 6643.60164331 4.23 0.0403 COH3 9.68840258 6.76925934 3.84377023 3.40092606 4875.68126580 3.10 0.0788 COH4 3227.97512318 1861.54193731 0.1525 CONS 4.87335850 2.05 3.88888839 1.18 0.2770 COH6 -4.23182766 8.54347920 7.62611806 8.45835590 1973.01470427 27104.00282521 1.26 0.2631 CON7 COM9 35,12115201 COH10 2.81155423 163675.55325963 104.12 0.0001 28.68827624 Bounds on condition number: 1.449415, 60.0479 Step 4 Variable COM6 Removed R-square = 0.32097810 C(p) = 3.54399802 F Prob>F DF Sum of Squares Mean Square 6 397706.50344638 66284.41724106 42.15 0.0001 Regression 841339.10985362 1572.59646702 535 Error Total 541 1239045.6133000 Parameter Standard Type 11 Variable Estimate Error Sum of Squares F Prob>F CONG 9.19346000 4.69166556 3.83443813 6038.39034914 3.84 0.0506 4474.40821682 CON4 6.46786414 2.85 0.0922 4.37364916 3.37036040 2648.21044595 1.68 0.1950 COHS COH7 7.77620994 7.59475936 1648.63765416 1.05 0.3063 8,42399152 26033 79757013 0.0001 mag 34.27504512 16.55 2.79361740 161823.65909249 COH10 28.33865853 102.90 0.0001 Bounds on condition number: 1.422989. 44.00458 R-square = 0.31964753 C(p) = 2.58753930 Step 5 Variable COM7 Removed DF Sum of Squares Mean Square F Prob>F Regression 5 396057.86579222 79211.57315844 50.37 0.0001 842987.74750778 1239045.6133000 Error 536 1572.73833490 541 Total Parameter Standard Type II Variable Sum of Squares F Prob>F Estimate Error 6457.54231439 4555.34107541 4.68297978 3.83419934 4.11 0.0432 0003 9.48915796 0.0894 COH4 6.52539644 2.90 COHS 3.37051156 2645.21753304 1.68 0.1952 4.37117587 34.36345976 8.42392888 26171.03240215 16.64 0.0001 CON9 106.23 0.0001 2.77846379 167076.10490409 CONTR 28.63740598 Bounds on condition number: 1.422989, 31,43602 Step 6 Variable COM5 Removed R-square = 0.31751264 C(p) = 2.26188761 DF Kean Square F Prob>F Sum of Squares 393412.64825918 98353.16206480 0.0001 4 537 62.46 Regression 845632.96504082 1574.73550287 Erro 1239045.6133000 Total 541 Standard Parameter Type II Sum of Squares F Prob>F Variable Estimate Error 10.07607015 7349.69255709 4.67 0.0312 4.66402002 0007 3,68062057 7308.01462149 4.64 0.0317 7.92897307 CON4 8.42180943 26923.63645789 2.61286367 · 205782.27682898 COH9 34.82318253 17.10 0.0001 130.68 0.0001 COH10 29.86874150

A-14

			1981+ FUE	L-INJECTED	VEHICLES - C	K DIAGHOST	ICS - ALL	SITES COMBINED	15:02 Tuesday,	May 2, 1995
	condition nu		1.213903,	18.347						
	bles left in									
	Summary of Bac						co			
	Variable	Number	Partial	Model						
Ste		In	R**2	R**2	C(p)		Prob>f	Label		
	I GN2 COH8	9 8	0.0000	0.3229 0.3227	8.0177 6.1823	0.0177 0.1648	0.6849	CATALYST		
	SENS2 COM6	76	0.0015	0.3225 0.3210	4.3657 3.5440	0.1841 1.1841	0.2770			
	CON7 CON5	5	0.0013 0.0021	0.3196 0.3175	2.5875 2.2619	1.0484 1.6819		SECONDARY AIR IGN TUNE-UP		

<pre>ttp 0 All Variables Entered R-square 0.3543783 C(p) = 10.00000000</pre>		Baci	ward Eliminati	on Procedure for	Dependent Variabl	e R_NOX		
Regression 0 327,75707240 32,775707247 33.19 0.0001 From 531 556.35860260 1.04775531 33.19 0.0001 Variable Parameter Standard Type II F COG -0.22330108 0.12181563 3.6018986 3.51 0.6615 COG -0.27372370 0.1065281 7.37009144 77.38 0.1001 COM 0.37772333 0.10065281 7.37009740 3.53 0.4001 COM -0.2737330 0.10065281 7.37009741 0.330 0.1001 COM -0.15971230 0.21075284 0.210710890 0.530 0.4271 COM -0.15971245 0.21075284 0.21071080 0.530 0.4271 COMI -0.15971453 0.21075284 0.41075284 0.77714 0.3732 COMI -0.15970425 0.21075284 0.41075028 0.51764521 7.3772777 Total S41 199.3222 52636437720 3.410.403204 0.7779 0.377	tep 0 All Variable	es Entered R-s	quare = 0.3846	3783 C(p) = 10	00000000			
Regression 10 347.75700740 32.775700740 32.19 0.001 Total 56.338462260 1.04775331 33.19 0.001 Variable Parameter Standard Type II F COVI -0.22330108 0.12181543 3.46918964 3.51 0.0613 COVI -0.22307108 0.10185281 7.3409744 4.539 0.501 0.5013 COVI -0.22307108 0.1005281 7.3409744 4.539 0.501 <th></th> <th></th> <th>DF</th> <th>Sum of Squares</th> <th>Hean Square</th> <th>F</th> <th>Prob>F</th> <th></th>			DF	Sum of Squares	Hean Square	F	Prob>F	
Error 531 556.35800200 1.04775631 Variable Parameter Standard Type II F Cod -0.2230108 0.1515633 3.5017860 3.51 0.6615 Cod -0.2230108 0.1515633 3.5017860 3.51 0.6615 Code -0.2237040 0.09035889 6.51399706 6.22 0.0130 Code 0.02377339 0.1016228 7.52971979 10.60 0.0031 Code 0.10527339 0.21375286 0.5529453 0.53 0.4479 Code -0.1593143 0.21375286 0.5371286 0.23717979 10.60 0.0031 Code -0.1593143 0.21375286 0.53122 10.232355 0.77 0.3722 Statez 0.1052442 0.1783481 0.325399410 0.3243595 0.5512 total 1.45923 119.3222 55.5589423 1.46420804 1.45728847 0.144420804 total 1.45923 119.3223 55.55897245 1.46420804 0.11		Respection	10			77 10	0.0001	
Variable Estimate Error Sun of Squares F Prob>F CON3 -0.2283008 0.12181533 3.68018964 3.13 0.6453 CON4 0.24774241 0.0895809 6.222 0.0130 CON5 0.1212140 0.0895809 0.22076644 0.212 0.6439 CON5 0.12737233 0.105220 7.05201069 0.230 0.6439 CON6 1.27272339 0.1022125 168.27017779 100.460 0.4001 CON6 -0.11373396 0.7372396 2.49277231 2.38 0.1235 CON6 -0.11373396 0.7372396 2.49277231 2.38 0.1235 SENS2 0.18179052 0.20396110 0.83235395 0.79 0.3732 aunds on condition number: 1.49823 119.3232 110.42280 1.0420804 36.91 0.0001 Variable CON5 Regression 9 347.3330274 38.61/20063 36.91 0.0001 Variable CON5 Regression 9		Error	531	556.35860260				
CDM4 0.24774241 0.09925889 6.5139706 6.2207664 0.21 0.6439 CDM5 0.0471261 0.0992664 0.2207664 0.2307664 0.21 0.6439 CDM5 0.0471261 0.1065221 73.7409714 70.38 0.4001 CDM5 1.2977333 0.1005221 166.2701777 102.40 0.233 0.4033 CDM5 0.105520720 0.1287564 0.33725847 0.33 0.4333 CDM7 0.136520720 0.17851461 0.33732847 0.34 0.5372 SENS2 0.18179052 0.20396110 0.833333 0.79 0.3732 conds on condition number: 1.49823 119.5222 1.0428034 1.017952 0.20396110 0.833333 top 1 Variable Regression 9 3.47330074 3.6477008 3.6.91 0.0001 Error 532 556.5567726 1.0428004 1.0428004 0.9777473 7.4.1 0.0653 CDM6 -0.25017934 0.117505094 0.52774733 <td></td> <td>Variable</td> <td></td> <td></td> <td></td> <td>F</td> <td>Prob>f</td> <td></td>		Variable				F	Prob>f	
CONG 0.041/23140 0.0892/26044 0.22407666 0.213 CONG 0.1356/2733 0.1016/221 73.74009146 70.38 0.0001 CONF 0.1356/27333 0.1001225 10.2271339 0.1001225 0.52717089 0.530 0.4675 CONF -0.156/3143 0.2187/5622 0.152729443 0.2187 0.162 0.4675 CONF -0.156/3143 0.2187/5622 0.152259447 0.38 0.1572 CONF -0.156/3143 0.2187/6522 0.137226 0.3572 0.4675 CONF -0.166/2342 0.17824541 0.37226 0.4675 0.5712 CONF -0.166/2389790 C(p) = 8.213663335 0.25722 0.467 0.3732 CONF Sum of Squares Nean Squares F Probof 7 Total 54.1 504.1570008 36.91 0.0001 1 Variable Estimate Error Sum of Squares F Probof CONG -0.22247794 0.12140543								
C046 0.85273799 0.10165221 73.74007144 70.38 0.0001 C047 0.13967233 0.10010225 168.27017979 160.400 0.0001 C049 -0.13973388 0.10271225 168.27017979 162.407 0.1385 0.4277 C0410 -0.13973388 0.1377244 2.4977231 2.38 0.1237 C0410 -0.13973388 0.137244 2.4977231 2.38 0.1237 C0410 -0.13973388 0.137244 2.4977231 2.38 0.1237 conds on condition number: 1.49823 119.3232								
$ \begin{array}{c} CM7 & 0.1367233 & 0.19691966 & 0.52711089 & 0.50 & 0.4785 \\ COM6 & 1.2227339 & 168.2217797 & 160.60 & 0.0001 \\ COM7 & -0.15893143 & 0.1275582 & 0.5529465 & 0.532 & 0.6479 \\ COM10 & -0.1157338 & 0.73723841 & 0.37259847 & 0.36 & 0.5512 \\ IGH2 & 0.10652492 & 0.7783441 & 0.37259847 & 0.36 & 0.5512 \\ IGH2 & 0.10652492 & 0.7363441 & 0.37259847 & 0.36 & 0.5512 \\ IGH2 & 0.10652492 & 0.7363441 & 0.37259847 & 0.36 & 0.5512 \\ IGH2 & 0.10652492 & 0.7783441 & 0.37259847 & 0.36 & 0.5512 \\ IGH2 & 0.1052492 & 0.7783441 & 0.37259847 & 0.36 & 0.5512 \\ IGH2 & 0.1052492 & 0.7783441 & 0.37259847 & 0.36 & 0.5512 \\ IGH2 & 0.1052492 & 0.7783441 & 0.37259847 & 0.36 & 0.5512 \\ IGH2 & 0.105233 & 0.001 & 0.823333 \\ \hline DF & Sum of Squares & Kean Square & F ProbF \\ \hline Regression & 9 & 367.53302074 & 30.61478008 & 36.91 & 0.0001 \\ \hline Error & 532 & 556.53267926 & 1.0462084 & 1.0462084 \\ Iotal & 541 & 90.411570000 \\ \hline Variable & Estimate & Standard & Type II \\ \hline Variable & Estimate & Standard & Type II \\ \hline Variable & Estimate & Standard & Type II \\ \hline COM5 & -0.22421794 & 0.12140553 & 0.57725322 & 0.4001 & 0.6653 \\ COM6 & 0.326015038 & 0.10095398 & 0.51726322 & 0.400 & 4.623 \\ COM6 & 0.326015038 & 0.10095393 & 0.51726322 & 0.400 & 4.623 \\ COM6 & 0.136540368 & 0.10095393 & 0.51726322 & 0.400 & 4.623 \\ COM6 & 0.15050362 & 0.10770594 & 0.4625117 & 0.450 & 0.5460 \\ COM7 & 0.1352446 & 0.10075338 & 0.51726322 & 0.4728 \\ COM10 & -0.15701444 & 0.21656488 & 0.53992284 & 0.52 & 0.4728 \\ IGH2 & 0.11602028 & 0.17075943 & 0.45517054 & 0.4550 & 0.5460 \\ COM7 & 0.15702042 & 0.4277744 & 0.33330485 & 41.51 & 0.0001 \\ COM7 & 0.1352716, 91.45643 & 0.53972714 & 0.85 & 0.3460 \\ Nards on condition number: & 1.332716, 91.45643 & 0.53972714 & 0.45 & 0.5460 \\ Nards on condition number: & 1.332716, 91.45643 & 0.10051977 & 75.6071714 & 0.65 & 0.5460 \\ COM5 & -0.22005572 & 0.12116217 & 5.46425312 & 3.30 & 0.6697 \\ COM5 & -0.22005572 & 0.12116217 & 5.46425312 & 3.30 & 0.6697 \\ COM5 & -0.22005572 & 0.12116217 & 5.46425312 & 3.30 & 0.6697 \\ COM5 & -0.22005572 & 0.121162$								
COMP -0.1582314.3 0.21372582 0.552394.45 0.325 0.225 IGN2 0.103525842 0.1737258 0.2337589.7 0.34 0.5512 SENS2 0.10817052 0.20394110 0.3235395 0.77 0.3732 sunds on condition number: 1.49823, 119.3232 Total 5.41 19.3232 Total 5.41 19.3232 Total 5.41 20074 38.61478008 36.91 0.0001 From 532 356.53267926 1.0420004 Total 5.41 904.11570000 Variable COMS Removed R-square = 0.38438999 C(p) = 8.21386333 DF Sum of Squares Mean Square F Prob>F Regression 9 3.7,7330074 38.61478008 36.91 0.0001 Total 5.41 904.11570000 Variable Parameter Standard Type II Variable Parameter Standard 0.1796594 4.0532 0.0001 COM6 0.28050364 0.10095397 75.59978115 77.22 0.0001 COM6 0.2805038 0.01905397 75.59978115 77.22 0.0001 COM6 0.2805038 0.01905397 75.59978115 77.22 0.0001 COM6 0.12051393 0.01975954 10.512 0.422 0.422 COM6 0.1055064 0.1097599 106.41423316 16(1):03 0.0001 COM6 0.10550304 0.01905397 75.59978115 77.22 0.0001 COM6 0.2805138 0.01975059 106.41423316 16(1):03 0.0001 COM6 0.10550304 0.01905397 75.59978115 77.22 0.0001 COM6 0.105701446 0.231 0.51270.414 0.532 0.4423 COM6 0.1055064 0.01905397 10.641423316 16(1):03 0.0001 COM7 0.11834408 0.51707594 0.512 0.4278 COM10 -0.1192284 0.27156654 2.26930338 2.17 0.1414 IN22 0.11804228 0.1707595 106.41423316 16(1):03 0.0001 COM7 0.11804228 0.1707595 0.46423317 0.4515 10.512 0.4728 COM10 -0.1192284 0.27156654 2.26930338 2.17 0.1414 IN22 0.11804228 0.1707595 106.41423316 16(1):03 0.0001 COM7 0.11804228 0.1707595 0.4653177 0.4525 0.5425 SENS2 0.19126339 0.20277946 0.53507352 4.1.51 0.0001 Total 541 994.11570000 Type II From 533 557.04926412 1.04512057 COM3 -0.22005392 0.12118217 3.44623312 3.30 0.06699 COM3 -0.22005392 0.12218217 3.44623312 3.30 0.06699 COM3 -0.22005392 0.12218217 3.44623312 3.30 0.06699 COM3 -0.22005392 0.10039407 7.54422312 3.30 0.06697 COM3 -0.22005392 0.10039407 7.54422312 3.00 0.06697 COM3 -0.22005392 0.10039407 7.54422312 3.30 0.06697 COM3 -0.22005392 0.10039407 7.54422312 0.510057 COM3 -0.22005392 0.10039407 7.54422312 0.50017 COM5				0,19691986	0.52711089			
IGN2 0.10622492 0.172633431 0.37258947 0.34 0.5512 ounds on condition number: 1.49623, 119.3232 0.373233335 0.77 0.3732 tcp 1 Variable CDMS Removed R-square = 0.38438999 C(p) = 8.21364333 F Probof tcp 1 Variable CDMS Removed R-square = 0.38438999 C(p) = 8.21364333 J DF Sum of Squares K Probof tcp 1 Variable CDMS Removed R-square = 0.38438999 C(p) = 8.21364333 J 0.0001 tcp 1 Variable Parameter Stan of Squares K Probof Probof tcp 1 Variable Parameter Standard Type II F Probof COM4 0.26015033 0.01573533 0.5172422 0.4001 O.6653 COM6 0.15804064 0.1097359 1.64.41253161 161.95 0.6001 COM6 0.15804284 0.2397264 0.125 0.4728 0.4728 COM7 0.13834408 0.21854684 0.2397264 0.252 0.47					168.27017979			
IGN2 0.10622492 0.172633431 0.37258947 0.34 0.5512 ounds on condition number: 1.49623, 119.3232 0.373233335 0.77 0.3732 tcp 1 Variable CDMS Removed R-square = 0.38438999 C(p) = 8.21364333 F Probof tcp 1 Variable CDMS Removed R-square = 0.38438999 C(p) = 8.21364333 J DF Sum of Squares K Probof tcp 1 Variable CDMS Removed R-square = 0.38438999 C(p) = 8.21364333 J 0.0001 tcp 1 Variable Parameter Stan of Squares K Probof Probof tcp 1 Variable Parameter Standard Type II F Probof COM4 0.26015033 0.01573533 0.5172422 0.4001 O.6653 COM6 0.15804064 0.1097359 1.64.41253161 161.95 0.6001 COM6 0.15804284 0.2397264 0.125 0.4728 0.4728 COM7 0.13834408 0.2185448 0.33972303 2.17 0.141					0.55299465			
SENS2 0.18179052 0.20396110 0.83235395 0.79 0.3732 sunds on condition number: 1.49823, 119.3232 ttp 1 Variable COMS Removed R-square = 0.38438999 C(p) = 8.21384333 DF Sum of Squares Mean Square F Prob>F Regression 9 347.53302074 38.61478008 36.91 0.0001 Error 532 556.5267726 1.04420804 0.001 Variable Estimate Error Sum of Squares F Prob>F Code 0.222421794 0.21405733 5.5647200 3.41 0.0053 Code 0.22421794 0.121405316 161.95 0.0001 Code 0.22421794 0.2145316 161.95 0.0001 Code 0.1037938 0.51774312 0.490 0.4823 Code 0.1037938 0.51724316 0.405 0.4728 Code 0.1037284 0.2077945 0.4638197 0.450 0.5455 Stat 0.10146233 0.450								
top 1 Variable CONS Removed R-square = 0.38438999 C(p) = 8.21384333 DF Sum of Squares Hean Square F Prob>F Regression 9 347.33302074 38.61478008 36.91 0.0001 Fror 525 556.5580726 1.04620804 1.04620804 Variable Parameter Standard Type II Variable CONS -0.22421794 0.12140543 3.56847420 3.41 0.0667 CONS -0.15701446 0.21160543 0.51724322 0.49 0.4223 0.4272 CONTO -0.11372884 0.070756545 2.5079338 0.17 0.431 0.3440 Namds on condition number: 1.332716, 91.45683 DF Sum of Squares F								
top 1 Variable CONS Removed R-square = 0.38438999 C(p) = 8.21384333 DF Sum of Squares Hean Square F Prob>F Regression 9 347.33302074 38.61478008 36.91 0.0001 Fror 525 556.5580726 1.04620804 1.04620804 Variable Parameter Standard Type II Variable CONS -0.22421794 0.12140543 3.56847420 3.41 0.0667 CONS -0.15701446 0.21160543 0.51724322 0.49 0.4223 0.4272 CONTO -0.11372884 0.070756545 2.5079338 0.17 0.431 0.3440 Namds on condition number: 1.332716, 91.45683 DF Sum of Squares F	ounds on condition nu	mber: 1,4982	3, 119.323	2				
DF Sum of Squares Hean Square F Prob>F Regression 9 347.53302074 38.61478008 36.91 0.0001 Error 532 556.58267926 1.04620804 36.91 0.0001 Variable Parameter Standard Type II F Frob>F COHS -0.22421794 0.12140543 3.56847420 3.41 0.06533 COHS -0.5200586 0.07559696 0.517743222 0.49 0.4823 COHS -0.526970 0.20170959 166.513792 0.4520338 2.17 0.1414 COH9 -0.11926284 0.070595464 0.53902929 0.20277946 0.59077114 0.89 0.3460 stills2 0.11804228 0.17675945 0.4				•••••		•••••		••••••
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CON4 0.26007203 0.09554717 7.74315593 7.41 0.0067 CON6 0.86322919 0.10059107 76.96614957 73.64 0.0001 CON7 0.13750989 0.1966714 0.51104484 0.49 0.4847 CON8 1.2975481 0.10168261 170.18386622 162.84 0.0001 CON9 -0.15269167 0.21835544 0.51105671 0.4847 CON10 -0.09888711 0.07012506 2.07825723 1.99 0.1591 SENS2 0.19183980 0.20267222 0.93638695 0.90 0.3443		Variable				F	Prob>F	
CON6 0.86322919 0.10059107 76.96614957 73.64 0.0001 CON7 0.13750989 0.19664714 0.51104484 0.49 0.4847 CON8 1.29754581 0.10168261 170.18386622 162.84 0.0001 CON9 -0.15269167 0.21835544 0.51105671 0.49 0.4847 CON10 -0.09888711 0.07012506 2.07825723 1.99 0.1591 SENS2 0.19183980 0.20267222 0.93638695 0.90 0.3443 unds on condition number: 1.317662, 72.71303								
CON7 0.13750989 0.19664714 0.51104484 0.49 0.4847 CON8 1.29754581 0.10168261 170.18386622 162.84 0.0001 CON9 -0.15269167 0.21835544 0.51105671 0.49 0.4847 CON10 -0.07888711 0.07012506 2.07825723 1.99 0.1591 SENS2 0.19183980 0.20267222 0.93638695 0.90 0.3443 unds on condition number: 1.317462, 72.71303								
CON8 1.29754581 0.10168261 170.18386622 162.84 0.0001 CON9 -0.15269167 0.21835544 0.51105671 0.49 0.4847 CON10 -0.09888711 0.07012506 2.07825723 1.99 0.1591 SENS2 0.19183980 0.20267222 0.93638695 0.90 0.3443								
COM9 -0.15269167 0.21835544 0.51105671 0.49 0.4847 COM10 -0.09888711 0.07012506 2.07825723 1.99 0.1591 SENS2 0.19183980 0.20267222 0.93638695 0.90 0.3443 unds on condition number: 1.317662, 72.71303								
COM10 -0.09888711 0.07012506 2.07825723 1.99 0.1591 SENS2 0.19183980 0.20267222 0.93638695 0.90 0.3443 unds on condition number: 1.317462. 72.71303					0.51105671	0.49	0.4847	
unds on condition number: 1.317462. 72.71303		CON10	-0.09888711	0.07012506	2.07825723	1.99	0.1591	
unds on condition number: 1.317462, 72.71303		SENS2	0.19183980	0.20267222	0.93638695	0.90	0.5443	
	unds on condition num	ber: 1.317462	, 72.71303					

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		1981+	FUEL-INJECTED	VEHICLES - OK DI	AGNOSTICS - ALL SI	TES COMBIN	ED 15:0	2 Tuesday, May 2, 19
Step 3	Variable COM7			0868 C(p) = 5				
			DF	Sum of Squares	Mean Square	F	,Prob>F	
		Regression Error	7 534	346.55539393 557.56030607		47.42	0.0001	
		Total	541	904.11570000 Standard	Type II			
		Variable	Parameter Estimate		Sum of Squares	F	Prob>F	
		C043	-0.21577480	0.12096964	3.32199712 7.75837125	3.18	0.0750	
		CON4		0.09550076	7.75837125	7.43	0.0066	
		CON6	0.86940813	0.10015426	78.67905281	75.35	0.0001	
		COM8	1.29847341	0.10162530	170.45629060	163.25	0.0001	
		COM9	-0.15265009	0.21825091	0.51004404	0.49	0.4846 0.1762	
		COM10 SENS2	0.19363331	0.00961003	0.51064464 1.91541952 0.95413021	1.65	0.3395	
					0.93413021	0.91	0.3375	
lounds (on condition num	ber: 1.30722	4, 56.2130		••••••	•••••		•••••
itep 4	Variable COH9	Removed R-s	quare = 0.3827	4388 C(p) = 3	.63429997			
			DF	Sum of Squares	Nean Square	F	Prob>F	
		Regression	6	346.04474929	57,67412488	55.29	0.0001	
		Error Total	535 541	558.07095071 904.11570000	1.04312327			
			Parameter	Standard	Type II			
		Variable	Estimate		Sum of Squares		Prob>F	
		C043	-0.21983557	0.12077249 0.09536450	3.45617356 7.60032289	3,31	0.0693	
		CON4	0.25741564	0 00536250	7,60032289	7.29	0_0077	
		COK6	0.86300284	0.09968694	78,17781496			
		COH8	0.86300284	0.09968694	78,17781496			
ounds o	on condition num		0.86300284 1.29760922 -0.09869325 0.18572826	0.09968694 0.10156925 0.06953534 0.20214676	78,17781496	163.22	0.0001	
		CON8 CON10 SENS2 ber: 1.29787	0.86300284 1.29760922 -0.09859325 0.18572826 7, 41.7231	0.09968694 0.10156925 0.06953534 0.20214676 8	78.17781496 170.25464734 2.10135483 0.88055816	163.22	0.0001	
		COM8 COM10 SENS2 ber: 1.29787	0.86300284 1.29760922 -0.09869325 0.18572826 7, 41.7231 	0.09968694 0.10156925 0.06953534 0.20214676 8	78.17781496 170.25464734 2.10135483 0.88055816	163.22 2.01 0.84	0.0001	
		CON8 CON10 SENS2 ber: 1.29787 Removed R-s	0.84300284 1.29760922 -0.09869325 0.18572826 7, 41.7231 	0.09968694 0.10156925 0.06953534 0.20214676 8 6993 C(p) = 2 Sum of Squares	78.17781496 170.25464734 2.10135483 0.88055816 .47472264 Mean Square	163.22 2.01 0.84	0.0001 0.1564 0.3586 Prob>F	
		COM8 COM10 SENS2 ber: 1.29787	0.86300284 1.29760922 -0.09869325 0.18572826 7, 41.7231 	0.09968694 0.10156925 0.06953534 0.20214676 8	78.17781496 170.25464734 2.10135483 0.88055816	163.22 2.01 0.84	0.0001 0.1564 0.3586	
		COM8 COM10 SEKS2 ber: 1.29787 Removed R-s Regression Error Total	0.84300284 1.29760922 -0.09869325 0.18572826 7, 41.7231 	0.09968694 0.10156925 0.06953534 0.20214676 8 5993 C(p) = 2 Sum of Squares 345.16419113 558.95150887 904.11570000 Standard	78.17781496 170.25464734 2.10135483 0.88055816 .47472264 Nean Square 69.03283823 1.04281998 Type 11	74.75 163.22 2.01 0.84 F 66.20	0.0001 0.1564 0.3586 Prob>F 0.0001	
		COM8 COM10 SENS2 ber: 1.29787 Removed R-s Regression Error Total Variable	0.84300284 1.29760922 -0.09869325 0.18572826 7, 41.7231 quare = 0.3817 Df 5 536 541 Parameter Estimate	6.09968694 0.10156925 0.06953534 0.20214676 8 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	78.17781496 170.25464734 2.10135483 0.88055816 .47472264 Nean Square 69.03283823 1.04281998 Type II Sum of Squares	F 666.20	0.0001 0.1564 0.3586 Prob>F 0.0001 Prob>F	
		COM8 COM10 SEKS2 ber: 1.29787 Removed R-s Regression Error Total Variable COM3	0.84300284 1.29760922 -0.09869325 0.18572826 7, 41.7231 quare = 0.3817 Df 5 536 541 Parameter Estimate -0.21733083	6.09968694 0.10156925 0.06953534 0.20214676 8 50993 C(p) = 2 Sum of Squares 345.16419113 558.95150887 904.11570000 Standard Error 0.12072416	78.17781496 170.25464734 2.10135483 0.88055816 .47472264 Mean Square 69.03283823 1.04281998 Type II Sum of Squares 3.37958699	F 666.20 F 3.24	0.0001 0.1564 0.3586 Prob>F 0.0001 Prob>F 0.0724	
		COM8 COM10 SENS2 ber: 1.29787 Removed R-s Regression Error Total Variable COM3 COM4	0.84300284 1.29760922 -0.09869325 0.18572826 7, 41.7231 	6.09968694 0.10156925 0.06953534 0.20214676 8 5993 C(p) = 2 Sum of Squares 345.16419113 558.95150887 904.11570000 Standard Error 0.12072416 0.09534364	78.17781496 170.25464734 2.10135483 0.88055816 .47472264 Mean Square 69.03283823 1.04281998 Type 11 Sum of Squares 3.37958699 7.66426008	F 666.20 F 3.24 7.35	0.0001 0.1564 0.3586 Probof 0.0001 Probof 0.0724 0.0069	
		COM8 COM10 SENS2 ber: 1.29787 Removed R-s Regression Error Total Variable COM3 COM4 COM6	0.84300284 1.29760922 -0.09869325 0.18572826 7, 41.7231 	6.09968694 0.10156925 0.06953534 0.20214676 8 5093 C(p) = 2 Sum of Squares 345.16419113 558.95150887 904.11570000 Standard Error 0.12072416 0.09534364 0.09954496	78.17781496 170.25464734 2.10135483 0.88055816 .47472264 Nean Square 69.03283823 1.04281998 Type 11 Sum of Squares 3.37958699 7.66426008 79.22150720	143.22 2.01 0.84 F 66.20 F 3.24 7.35 75.97	0.0001 0.1564 0.3586 Prob>F 0.0001 Prob>F 0.0001	
		COM8 COM10 SEKS2 ber: 1.29787 Removed R-s Regression Error Total Variable COM3 COM4 COM8	0.84300284 1.29760922 -0.09869325 0.18572826 7, 41.7231 	6.09968694 0.10156925 0.06953534 0.20214676 8 50993 C(p) = 2 51m of Squares 345.16419113 558.95150887 904.1157000 Standard Error 0.12072416 0.09534364 0.09954498 0.10154608	78.17781496 170.25464734 2.10135483 0.88055816 .47472264 Mean Square 69.03283823 1.04281998 Type II Sum of Squares 3.37958699 7.66426008 79.22150720 170.59814802	F 66.20 F 3.24 7.35 75.97 163.59	0.0001 0.1564 0.3586 Prob>F 0.0001 Prob>F 0.0724 0.0069 0.0001 0.0001	
tep 5	Variable SENS2	COM8 COM10 SENS2 ber: 1.29787 Removed R-s Regression Error Total Variable COM3 COM4 COM6 COM10	0.84300284 1.29760922 -0.09869325 0.18572826 7, 41.7231 	6.09968694 0.10156925 0.06953534 0.20214676 8 5093 C(p) = 2 Sum of Squares 345.16419113 558.95150887 904.11570000 Standard Error 0.12072416 0.09534364 0.0954498 0.10154608 0.06931784	78.17781496 170.25464734 2.10135483 0.88055816 .47472264 Nean Square 69.03283823 1.04281998 Type 11 Sum of Squares 3.37958699 7.66426008 79.22150720	F 66.20 F 3.24 7.35 75.97 163.59	0.0001 0.1564 0.3586 Prob>F 0.0001 Prob>F 0.0001	
tep 5		COM8 COM10 SENS2 ber: 1.29787 Removed R-s Regression Error Total Variable COM3 COM4 COM6 COM8 COM10	0.84300284 1.29760922 -0.09869325 0.18572826 7, 41.7231 	6.09968694 0.10156925 0.06953534 0.20214676 8 5093 C(p) = 2 Sum of Squares 345.16419113 558.95150887 904.11570000 Standard Error 0.12072416 0.09534364 0.0954498 0.10154608 0.06931784	78.17781496 170.25464734 2.10135483 0.88055816 .47472264 Nean Square 69.03283823 1.04281998 Type 11 Sum of Squares 3.37958699 7.66426008 79.22150720 170.59814802 1.90799002	F 666.20 F 3.24 F 666.20 F 3.24 7.35 75.97 163.59 1.83	0.0001 0.1564 0.3586 Prob>F 0.0001 Prob>F 0.0724 0.0069 0.0001 0.0001 0.1767	
tep 5 ounds o	Variable SENS2	COM8 COM10 SENS2 ber: 1.29787 Removed R-s Regression Error Total Variable COM3 COM4 COM6 COM8 COM10 ber: 1.290144	0.84300284 1.29760922 -0.09869325 0.18572826 7, 41.7231 	6.09968694 0.10156925 0.06953534 0.20214676 8 5093 C(p) = 2 Sum of Squares 345.16419113 558.95150887 904.11570000 Standard Error 0.12072416 0.09534364 0.0954498 0.10154608 0.06931784	78.17781496 170.25464734 2.10135483 0.88055816 .47472264 Nean Square 69.03283823 1.04281998 Type 11 Sum of Squares 3.37958699 7.66426008 79.22150720 170.59814802 1.90799002	F 666.20 F 3.24 F 666.20 F 3.24 7.35 75.97 163.59 1.83	0.0001 0.1564 0.3586 Prob>F 0.0001 Prob>F 0.0724 0.0069 0.0001 0.0001 0.1767	
tep 5 ounds o	Variable SENS2	COM8 COM10 SENS2 ber: 1.29787 Removed R-s Regression Error Total Variable COM3 COM4 COM6 COM8 COM10 ber: 1.290144	0.84300284 1.29760922 -0.09869325 0.18572826 7, 41.7231 	6.09968694 0.10156925 0.06953534 0.20214676 8 5093 C(p) = 2 Sum of Squares 345.16419113 558.95150887 904.11570000 Standard Error 0.12072416 0.09954498 0.10154608 0.00954498 0.10154608 0.06931784	78.17781496 170.25464734 2.10135483 0.88055816 .47472264 Nean Square 69.03283823 1.04281998 Type 11 Sum of Squares 3.37958699 7.66426008 79.22150720 170.59814802 1.90799002	F 66.20 F 3.24 7.35 75.97 1.83	0.0001 0.1564 0.3586 Prob>F 0.0001 Prob>F 0.0724 0.0069 0.0001 0.0001 0.1767	
tep 5 ounds o	Variable SENS2	COM8 COM10 SENS2 ber: 1.29787 Removed R-s Regression Error Total Variable COM4 COM4 COM4 COM4 COM4 COM4 COM4 COM4	0.84300284 1.29760922 -0.09869325 0.18572826 7, 41.7231 quare = 0.3817 Df 5 536 541 Parameter Estimate -0.21733083 0.25847715 0.86763340 1.29881003 -0.09376234 6, 29.6185 quare = 0.3796! DF 4	0.09968694 0.10156925 0.06953534 0.20214676 8 50993 C(p) = 2 51m of Squares 345.16419113 558.95150887 904.11570000 Standard Error 0.12072416 0.09534364 0.09934498 0.10154608 0.06931784 7	78.17781496 170.25464734 2.10135483 0.88055816 .47472264 Mean Square 69.03283823 1.04281998 Type II Sum of Squares 3.37958699 7.66426008 79.22150720 170.59814802 1.90799002 	F 66.20 F 3.24 7.35 75.97 1.83	0.0001 0.1564 0.3586 ProboF 0.0001 ProboF 0.0724 0.0001 0.0001 0.1767 ProboF	
tep 5 ounds o	Variable SENS2	CONS CONS CON10 SENS2 ber: 1.29787 Removed R-s Regression Error Total Variable CONS CON4 CON4 CON6 CON6 CON10 ber: 1.290144 Removed R-s4	0.84300284 1.29760922 -0.09869325 0.18572826 7, 41.7231 quare = 0.3817 Df 5 536 541 Parameter Estimate -0.21733083 0.25847715 0.86763340 1.29881003 -0.09376234 6, 29.61855 quare = 0.37965 DF	6.09968694 0.10156925 0.06953534 0.20214676 8 6993 C(p) = 2 Sum of Squares 345.16419113 558.95150887 904.11570000 Standard Error 0.12072416 0.09534364 0.09534364 0.09554498 0.10154608 0.10154608 0.06931784 7 5960 C(p) = 2. Sum of Squares	78.17781496 170.25464734 2.10135483 0.88055816 .47472264 Nean Square 69.03283823 1.04281998 Type II Sum of Squares 3.37958699 7.66426008 79.22150720 170.59814802 1.90799002	r4.,57 163.22 2.01 0.84 F 66.20 F 3.24 7.35 75.97 163.59 1.83 F	0.0001 0.1564 0.3586 ProboF 0.0001 ProboF 0.0724 0.0001 0.0001 0.1767 ProboF	
ounds o	Variable SENS2	COM8 COM10 SENS2 ber: 1.29787 Removed R-s Regression Error Total Variable COM3 COM4 COM4 COM6 COM3 COM10 ber: 1.290144 Removed R-su Regression Error Total	0.64300284 1.29760922 -0.09869325 0.18572826 7, 41.7231 	6.09968694 0.10156925 0.06953534 0.20214676 8 5993 C(p) = 2 Sum of Squares 345.16419113 558.95150887 904.11570000 Standard Error 0.12072416 0.09534364 0.09954498 0.10154608 0.06931784 7 5960 C(p) = 2 Sum of Squares 343.25620111 560.85949889 904.11570000 Standard	78.17781496 170.25464734 2.10135483 0.88055816 .47472264 Mean Square 69.03283823 1.04281998 Type 11 Sum of Squares 3.37958659 7.66426008 79.22150720 170.59814802 1.90799002 	F 3.24 7.35 75.97 163.59 1.83 F 82.16	0.0001 0.1564 0.3586 Prob≥F 0.0001 Prob≥F 0.0001 0.0001 0.0001 0.1767 Prob≥F 0.0001	
tep 5 ounds o	Variable SENS2	COM8 COM10 SENS2 ber: 1.29787 Removed R-s Regression Error Total Variable COM4 COM4 COM4 COM6 COM8 COM10 ber: 1.29014 Removed R-s4 Regression Error Total Variable	0.84300284 1.29760922 -0.09869325 0.18572826 7, 41.7231 off 5 536 541 Parameter Estimate -0.21733083 0.25847715 0.86763340 1.29881003 -0.09376234 6, 29.61855 off 4 537 541 Parameter Estimate	0.09968694 0.10156925 0.06953534 0.20214676 8 50993 C(p) = 2 5um of Squares 345.16419113 558.95150887 904.11570000 Standard Error 0.12072416 0.09534364 0.09534364 0.09534364 0.09534784 7 5960 C(p) = 2. 500 C(p) = 2. 500 C(p) = 2. 500 Squares 343.25620111 560.85949889 904.11570000 Standard Error	78.17781496 170.25464734 2.10135483 0.88055816 .47472264 Mean Square 69.03283823 1.04281998 Type II Sum of Squares 3.37958699 7.66426008 79.22150720 170.59814802 1.90799002 	F 66.20 F 3.24 7.35 75.97 1.83 F 82.16 F	0.0001 0.1564 0.3586 Prob>F 0.0001 Prob>F 0.0724 0.0001 0.1767 Prob>F 0.0001 Prob>F 0.0001	
ounds o	Variable SENS2	COM8 COM10 SENS2 ber: 1.29787 Removed R-s Regression Error Total Variable COM3 COM4 COM4 COM4 COM4 COM4 COM4 COM4 COM4	0.64300284 1.29760922 -0.09869325 0.18572826 7, 41.7231 	6.09968694 0.10156925 0.06953534 0.20214676 8 5993 C(p) = 2 Sum of Squares 345.16419113 558.95150887 904.11570000 Standard Error 0.1075436 0.09954498 0.10154608 0.00934364 0.09954498 0.10154608 0.06931784 7 5960 C(p) = 2 Sum of Squares 343.25620111 560.85949889 904.11570000 Standard Error 0.11927312	78.17781496 170.25464734 2.10135483 0.88055816 .47472264 Nean Square 69.03283823 1.04281998 Type 11 Sum of Squares 3.37958659 7.66426008 79.22150720 170.59814802 1.90799002 	F 3.24 7.35 75.97 163.59 1.83 F 82.16 F 4.16	0.0001 0.1564 0.3586 Prob>F 0.0001 Prob>F 0.0001 0.0001 0.0001 0.0001 0.1767 Prob>F 0.0001 Prob>F 0.0001	
ounds o	Variable SENS2	COM8 COM10 SENS2 ber: 1.29787 Removed R-s Regression Error Total Variable COM4 COM4 COM4 COM6 COM8 COM10 ber: 1.29014 Removed R-s4 Regression Error Total Variable	0.84300284 1.29760922 -0.09869325 0.18572826 7, 41.7231 off 5 536 541 Parameter Estimate -0.21733083 0.25847715 0.86763340 1.29881003 -0.09376234 6, 29.61855 off 4 537 541 Parameter Estimate	0.09968694 0.10156925 0.06953534 0.20214676 8 50993 C(p) = 2 5um of Squares 345.16419113 558.95150887 904.11570000 Standard Error 0.12072416 0.09534364 0.09534364 0.09534364 0.09534784 7 5960 C(p) = 2. 500 C(p) = 2. 500 C(p) = 2. 500 Squares 343.25620111 560.85949889 904.11570000 Standard Error	78.17781496 170.25464734 2.10135483 0.88055816 .47472264 Mean Square 69.03283823 1.04281998 Type II Sum of Squares 3.37958699 7.66426008 79.22150720 170.59814802 1.90799002 	F 66.20 F 3.24 7.35 75.97 1.83 F 82.16 F	0.0001 0.1564 0.3586 Prob>F 0.0001 Prob>F 0.0724 0.0001 0.1767 Prob>F 0.0001 Prob>F 0.0001	

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	ondition nu		1.134228,	17.800	i6 		·····		 •••••••
					ne 0.1000 lev • Dependent V		NOX		
	Variable	Number	Partial R**2	Nodel R=2	C(p)		Prob>F	Label	
Step 1 2 3 4	Removed COH5 IGN2 COH7 COH9 SSUS2	6	0.0002 0.0005 0.0006 0.0006	0.3844 0.3839 0.3833 0.3827	8.2139 6.6592 5.1469 3.6343 2.4747	0.2139 0.4460 0.4890 0.4891 0.8442	0.6439 0.5045 0.4847 0.4846 0.3586	IGN TUNE-UP SECONDARY AIR ECU	
5 6	SENS2 COH10	5		0.3818 0.3797	2,2957	1.8296		02 SENSOR	

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				VERICLES . OK DI	AGNOSTICS - ALL SI		IEU 13:02	10esuay, kay 2, 19
		Backı	ward Eliminat	ion Procedure for	Dependent Variabl	e R_SCORE		
Step 0	All Variables	Entered R-so	quare = 0.368	08186 C(p) = 10	.00000000			
			DF	Sum of Squares	Hean Square	F	Prob>f	
		Regression	10	11881.68075654	1188.16807565	1 0 07	0.0001	
		Error	531	20398.31456146	38.41490501	50.75		
		Total	541	32279.99531800				
		Variable	Parameter Estimate		Type II Sum of Squares	F	Prob>F	
	•				·	•		
		CON3 CON4	1.35508384		129.65420894 201.83012252	3.38 5.25	0.0667 0.0223	
		CONS	0.86886240	0.54051280	99.26355032	2.58	0.1085	
		COH6 COH7	0.13912756		1.96267271 100.21985937	0.05 2.61	0.8213	
		COH8	1.54340882	0.61769213	739.83777447	6.24		
		CON9	6.79207199	1.32464412	1009.96399731	26.29	0.0001	
		COM10 IGN2	4.06059061		3177.71824626 35.51918401	82.72	0.0001 0.3367	
		SENS2	0.79731875		16.01140831		0.5188	
Rounds o	n condition numb	er: 1.49823	, 119.323	12				
						•••••		
Step 1	Variable CON6 R	emoved R-sq	uare = 0.3680)2106 C(p) = 8	.05109144			
			DF	Sum of Squares	Mean Square	F	Prob>F	
		Regression			1319.96867598	34.42	0.0001	
		Error Total	532 541	20400.27723416 32279.99531800	38.34638578			
			- -		• • •			
		Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F	
		COH3	1.36989912	0.73402964	133.55938736	3.48		
		COH4 COH5	1.38855654	0.59960816 0.53666150	205.64421920 103.69106408	5.36 2.70	0.0209 0.1007	
		CON7	1.94993519	1.18655910	103.55856928	2.70	0.1009	
		COH8	1.56288057			6.54	0.0108	
		CON9 CON10	6.81775751 4.06902464	1.31858343 0.44449989		26.73 83.80		
		IGN2	1.05483292	1.07871379	36.66733312	0.%		
		SENSZ	0.80617444	1.23327744	16.38554589	0.43		
ounds on	condition numbe	r: 1.479594	, 95.8664	1				
tep 2	Variable SENSZ R	emoved R-sq	uare = 0.3675	1345 C(p) = 6.	47763280			
			DF	Sum of Squares	Mean Square	F	Prob>F	
		Regression	8	11863-33253794	1482.91656724	38.71	0.0001	
		Error	533	20416.66278006	38.30518345			
		Total	541	32279.99531800				
		Variable	Parameter	Standard	Type II	e	Dania - E	
			Estimate		Sum of Squares	r	Prob>F	
		CON3	1.37679930	0.73355932	134.93615821		0.0611	
		COH4 COH5	1.38238662 0.91921607	0.59921169 0.53342538	203.87127718 113.74842919	5.32	0.0214 0.0854	
		CON7	1.96310948		104.99292655		0.0984	
		COH8	1.56724899	0.61074495	252.23989394	6.59	0.0106	
		CON10	6.86637698	1.31577659 0.44389751	1043.15422815 3237.26123825	27.23		
			4.08077650 1.04924107	1.07810021	36.28188561	84.51 0.95		
ounos on	condition number	r: 1.463376,	76.7808					

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1981+ FUEL-INJECTED VEHICLES - OK DIAGNOSTICS - ALL SITES COMBINED 15:02 Tuesday, May 2, 1995 Step 3 Variable IGN2 Removed R-square = 0.36638948 C(p) = 5.42210697 F Prob>F DF Sum of Squares Mean Square 7 1689.57866462 44.11 0.0001 Regression 11827.05065234 20452.94466566 32279.99531800 534 38.30139450 Error Total 541 Standard Type II Parameter Sum of Squares Variable F Prob>F Estimate Error 3.70 5.17 3.56 2.74 6.76 27.59 COH3 COH4 1.40973923 0.73274185 141.77190132 0.0549 COHS 0.99569503 0.52757928 136.42432381 0.0597 1.18569115 0.61036609 1.31505294 105.11620457 259.04112251 1056.55725389 COH7 1.96426067 0.0982 COH8 1.58733087 6.90688875 COH9 0.0001 COH10 4.10950938 0.44289274 3297.59580732 86.10 0.0001 Bounds on condition number: 1.433972, 59,43799 All variables left in the model are significant at the 0.1000 level. Summary of Backward Elimination Procedure for Dependent Variable R_SCORE Number Variable Partial Nodel R**2 In C(p) F Prob>F R**2 Label Step Removed 0.3680 0.3675 8.0511 9 0.0001 0.0511 0.8213 EGR 1 CON6 SENSZ 8 0.0005 6.4776 0.4273 0.5136 23 I GN2 0.0011 0.3664 5,4221 0.9472 0.3309

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