A STUDY OF THE EPA MOTOR VEHICLE CERTIFICATION PROCESS

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EXECUTIVE SUMMARY

A preliminary analysis of the procedures used by the Environmental Protection Agency (EPA) to certify motor vehicle compliance with the Clean Air Act revealed a number of activities which might be made more cost effective. A subsequent investigation, reported on here, focused on three of these activities: (1) EPA's classification of the manufacturer's model line into engine families; (2) EPA's identification of "worst case" prototype vehicle configurations from each of these families; and (3) EPA's decisions regarding whether to test certain vehicles. The analysis of these activities concentrated on EPA procedures designed to assess the initial emission levels of vehicles and did not examine the components of these activities concerned with estimating the deterioration in these emissions with time or vehicle usage. The following paragraphs provide a brief description of each of these activities and the results of the analysis performed on them.

Engine Family Classification

EPA classifies each manufacturer's model line into engine families to separate vehicles with one set of engine and control system parameters from those with another. The vehicle parameters used in this sorting process are selected under the assumption that they provide the significant determinants of a vehicle's lifetime emissions. Thus, vehicle configurations within one engine family should be more similar in emission characteristics than configurations classed in different families. Assuming the classification scheme performs the appropriate segregation, EPA's certification of emission level compliance is then performed on an engine-family by engine-family basis. That is, all vehicles in a family are certified if selected configurations from the family comply with the standards.

If the classification scheme produces too many engine families, then the certification process is unnecessarily costly. Conversely, a scheme which results in too few engine family classes increases the likelihood that EPA will incorrectly certify a vehicle configuration whose lifetime emissions exceed the standards. Therefore, an analysis was performed to determine whether the current classification scheme might be revised to one which appeared to be more cost effective than the current scheme, yet feasible to implement.

An exploration of the initial (4,000-mile) emission levels of 1977 certification vehicles revealed a greater difference among emission levels of vehicles from different engine families than among those of vehicles within the same family. Thus, the current engine family classification procedure does group vehicles with similar emissions and segregate those that are dissimilar. Further examination of the engine family classes indicated that EPA may be able to reduce the number of engine families by about ten percent without grouping vehicles with dissimilar initial emission levels. This reduction would be achieved by reducing the number of parameters defining families from the ten or more parameters generally used to distinguish between engine families. Further analysis of the relationship between the emission deterioration and the engine family classification procedure is necessary, however, before recommending such a reduction.

Prototype Vehicle Identification

Given that the classification of vehicles into families provides a reasonable stratification of the manufacturer's vehicle fleet, EPA then must identify the configurations from each family to be used to determine whether all of the vehicle configurations in the family meet federal standards. Two types of vehicles are selected: configurations with anticipated high sales are chosen first and then configurations expected to have the greatest chance of exceeding emission standards are selected from the remaining members of the family. Identifying the first type is relatively straightforward, requiring limited EPA effort.

The identification of potential "high emitters", however, is a difficult and time consuming task. The rationale for identifying these vehicles is that all vehicle configurations within an engine family will by definition comply with the standards if it can be demonstrated that the "highest emitters" within that family meet the standards. If, however, the process of identifying these vehicles does not in fact produce the "high emitters", then the EPA effort dedicated to this task should be re-evaluated.

An extensive analysis was conducted to compare the emission levels of vehicles selected as potentially high emitters to those selected on the basis of a high sales criterion. Although there is a clear difference among the emission levels of individual vehicles within an engine family, no significant difference could be found between emissions of the vehicles in the high sales category and those of vehicles in the "high emitter" category. The likelihood of exceeding the standards, as well as the average and variability of the emission levels of vehicles in one category were not distinguishable from those in the other.

Given the evidence that vehicles with high sales configurations are not necessarily high emitters, the above results suggest that EPA should re-evaluate and alter current procedures for identifying prototype configurations. For example, vehicles could be selected at random from each family, or the process of selecting any remaining high emitter vehicles could be refined, or both. A random selection scheme could be fully random, or it could employ a form of bias (such as selecting high sales vehicles with a greater probability than others). The judgmental procedures could be improved by augmenting the knowledge used to relate emissions to vehicle specification with data collected during certification. That is, a greater reliance could be placed on a continued analysis of the current model year data (e.g., low mileage deterioration vehicle results) and historical manufacturer and EPA data collected on the emission levels of similar vehicles from previous years.

The most promising alternative appears to be one which would be expected to improve judgmental procedures (such as an increased analysis of historical data) and utilize a random sampling mechanism in areas where use of judgment appears to provide little advantage. For example, the decision of whether judgment or random sampling is to be used in a particular engine family could be based on the likelihood that the family will have low or high emission levels, with judgment being reserved for the families falling in the latter category. That is, judgment should be at least as good as random sampling and may, in some instances, be clearly superior. Therefore, when used, it should be applied to selecting vehicles from engine families which are likely to contain failing configurations, i.e., families with a previous history, early deterioration results, or other evidence that suggests they contain such configurations. Alternatively, both selection techniques could be used on most families, permitting EPA to evaluate engineering judgment further as a method for prototype vehicle identification.

Testing Strategies and Certification Criteria

Once EPA selects a vehicle for testing, it then must determine (1) whether to test the vehicle, (2) if tested, how many times to test it, and (3) how to use the test results to determine whether to certify its engine family. Under the current procedure, EPA tests all prototype vehicles selected from an engine family, and certifies the family if every vehicle tested in the family complies with all standards. If a particular vehicle fails the test, the manufacturer may request a retest, in which case the results of the second test are used in the certification decision.

EPA's current decision to test a vehicle is generally independent of the test results of other vehicles, thus reducing the organization's flexibility to adapt its testing strategy with knowledge about the emissions performance of similar vehicles tested previously. In the current procedure, EPA tests all prototype vehicles in an engine family irrespective of the test results from the first vehicle tested in that family. A more adaptive approach to EPA's testing program would be a sequential testing strategy. Using such an approach, EPA would determine the desirability of subsequent tests based on initial vehicle test results. If tests on one or two prototypes in a family resulted in relatively low emissions, it might be desirable to certify the family without further testing.

A broad class of such sequential testing strategies has been identified which would reduce EPA's testing workload without significantly increasing the risk of incorrectly certifying an engine family in violation of the standards. These strategies could save EPA between 10 and 25 percent of its 4000-mile certification tests per year by using the test results from one or two vehicles to determine whether further testing is necessary in a family. In addition, if the families which are most likely to contain failing vehicles could be identified in advance of testing, this identification could be used either instead of or in conjuction with a sequential testing strategy to identify those families on which testing should be concentrated.

EPA's current practice of using the results of a second test for a vehicle which fails a single test has the effect of basing certification decisions on biased estimates of the true emissions of these vehicles. For this reason, EPA may wish to consider a policy of averaging test results when a manufacturer requests a retest. This policy would decrease the chances of certifying engine families containing vehicles which exceed the standards. However, such a policy would also cause an increase in the risk of erroneously rejecting families. Combining this averaging with a sequential testing strategy would allow a reduction in the risk of erroneous rejection. An alternative policy would have EPA test every vehicle twice and average the results. However since nearly all vehicles which pass the first test would also pass the second one, such a policy would produce results which are essentially identical to those produced by the policy of retesting only failed vehicles, while requiring EPA to conduct considerably more tests.

Running Change Testing

In addition to selecting prototype vehicles for certification, EPA must also decide whether changes to previously certified configurations (i.e., running changes) may have a significant effect on emissions and must therefore be tested to insure continued compliance with federal standards. Since the review and testing of running changes constitute a significant amount of the certification workload, an investigation of running change emissions appeared to be warranted.

An analysis of the test results from running changes revealed that the time spent making the decision to test these vehicles was for the most part nonproductive. That is, the chance that a running change would fail to meet the standards appeared to be independent of EPA's decision to test (or not test) the running change. The running changes tested by EPA had emission levels which were symmetric about and very near to the levels of their corresponding certified configurations. Furthermore, the difference in emissions between the certified vehicle and the running change was in general less than the difference in emissions between any two vehicles chosen at random from within an engine family. Since the EPA decision to test a running change should reflect the likelihood the change will raise emission levels above the standards, EPA tests should primarily be performed on changes to families for which the emissions of previously-tested vehicles exceed prespecified thresholds. The results of manufacturer testing should determine whether or not other running changes are certified, with only random review and testing by EPA.

Resource Implications

The above recommendations may require additional investigation to determine whether operational, political, or engineering constraints would make their implementation infeasible. Thus, the net effects of the above recommendations, in terms of changes in resources required to operate the certification process, depend on which recommendations are considered feasible and, of these, which are adopted by EPA. For example, a ten percent reduction in the number of engine families combined with a random selection of prototype vehicles which then used a sequential testing strategy to determine which vehicles were tested could reduce the EPA engineering workload by about two person years per year (approximately one year in family reduction, less than one year in vehicle identification and approximately one-quarter of a year using sequential testing). An additional savings of one to four engineering person years could be realized if EPA were to reduce the amount of time reviewing running change applications as is suggested by the analysis of running change vehicle test results. The net implications on the EPA testing workload of adopting these recommendations would be a reduction of over 1,000 tests per year. About two-thirds of this test savings would be realized from a reduction in the number of tests on running change vehicles and the remainder on initial 4,000-mile certification vehicles.

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1.0 INTRODUCTION

This document is a final report of work performed on Contract No. 68-03-2466 by Vector Research, Incorporated, (VRI) for the Environmental Protection Agency (EPA). The report describes the second part of a two-part study designed to analyze the cost-effectiveness of EPA activities used to certify motor vehicle compliance with federal emission standards. The first study [VRI, 1976] was designed to assist EPA with decisions regarding efficient utilization of its resources used to certify motor vehicle emissions in fiscal year 1977. The second study, reported on here, examines those activities identified in the first study which might be made more cost effective over a longer time frame.

1.1 Organization of the Report

The material in the report is presented at three levels of detail. The executive summary which precedes this introductory chapter contains an overview of the study. It is intended to provide the time-constrained reader with a description of the EPA procedures investigated during the study and a synopsis of the major results of this investigation. The main body of the report amplifies and explains many of the statements found in the executive summary. It is organized into four chapters, each of which corresponds to a major research task of the study. A sufficient level of detail is provided in these chapters to permit an understanding of the general approach used in the analyses and the conclusions derived from this work. The appendices contain further detail about the data, analytic methods, and results used to develop the material in the main body of the text. The hierarchical organization of detail in the executive summary, main body, and appendices required some repetition to facilitate presentation. Wherever possible, however, such redundant information has been kept to a minimum.

The remainder of this introductory chapter describes the purpose and scope of the study. The remaining three chapters describe the investigation of three EPA certification procedures--(1) engine family classification; (2) prototype vehicle identification; and (3) testing and certification decision making. The techniques used in each of these investigations are then described in the seven technical appendices, with the bibliography of reference material provided at the end of the report.

1.2 *Purpose and Scope of the Study*

The purpose of the study was to analyze and make recommendations for the conduct of EPA's motor vehicle emission certification program in order to enhance the program's cost-effectiveness. The recommendations produced by the study were those which appeared to provide a favorable tradeoff between: (1) the certification resources expended by EPA (and others); and (2) the error inherent in the certification process. The implementation of the recommendations developed could require changes or additions to EPA regulations and advisory circulars, as well as changes to current certification practices and procedures.

The types of recommendations considered for analysis in this project were those which would:

(1) revise EPA's method of sorting vehicle configurations into engine families to improve the degree to which this classification scheme groups vehicles with similar emissions characteristics;

(2) alter EPA's procedures for identifying which prototype vehicles should be built by manufacturers in order to provide a sufficient representation of the manufacturer's fleet;

(3) result in an overall reduction in the number of EPA tests without significantly affecting certification performance; and

(4) institute a test averaging procedure to provide an unbiased estimate of whether vehicles which failed and then passed an emissions test were in compliance with the standards.

The study recommendations are based primarily upon a statistical analysis of the exhaust emission test results collected by EPA during its certification of 1976 and 1977 model year vehicles. As such, the recommendations may require additional investigation to determine whether operational, political, or engineering constraints would make their implementation infeasible. Although some of the analyses (particularly the investigation of alternative EPA testing strategies) considered certain elements of these constraints, most of the results do not, in general, reflect a detailed investigation of their impact. Therefore, adoption of the study recommendations should only occur subsequent to an investigation of their implications on these practical and political constraints.

Test results from 583 vehicles manufactured by three domestic and six foreign manufacturers were statistically analyzed to provide insight into the effectiveness of existing EPA procedures, in terms of the tradeoff between the resources required to certify vehicles and the risks of certifying vehicles which do not meet standards and not certifying those that do. Most of these analyses concentrated on the 4,000-mile test results from 335 vehicles from the 1977 model year certification program.[1] These vehicles represented 88 percent[2] of the fleet of 4,000-mile light duty vehicles required by EPA to certify three domestic (Chrysler, Ford, and General Motors) and six foreign (BMW, Datsun, Fiat, Honda, Mazda, and Volvo) manufacturers. The analyses of running changes examined results of tests performed by those 1976 and 1977 domestic vehicles which were used both to certify a family and determine approval of a running change request. Although the 66 vehicles used in these analyses appeared to be representative, they comprise only a small fraction (about ten percent) of the total number of vehicles tested in this environment.[3]

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[1]The primary reasons for concentrating on the 1977 model-year test results were the difficulties in obtaining a consistent and comprehensive automated data base for 1976 model-year vehicles (see appendix A for discussion).

[2]The remainder, twelve percent) were additions to the manufacturer's fleet of configurations after initial certification (e.g., the Ford Fiesta). The absence of these configurations should not, however, bias any of the study conclusions.

[3]The reason for this small sample was that this was the only set of running changes for which the before and after test results could be identified from the data base. The inherent bias in this data set was that it included only those running change tests performed on vehicles used in original certification. Consequently, the analysis may be biased if these running changes were generally less extensive in nature and were less likely to influence emission levels. However, there is limited evidence or rationale to suggest that such a difference exists.

In this investigation, only emission test results on emission data vehicles (i.e., 4,000-mile vehicles) were examined. The study was not designed to include an analysis of the emission tests used by EPA to determine the deterioration of vehicle emissions with time and vehicle usage. Consequently, further analysis may be necessary to determine whether the recommended changes still hold after consideration of this deterioration data.

2.0 ENGINE FAMILY CLASSIFICATION

Manufacturer model lines are divided into engine families to separate vehicles with one set of engine amd control system parameters from those with another. The parameters used in this sorting process provide a description of the characteristics of configurations in a family and are generally selected to provide an indication of the lifetime emission levels of vehicles within the family. Thus, vehicle configurations within one engine family should be more similar in emission characteristics than configurations in different families. If this is not the case, then the engine family classification scheme may be inappropriate and more costly to EPA, either in terms of miscertifying families or in terms of requiring an unnecessary workload,[1] than some alternative.

Since the engine family classification is an important determinant of the workload and effectiveness of EPA's program, it was considered worthwhile to examine the degree to which vehicle configurations in different families did have different emission characteristics. One approach to investigating this question is to compare the emission levels of emission data vehicles from different engine families.[2] Although the emission data vehicles (EDVs) are a subset of the configurations contained in each family, the results of the analysis of prototype vehicle selection (see chapter 3.0) indicate they are representative. That is, the analysis shows that EDVs within the same

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[1]For example, if the emission characteristics of different vehicle configurations within an engine family are not similar, then EPA may miscertify configurations in that family which are assumed to be similar to those tested in the certification process. Similarly, if the emission characteristics of vehicle configurations from separate families are not different, then the EPA expends additional effort reviewing and testing more families than is necessary.

[2]Since the current study does not consider the deterioration of vehicle emissions, results of this investigation apply only to 4,000-mile vehicle emission levels.

family have very similar emission levels, even though they were selected on two rather divergent criteria--high sales and high emissions.[1] The examination of family-to-family differences in emission levels was therefore conducted using the test results from the 1977 model year certification of emission data vehicles.[2]

Three types of analyses were performed. The first was a statistical comparison of the emission level variability of EDVs in the same family with variability in emission levels across families. The second was an investigation of the degree to which the values of specific vehicle parameters might be used to predict the average emission levels of an engine family, thereby indicating possible alternatives to the current method of grouping vehicles into families. The last was a manual review of engine family characteristics and vehicle emission levels within each family, to see if any regrouping or clustering of current families might be available. The results of these three analyses are presented in the following sections.

2.1 Analysis of Family Groupings

To address whether current engine family classifications group vehicles with similar emission levels, and segregate those that are dissimilar, engine families were differentiated by domestic and foreign manufacture and by catalyst and non-catalyst categories. The emission levels in each of these categories were then analyzed using an analysis of variance technique.[3]

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[1]Although these criteria are rather divergent, they may result in the same vehicle being chosen. However, an analysis of high sales vehicle emission levels did not indicate that these vehicles would, in general, also be "high emitters".

[2]If the EDVs cannot be considered a random sample of vehicles from an engine family, then the results of this analysis will tend to be conservative (i.e., if high sales vehicles have above average emission levels, then the analysis will tend to find similar emission levels among vehicles within a family and dissimilar levels when comparing vehicles from different families).

[3]See section C.1 of appendix C for details.

The results confirmed the hypothesis that there was a significant difference in the average emission levels between engine families. That is, the difference in emission levels between families is significantly greater than the difference in the emission levels between vehicles in the same family.

Since only emission data vehicle tests were analyzed, it was conjectured that this difference in the emission levels from one family to the next might be explained by differences in the family deterioration factor (df). Since the df is known to the manufacturer in advance, each vehicle may be calibrated or designed so that the product of its 4,000-mile emission level and df would achieve some pretargeted value. If this were the case, then a difference in average family emission levels might disappear with the application of the deterioration factor. This possibility, albeit remote, was examined by observing the differences in the average family emission levels with and without application of the df.[1] The results (see section C.1 of appendix C) indicate that the differences in engine family emission levels cannot be solely explained by differences in the deterioration factor.

The results of the above analyses therefore led to the conclusion that the current method of segregating vehicles into engine families does, in the aggregate, perform its function. Vehicles with dissimilar emission levels are generally found in separate families. The results do not, however, imply that the engine family classification performs the best method of grouping.

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[1]Since an investigation of deterioration was outside the scope of the current study, the purpose of this examination was only to investigate whether differences in family means were primarily attributable to differences in deterioration factors.

2.2 Regression-Based Family Definitions

One approach to investigating alternative engine family classification schemes was to analyze the relationship between the vehicle parameters of a family and its average emission level. For each domestic manufacturer,[1] a multiple stepwise regression (see appendix C, section C.2 for details) was performed to determine whether vehicle parameters can be used to predict the mean emission levels for an engine family. The vehicle parameters considered were: inertia weight, displacement, bore, stroke, rated horsepower, number of cylinders, compression ratio, axle ratio, and timing RPM. Also considered were the following ratios: bore divided by stroke, displacement per cylinder, and inertia weight divided by displacement.[2]

The results showed that the vehicle parameters do not consistently predict the mean emission level of engine families. Although one parameter (timing RPM) was selected as a significant predictor of the mean emission levels of Chrysler engine families, this parameter did not demonstrate a similar effect on the emission levels in other manufacturer engine families. Further regressions performed on the combined manufacturer data did not select any parameter as a consistent predictor of pollutant levels. Thus, it was not

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[1]Since engine families were analyzed by manufacturer, the domestic manufacturers were chosen because they had more engine families than did the foreign manufacturers, as shown in appendix C. Furthermore, data from only one test per vehicle was used to ensure that all data points within a family had the same distribution.

[2]These parameters were those suggested in [Patterson, 1972] and were easily obtained from the information available.

possible from the data used in this analysis to develop new engine family definitions from an analysis of the relationship between vehicle parameter values and emission levels.

2.3 *Heuristic Family Definitions*

Since the above regression-based family definitions did not show any potential for changes in family definitions, two heuristic clustering approaches were examined. The first of these was to plot one pollutant against another to see if any two-way clustering was evident. This analysis was performed for three domestic manufacturers to determine if separate engine families had visibly similar emission levels. That is, would scatter plots of the average family emission levels for one pollutant versus another reveal clusters of engine families? A review of such plots did not reveal any clustering with the possible exception of CO - NO_x pairings for Chrysler families.[1]

The second heuristic analysis was a manual review of 1977 Summary Data Sheets. The purpose of this review was to examine subjective criteria which grouped several existing engine families into one family. In this analysis, a subset of the 1977 engine families from a single manufacturer (Chrysler) was used to develop the criteria, with the families from the other manufacturers reserved as an independent data base on which to analyze the performance of the new criteria in grouping vehicles with similar emission levels.

In the initial phase, the Chrysler families were stratified, by subjective clustering, into three groups on the basis of three different levels of 4,000-mile emissions. The groupings were then analyzed to identify those vehicle

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[1]This slight degree of clustering can be seen in the scatter plots provided in section C.3 of appendix C.

parameters which had similar values for families within a single grouping, and different values for families in different groupings. The analysis was conducted independently by three investigators, in order to ensure both comprehensive and accurate analysis of the potential clustering methods. No clustering of California with 49-state families was considered, so any reduction in the number of families was limited to 49-state families.

From these analyses, only one potential method for generating broader family definitions was identified. Specifically, the newly defined families were those in which: (1) the displacements were within 15 percent of 50 cubic inches of one another; (2) the types of emission control systems used were identical; and (3) the numbers of cylinders, the numbers of carburetors, and the numbers of barrels did not vary.[1] Such a regrouping would lead, for 1977 Chrysler families, to a reduction from 15 to 12 families.[2] The 12 redefined families contained nine families which were identical to the

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[1]The actual aggregation rule used initially was qualitatively phrased: the families to be aggregated should have identical types of control systems and identical engine configurations and carburetion and should be "similar" in displacement. During the analysis, it was found that the 15 percent or 50 cubic inch standard which is used by EPA in family classification could be used to define "similar" displacements. The revised criteria differ from the present classification rules in that fewer criteria were used to distinguish one family from another (the *Federal Register*, Vol. 40, No. 126, June 30, 1976 specifies approximately fifteen mandatory parameters to be used in classifying configurations into engine families) and no judgment was incorporated into the sorting process. The application of these rules also differs from that experienced by EPA since the number of engine families per manufacturer in this regrouping is much smaller than that originally submitted to EPA.

[2]To determine which parameters defined the 15 but not the 12 families requires investigation of the criteria used by the engineers who made the original classification. The identification of the Chrysler engine families aggregated in this analysis is provided in exhibit C-15, section C.3 of appendix C.

original set and three families which contained three pairs of six families under the original definition.

The three pairs of combined engine families were examined quantitatively to analyze the emission level differences between each pair of families. This analysis did not reveal any statistically significant difference in either the average or the variability of emission levels for each pair of families.[1] That is, the emission levels found in each set of family pairs were highly similar.

Thus, for the initial Chrysler sample, it was found that the 15 families presently defined actually constituted only 12 groups for which family-to-family differences in emission levels could be found, and that the clustering of the 15 families into the 12 groups could be accomplished by aggregating families using essentially the same distinguishing characteristics for families that are now used by EPA. No other clustering mechanism which could accomplish such grouping was found. Given this result, the next step of the analysis was to examine the use of the clustering scheme on other manufacturers' fleets in order to ascertain its general utility.

Exhibit 1 summarizes the results of this analysis for 90 engine families[2] for 9 manufacturers. As can be seen from the table, the results for all manufacturers examined bore out the tentative results from the Chrysler sample--there are clusters of families which cannot be distinguished by emission

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[1]The statistical tests used were standard t-tests and F-tests at the one percent level. When tested at the five percent level, one of the 18 tests was statistically significant: if the families being combined were identical, an average of one out of twenty such tests should be significant.

[2]Family count includes California families although no California aggregation or California 49-state aggregation was performed.

EXHIBIT 1: STATISTICAL TESTS OF IDENTITY OF EMISSION CHARACTERISTICS OF FAMILIES PROPOSED FOR GROUPING

Manufacturer	Original	Aggregate	Differences Significant at 1% Level	Differences Significant at 5% Level	Number of Statistical Tests
CHRYSLER	15	12	0	1	18
FORD[1]	22	18	0	0	24
GENERAL MOTORS[2]	25	22	0	0	18
BMW	3	3	-	-	-
FIAT	4	4	-	-	-
HONDA	3	3	-	-	-
DATSUN	9	7	0	0	12
VOLVO	4	4			
MAZDA	5	5	-	-	-
TOTAL	90	78	0	1	72

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[1]Some Ford engine families in the 1977 data base are identical with subsets of others, so that uniting them would literally combine the same vehicle designs. These cases exist because the differences in the families only affect the vehicle after 4,000 miles (e.g., scheduled maintenance); therefore, the same EDV test is used to certify both families. There were two sets of two families each of this kind. They were not proposed for union in this analysis, since they had clearly been deliberately separated.

[2]No useful aggregation of GM families across divisions--whether on the basis of the present criterion or any other--was found, supporting the engineering judgment that the divisional lines are actually quite distinct.

characteristics and which can be defined by the engine/control system similarities described earlier. Because this study did not include a statistical analysis of the accuracy of deterioration factor measurement, it is impossible to state whether the aggregations which were identified here involved statistically significant differences in deterioration. They did involve the aggregation of a few family pairs with what appeared to be numerically different deterioration factors, but the variances may have been within the statistically expected variability.

If analysis of the deterioration[1] factor measurement process shows that an additional family aggregation of the kind analyzed here does preserve the family characteristics (within the expected statistical variability), it appears that a reduction of about 10 to 20 percent of the number of families could be expected.

It is difficult to determine precisely what cost savings would be realized by eliminating 10 to 20 percent of the families. The concomitant reduction in EPA workload would primarily be in two areas--engineering review and testing. Using EPA's estimate[2] of the amount of engineering manpower devoted to individual certification activities, a 20 percent reduction in the number of families represents about a 20 percent reduction in workload. Such an estimate is clearly tenuous since it presumes that certification of every engine family takes approximately the same effort. However, even if only a ten percent reduction in families could be achieved by combining families, and these take approximately one-half the "normal"

[1]This study has been restricted to the analysis of emission data testing. However, the final definitions of families must not only cluster the initial emission levels (4,000-mile) of the designs involved but also the deterioration characteristics.

[2]See [EPA, 1976-j].

effort to certify, EPA could reduce its certification burden by over a person-year of engineering effort.

Estimating the reduction in testing workload with a reduction in the number of families is even more difficult since two original families each having three to four emission data vehicles could be combined into a single family having three to eight EDVs. Thus, the percent reduction in EDV testing workload could vary from zero to the percentage reduction in the number of families.[1] Test workload savings (per durability vehicle) would be nearly proportional to the reduction in families, since each family typically has only one durability vehicle. A reduction in the number of families should not influence the number of running changes proposed by the manufacturer, hence no test savings are likely to be realized in this area. Therefore, if analysis of vehicle deterioration permits the merging of families suggested above, then the majority of EPA's workload savings realized will be in the area of engineering review and analysis.

In addition to EPA's potential savings, the reduction in the requirement for durability vehicles and emission data vehicles would provide a substantial savings to the manufacturers.[2] It is estimated that development

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[1]Any savings in EDV testing at EPA could be partially negated by EPA's current policy that 25 percent of all fuel economy data vehicles (FEDVs) be tested at the EPA facility. That is, FEDVs are essentially EDVs which are developed solely for the fuel economy testing program. The removal of one EDV could augment the number of FEDVs by one. Thus, for every four EDVs removed the fuel economy program would, at most, require EPA to test one of these as an FEDV.

[2]In spite of these savings, some manufacturer representatives have expressed concern about reducing the number of engine families, probably because certification of a larger portion of a manufacturer's fleet would depend on test results from a smaller number of vehicles.

of each durability vehicle costs the manufacturer between $85 thousand and $125 thousand, while the typical cost for development of an EDV[1] is between $17 thousand and $35 thousand ([Ford, 1976] and [EPA, 1977]).

[1]Savings to manufacturers by reducing EDVs may be negligible, since many EDVs may have to be replaced by equivalent FEDVs to comply with fuel economy program requirements. A rough estimate is that one out of every three EDVs removed would be replaced by an FEDV.

3.0 PROTOTYPE VEHICLE IDENTIFICATION

The previous chapter indicated that current engine family classification performs a reasonable job of grouping vehicles with similar emission characteristics into the same family. This chapter investigates the effectiveness of current procedures for using engineering judgment to identify the "high emitter" vehicle configurations in each engine family. The results suggest ways in which these procedures might be modified. The chapter includes a general description of engineering judgment in the context of the above activity, a description of and rationale for the technical approach taken to analyze the outcome of decisions using such judgment, and a presentation of the results and observations derived from them.

3.1 Current Methods of Vehicle Identification

The emissions from an automobile are determined by a complex process which is not completely understood. For this reason, estimates of anticipated emissions cannot be made via a fixed set of rules but must instead involve professional judgment. Such judgment is used at several points in the certification process. One of its most difficult and time-consuming applications involves the identification of configurations which are likely to be high emitters of pollutants and which, therefore, should be built in advance (as prototype vehicles) for analysis prior to certification by EPA. The rationale for selecting these vehicles is that all configurations within an engine family will by definition meet the standards, if it can be demonstrated that the vehicles representing configurations with the highest emissions in the family meet the standard.

The problem of selecting configurations which appear to have a low probability of meeting emissions standards is a complex and difficult one. Many factors affect vehicle emissions, and a manufacturer is likely to balance these factors against one another in designing automobiles to achieve approximately the same average emission levels for all vehicles.[1] This complex trading off of vehicle characteristics, plus the fact that vehicles with similar engine and control system parameters have already been grouped by engine family, makes the identification of "high emitter" configurations (represented by type B vehicles) within each family very difficult.

In their examination of proposed vehicle specifications, the EPA engineers review several vehicle parameters to determine if the combination of proposed values is likely to lead to high emissions. Although a number of parameters[2] are suggested for review [Marzen, 1976], the final selection of high emitters is left largely to the judgment of the individual engineers.

The complexity of this task is further compounded by requirements which tend to emphasize that the type B vehicles be representative of certain segments of the family as well as the "higher emitters". The fact that this condition exists is evidenced by EPA's requirement that each engine system combination within a family must be represented by an emission data vehicle and also by EPA's attempt to select EDVs so that most of the base levels in EPA's fuel economy testing program are also represented.[3] Since a large

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[1]VRI believes that these target levels are generally approximately 60 percent of the emissions standards, in order to assure that the vehicles will have a high probability of passing certification tests. Conversations with manufacturers indicated that they concurred that a design target below standards existed; however, no information was provided concerning its level.

[2]These parameters include: inertia weight class, transmission options, N/V ratio (a combination of axle ratio and tire size), engine code (specifying characteristics of the engine), body type, characteristics of the catalyst, starting and shifting procedures, and road load horsepower requirements.

[3]See [Marzen, 1976].

number of individuals are involved in exercising their judgment to select a combination of "representative" and/or "high emitter" EDVs, the final selection may depend on which engineers were tasked to identify the EDVs from which family. Therefore, the question arises: does the effort expended selecting the type B vehicles produce an effective result, i.e., are the emission levels of selected vehicles, in general, higher than the emissions of other vehicles in the engine family?

Preliminary analyses of this question were conducted on a limited amount of data in a previous study [VRI, 1976-a]. A test was performed to determine whether vehicles chosen as high emitters (type B emission data vehicles) had higher emissions than the corresponding high sales vehicles (type A emission data vehicles) for each engine family. The results from this analysis indicated that the average differences in emission levels between type A and type B emission data vehicles were small and possibly non-existent.

3.2 *Comparison of Type A and Type B Vehicle Emissions*

One purpose of the current study was to provide an extension of the previous work by analyzing in greater detail the degree to which judgment has been used to identify vehicles with potentially high emission levels. In this analysis, a number of statistical techniques were used to compare the emission levels of vehicles selected as high emission vehicle (type B) with the levels of vehicles selected as high sales vehicles (type A).

Three different sets of analyses were performed. In the first set, the fraction of type B vehicles rejected by the certification process was compared to that for type A vehicles in model year 1977. The second set of analyses compared the relative amounts of pollutant measured by the certification tests performed on these vehicles. The last set compared the variability of the pollutant from type A vehicles to that measured for the type B vehicles.

3.2.1 Vehicle Rejection Rate

If the type B vehicle configurations consistently represent the higher emitters in each engine family and the type A configurations may or may not have emissions which fall into this higher range, then the type B vehicles would be expected to be rejected for non-compliance more often. To determine whether this was true, the frequency of type B rejections was compared to that for type A vehicles. Specifically, exhibit 2 shows that 8.3 percent of 1977 emissions data vehicles from Chrysler, Ford, and General Motors did not comply with the standards. If this percent was the same for both types of vehicles, then 6 of the type A vehicles and 15 of the type B vehicles would be expected to be rejected during certification. The exhibit shows that in actuality, 5 type A vehicles and 16 type B vehicles were rejected.

EXHIBIT 2: REJECTION RATES FOR DOMESTIC VEHICLES

	Vehicles Tested	Rejected for Non-Compliance	Percent Rejected
All EDVs	252	21	8.3%
Type As	77	5	6.5%
Type Bs	175	16	9.1%

A test on this data indicated that the probability of not complying with the standards is nearly the same for both type A and type B vehicles.[1] Similar tests on vehicles from individual domestic manufacturers, or on those manufactured by foreign companies, were not possible due to the small number of observed failures. However, the results of the combined domestic manufacturer tests strongly indicate that vehicles selected as high emitters are as likely to be rejected during certification for non-compliance as are vehicles selected on the basis of projected high sales.

3.2.2 Correlation between Pollutants

Given that the rejection rates appear to be similar, the type B vehicles may still have slightly higher emissions than the type A vehicles. To examine this question it is necessary to determine, in general, whether all three pollutants of a type B vehicle might be higher than those for a type A vehicle, or whether one might be higher and another lower.

Thus, to examine the potential differences between type A and type B vehicle emissions, two possible situations must be treated. In the first, the emission levels of different pollutants (measured under standard test conditions) are generally independent or show a positive association (correlation) as vehicle designs vary. In this situation engineering

[1]A Chi-squared test was performed to examine whether the probability of rejection was dependent on the type (A or B) of vehicle. The hypothesis that this probability was identical was accepted at the 5 percent significant level for these three domestic manufacturers. (See appendix D, section D.1 for details.)

judgment should be expected to select type B vehicles whose three pollutant levels were, on the average, greater than those for type A vehicles. The second situation is one in which the emission levels of different pollutants show a negative association (correlation) as vehicle designs vary. In this case, vehicle designs which have a high level of emissions in one pollutant would generally have a low amount in another. Engineering judgment in this situation might select some type B vehicles based on one pollutant and some vehicles based on another pollutant (which is negatively associated with the first). Under these circumstances a comparison of the average emission levels for type B to those of type A could show no difference, even though there is in fact a difference in emissions between type A and type B vehicles.

Therefore, it was necessary to examine the correlation between each pair of pollutants to determine which situation holds. Based on the assumption that the correlation among pollutants within engine families is a constant,[1] tests show no significant negative correlation between HC and CO or between HC and NO_x. A negative correlation between CO and NO_x was, however, found to exist[2] for domestic vehicles in engine families containing catalyst equipped vehicles. The range of values for the correlation coefficient between CO and NO_x for vehicle designs in the domestic engine families was found to be -.03 to -.35, with a median value of -.19,[3] a relatively small correlation.

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[1]The mean and standard deviation of emission levels are not assumed to be constant within engine families (see appendix D, section D.2 for details).

[2]At the .05 level of significance.

[3]No other negative correlation between pollutants was found when vehicles were stratified by a number of vehicle parameters (see appendix D, section D.2).

Since a negative correlation appears to exist between NO_x and CO and since it appears to be only slightly negative in magnitude, two types of analyses were used to investigate the degree to which type B vehicles have higher emission levels than type A vehicles. The first, which examined type A versus type B average emission levels, assumed that the correlation between all pollutant pairs is non-negative. The second, which examined the emission level variability of type A versus type B vehicles, assumed a negative correlation between CO and NO_x. The results of these two analyses are presented in the following two subsections.

3.2.3 Average Emission Levels

The relative magnitude of emissions from type B vehicles and those from type A vehicles[1] were compared using test results from 335 emission data vehicles from the 1977 model year. The vehicles were stratified by domestic versus foreign manufacturer and by catalyst versus non-catalyst equipped vehicles.[2] Three hypotheses were examined:[3]

(1) for vehicles of the same type (A or B), belonging to the same engine family, the average emission level of one vehicle is not different from the average emission level of another vehicle;

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[1]The details of these three analyses are presented in appendix D, section D.3.

[2]These strata were selected since it was felt that the complexity of identifying high emitters may differ for vehicles with and without catalysts and for domestic versus foreign vehicles.

[3]A nested analysis of variance model was used to explain the effects of engine family, type of selection, vehicle configuration and test-to-test differences in emission levels (see section D.3.1 of appendix D).

(2) for vehicles within the same engine family, the average emission levels of type B vehicles are not different from the average emission levels of type A vehicles; and

(3) the average emission levels of vehicles in a family do not differ from those in another family.

Each hypothesis above was tested on a pollutant-by-pollutant basis under a number of assumptions concerning the magnitude of the test-to-test variability[1] and its relationship to average vehicle emissions. In all, the above hypotheses were tested a total of 45 times (three pollutants, five vehicle categories and three test-to-test variability assumptions) without once rejecting the second hypothesis (i.e., emission levels of type B and type A vehicles are equal). Conversely the first and third hypotheses were accepted a total of 39 and 42 times, respectively.

These results indicate that:

(1) the difference between the emission levels of vehicles within a family is greater than can be attributed to test-to-test variability;

(2) the difference between the average emission levels of the type B vehicles and those of the type A vehicles in the same family is not significantly greater than the difference between the emission levels of any two vehicles selected at random in a family; and

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[1]If the estimated value of test-to-test variability used in this analysis were larger than in actuality then the test might erroneously accept the hypothesis of no difference when in fact a difference does exist. Therefore, to reduce the chance of adopting such a conclusion, three estimates of test-to-test variability were used (two from data collected in this study and a recent estimate made by General Motors investigators). All three estimates were in approximately the same range (e.g., when expressed as a percent of average emissions; 10 percent-13 percent for HC, 13 percent-16 percent for CO, and 4 percent-9 percent for NO_x), and the results of the analyses using any of these estimates were essentially identical.

(3) the difference between the average emission levels of vehicles from different families is greater than the difference between the emission levels of vehicles within the same family.

The above conclusions require assumptions concerning the distribution of the emission levels of vehicles in a particular family or class about the average of that class[1] and the degree to which variability of emissions in one family equals that of all other families.[1] Since these assumptions may not be precisely correct, two additional analyses were performed, which do not necessarily rely on these assumptions.

The first compared the number of times that the emission levels of a type B vehicle exceed those for a type A vehicle (within an engine family) with the number of times this condition would be expected if the emission levels were equal.[2] The second examined the degree to which the difference between type B vehicle and type A vehicle emission levels appeared to vary evenly about zero.[3] The results of these analyses supported the above finding, i.e., type B emission levels are not distinguishable from type A emission levels.

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[1]Specifically, the analyses of variance model assumes: (1) that each of the effects (i.e., engine family, selection criteria, and configuration) is a independently-normal random variable with zero mean and known variance, and (2) that the variability of emission levels within an engine family is a constant from one family to the next.

[2]A Mann-Whitney test was used to provide a non-parametric method of comparing the relative rank of type B vehicles to type A vehicles (see section D.3.2 of appendix D).

[3]The special purpose test examined the distribution of t-statistics as discussed in section D.3.3 of appendix D.

3.2.4 Emission Level Variability

Under the assumption that the correlation between pollutants is negative, the analysis of whether type B vehicles could have been identified appropriately (i.e., as high emitters in at least one pollutant) becomes a comparison o type A and type B emission level variability. Such an analysis presumes that the type B vehicles within a particular family were alternatively selected on the basis of anticipated high emission levels of CO and NO_x. Under this presumption, the above finding that the average emission of type A and type B vehicles were approximately equal would be expected even if engineering judgment had indeed selected those vehicles with high CO and high NO_x in a particular family.[1]

The variability of type A vehicle emission was found to be indistinguishable from the variability of the type B vehicle emissions. That is, ratios of type B vehicle variance to type A vehicle variance could not be shown to differ significantly from 1.0. However, the general range of the values for these ratios demonstrated a general bias, albeit insignificant, favoring the hypothesis that type A variability is greater than that for type B.[2] These results appear to refute the situation presumed above, i.e., that type B vehicles were appropriately selected on the basis of expected high emission levels for either NO_x or CO (but not both).

Thus, the comparison of type B vehicle to type A vehicle emission levels reaches the same conclusion irrespective of the correlation among pollutants. A difference between the emission levels of vehicles in these two categories does not exist.

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[1]See appendix D, section D.2.

[2]Details of this analysis are provided in section D.4 of appendix D.

3.3 *Interpretation of Results*

The results of the previous analyses demonstrate the similarity between the emission levels of two types of prototype vehicles selected on rather different criteria--high sales and high emissions. Consequently, the results imply either that, in general, the collection of high sales vehicles are also high emitters or that the vehicles selected on the basis of emissions do not necessarily have higher emission levels. It is difficult to determine which case holds without test results on vehicles representing all configurations within a family. However, an analysis of the relationship between emission levels and engine family size[1] (a proxy) for sales level) found no significant correlation, indicating that high sales vehicles selected for testing should not be expected also to have high emission levels. Therefore, the vehicles selected as high emitters do not appear to represent the configurations with the highest emissions within a family.

The interpretation of the above result is dependent on the degree to which EPA engineers are making the tradeoff between selecting vehicles with the anticipated highest emission levels and selecting these vehicles on other criteria (e.g., a fuel economy criterion). The extent that the type B selection is based on a "representativeness" criterion rather than simply a "high emission" criterion, will affect the degree to which type B vehicle emission levels are the same as those for type A vehicles. However, if the higher emitters from a small set of representative sub-family groupings[2]

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[1]Engine family size was measured by the number of EDVs used to certify the family.

[2]A review of the vehicle parameter values for the 1977 emission data fleet revealed a relatively wide array of values, indicating that individual engineers may be attempting to select vehicles which represent the various subclasses within a family.

were selected as type B vehicles, the type A vehicles would have lower expected emission levels, in general. Since this was not reflected by the results in the above analysis, one must conclude that judgmental selection tends to favor representativeness over high emissions or that EPA's ability to identify high emitters is not as effective as it could be (under the assumption and evidence that high sales vehicles are not abnormally high emitters).

If emission data vehicles are selected to represent a segment of an engine family, then failure of an EDV increases the likelihood that other vehicles in that segment fail to comply with the standards. A modification of the EDV by the manufacturer in a subsequent submission of that family then requires a second and different kind of engineering judgment to determine which of the configurations in the family must be likewise modified. EPA's current practice is to examine this resubmission as though it were an original application and choose the highest emitter(s) in the family to replace the failed vehicle(s). The knowledge about characteristics of the failed configurations should improve the engineers' ability to identify potential high emitters and, hence, relate configurations that are similar within families.

However, without a detailed examination of the history of a number of families which failed, were modified, and then passed, it is difficult to determine the ability of EPA's engineers to relate configurations in this manner.

3.4 Alternative Methods of Vehicle Identification

The conclusion drawn from the preceding analysis is that engineering judgment has not been effective in selecting the high-emission vehicles within engine families for the 1977 model year. There are at least five possible explanations for this conclusion.

(1) A single engine family is defined to consist of vehicles which have similar emissions. The degree to which this similarity is achieved will determine the degree to which certain vehicles within a family will have higher emission levels than the rest.

(2) If the manufacturer attempts to design all vehicles in a family to some "target" emission levels, he does so by making complex tradeoffs among the values of many parameters of the vehicle designs. It is then very difficult even for the manufacturers,[1] let alone EPA's engineers, to identify, in advance of testing, which vehicles will tend to deviate from these target levels.

(3) EPA's engineers have insufficient time, experience, or data to perform the task of identifying high emitters.

(4) Current procedures for selecting type B vehicles place too great an emphasis on identifying a representative set of vehicles from each engine family to allow the flexibility necessary to identify high emitters.

(5) EPA is currently selecting too many type B vehicles. In attempting to fill its quota of prototype vehicles, EPA has included some vehicles with low emissions along with one or two high emitters.

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[1]Conversations with Ford and GM personnel concerned with certification revealed that they would have difficulty identifying in advance which vehicles in a family would have the highest emission levels.

Although any of the above reasons could explain why the vehicles selected as high emitters do not have, in general, the higher emission levels within a family, a combination of three of these explanations appears to be most likely. First, the differences in the emission levels of tested vehicles are relatively small (often being statistically insignificant for NO_x in many families[1]). Second, given this small difference, the complexity of selecting the high emission designs within each family is increased by the numerous adjustments which the manufacturers may use to vary the emission levels from one design to the next. Finally, any incentive to select a representative sample of test vehicles (such as ones designed to represent subclasses of engine families or cover fuel economy testing requirements) dilutes EPA's ability to focus solely on a high emitter criterion.

The relative contribution of each of these three explanations to the resultant selection cannot be ascertained without an examination of the vehicle selection process on a case-by-case basis. If the primary cause is the fact that engine families are so small that vehicles within them have very similar emission levels, then the solution is to restructure the family classification or simply select vehicles within each family at random. If, however, the problem is created by the complexity of the relationship between emissions and combinations of vehicle parameters or by an interest in providing more representative vehicles, then a restructuring of the selection process (possibly including some random selection) seems appropriate. Such a restructuring

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[1]See appendix C, exhibits C-2 and C-3.

could alter the amount of time spent selecting the high emitter vehicles or improve EPA's ability to identify these vehicles, or both. Three possible alternatives are:

(1) to rely totally on mechanized selection methods;

(2) to enhance judgment criteria by increasing the use of data; feedback from other engineers, etc.; and/or

(3) to combine new judgment procedures with mechanized selection procedures.

The first of the above alternatives would essentially replace the time currently spent by the engineering teams selecting type B vehicles with an automatic selection methodology. Such a methodology should have a random component to avoid situations in which the knowledge about how the vehicles were selected would promote potentially deceptive practices by the manufacturers. The scheme could be totally random or contain some form of bias (e.g., selecting vehicles with certain parameter values with a greater probability).

The potential annual savings in engineering analysis time used to select these vehicles would be approximately a man year or less.[1] The gain would free some of EPA's engineering talent to perform other tasks; however, it would require other resources, primarily in the data processing area. Thus,

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[1]EPA's annual estimates of the number of families submitted for review vary between 300 and 400. EPA further estimates that the selection of EDVs from a typical family takes between three and five hours. Thus, a rough average of EPA workload to select emission data vehicles is about 1400 man hours per year, or about three-fourths of a man year. (This estimate probably does not include the time necessary for supervising personnel to approve the selection nor the time necessary for EPA to deal with manufacturer problems concerning this selection or with approval of carry-over or carry-across requests [EPA, undated].)

EPA would realize little net savings in total resources by adopting a totally mechanized selection process.[1]

The second of the above alternatives (alter current judgment practices) appears to offer limited improvement without a more detailed examination of the performance of individual engineers. That is, one must investigate the extent to which the application of engineering judgment could be improved by increasing the time to make the decision, improving the understanding of the emission production process, greater reliance on routinized procedures, etc.

Finally, a combination of mechanized solutions and improved judgmental procedures appears to offer the greatest promise. Under this alternative, EPA could vary the number of selections made mechanically and judgmentally as circumstances dictate. For example, current procedures could be used to select the type A vehicles and one type B vehicle while the remaining vehicles would be selected at random.[2] This would provide a mechanism for the engineers to monitor their performance against a random sample and possibly stimulate an improvement in the ability to identify vehicle characteristics which indicate potential high emissions. Further, a combined procedure would provide a method to compare the performance of a variety of mechanical schemes to engineering judgment and vice versa. This approach

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[1]This conclusion is clearly erroneous if mechanized selection would permit EPA to eliminate much of the time consumed reviewing the manufacturers' applications. However, since this review is necessary to perform other EPA tasks (e.g., designation of engine families, selection of durability vehicles, review of required disclosures, identification of defeat devices, etc.), elimination of the EDV selections would not alone preclude this activity.

[2]This random selection could be designed to account for current selection criteria which stipulate coverage of engine-system combinations, high altitude, and fuel economy base-level configurations.

could be implemented almost immediately without incurring additional workload and without degrading certification program performance.[1]

A more extensive change in current procedures would adopt some new judgment methods and combine them with mechanized sampling. Such a procedure could use data from previous years, low mileage durability vehicle tests and/or manufacturer development data to determine where judgment versus random sampling techniques would be used to select vehicles. For example, judgment might be used to select vehicles from families suspected of having a greater likelihood of having vehicle configurations whose emissions exceed standards, and random sampling used on the remainder. Similarly, characteristics of vehicles which failed one or more emission tests[2] could be compiled and analyzed continuously to provide a mechanism to update judgment procedures or modify mechanized sampling routines which reflect the knowledge gained in this monitoring process.

It should be noted that none of the actions suggested above would significantly reduce EPA's engineering or testing workload.[3] Rather, the primary gain from any of the above actions other than completely random selection would be to improve the capability of the certification process to identify engine families (and vehicles within these families) which do not comply with the Clean Air Act.

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[1]The results of the analyses in the first part of this chapter show current judgment is very similar to a random selection of vehicles.

[2]These tests could include those from the fuel economy, durability running change, and emission data testing programs.

[3]As noted previously, EPA's estimate of the workload to select emission data vehicles is less than a man-year [EPA, undated].

4.0 VEHICLE TESTING STRATEGIES AND COMPLIANCE CRITERIA

After a set of emission data vehicles has been selected and built for a given engine family, EPA's current procedures require that EPA test all of these vehicles and certify the engine family only if, for each of the vehicles, the measured emission levels (after application of a deterioration factor) are within the standards on at least one of two tests.[1] Section 4.1 of this chapter compares this testing strategy (i.e., the requirement that all EDVs be tested by EPA) and this criterion for vehicle compliance (i.e., the requirement that a vehicle pass one of two possible tests) with certain alternative strategies and criteria. These alternatives may allow EPA to save resources without substantially increasing either the risk of erroneously passing vehicles as complying with the standards or the risk of erroneously failing them.

Alternative strategies for testing "running changes" are the subject of section 4.2 of this chapter. Once an engine family has been certified, the manufacturer is likely to want to make modifications to designs within the family, for various reasons relating to the manufacturing process or the performance of the vehicles. Although these changes may not be intended to improve (or degrade) emission levels, the complexity and interrelatedness of the total automobile power train system will cause the changes to have potential effects on these levels. For this reason, EPA must approve all proposed running changes affecting emission-related parameters before they may be implemented.

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[1]The second test is conducted only in the case of a failure on the first test and a subsequent request for a retest by the manufacturer.

Each is examined by EPA engineers, who may authorize the change directly, may require manufacturer tests of the change, or may require EPA tests of the change. Testing may involve tests of the changed version of the vehicle only, or may consist of "back-to-back" testing in which the original test vehicle is tested first in the initial configuration and then as modified.

4.1 *Analysis of Emission Data Vehicle Testing Strategies and Compliance Criteria*

An analysis of alternative testing strategies and of alternative criteria for determining compliance of a single EDV was conducted on a representative fleet of 1977 model year vehicles.[1] Emission data for this fleet were used to develop probability distributions of true emission levels for prototype vehicles. These distributions were used in conjunction with statistical estimates of test variability to predict the effectiveness of each of several sets of procedures for conducting the certification process. For each set of procedures evaluated, several effectiveness measures were computed, including

(1) the fraction of EDVs failed by the certification process;

(2) the fraction of EDVs failed by the process when at least one of their true emission rates exceeded the standards;[2] and

(3) the fraction of EDVs failed by the process when all their true emission rates were within the standards.[3]

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[1]Appendix E includes a detailed description of this data base, and of the results of the analysis. The analytical procedures used are described in appendix F.

[2]One minus this fraction is referred to as the probability of erroneously passing a vehicle.

[3]This is referred to as the probability of erroneously failing a vehicle.

All these measures are expressed as failure rates of EDVs rather than as rates of failing to certify engine families. It is VRI's understanding that the usual effect of failure of an EDV is that the manufacturer modifies the specifications of the vehicles in the portion of the engine family associated with the failure so that the family eventually is able to be certified. These EDV failure rates reflect the frequency at which this activity occurs and whether or not the activity should have been required by EPA. A change in the first of these effectiveness measures would represent a change in the cost of the certification process to the manufacturer; a substantial change in this value might therefore be expected to produce a change in manufacturer behavior.[1] The second of these measures represents the effectiveness of the certification process in terms of its ability to detect vehicles which exceed the standards. The third measure reflects the frequency with which EPA makes the error of failing vehicles which meet the standards. Failure to keep this frequency at a reasonably low level would impose an unfair burden on the manufacturer which he (and society) might be unwilling to bear.[2] In addition to these three measures of effectiveness, differences in pollution emitted by vehicles certified under the alternative strategies were predicted, and differences in the resources required to implement the various strategies were estimated. The following three sections discuss the results of this analysis.

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[1]For most strategies analyzed in this study, the effects of a change in manufacturer behavior were not explicitly included in the analysis. However, a discussion of the impact of such a change is provided later in this chapter.

[2]Note that there is an inherent tradeoff between the second and third of these measures--an increase in one tends to lead to an increase in the other.

4.1.1 Current Procedure and Manufacturer Behavior

In order to develop estimates of changes in effectiveness resulting from alternative strategies, the effectiveness of EPA's current process was first estimated by analyzing EDV test results. The result[1] was that approximately ten percent of EDVs were predicted to fail under current procedures. Of all vehicles whose true emissions are within all three exhaust emission standards, approximately two percent are erroneously failed by the process, while 62 percent of all vehicles which actually exceed the standards are failed by the process.

The relatively low failure rate predicted for the current process (which is consistent with EPA experience) is the result of the fact that most vehicles (approximately 87 percent in the domestic portion of the fleet) which are submitted for certification meet all exhaust emission standards, presumably to avoid the cost of failures by the certification process. As a result, the direct effect of EPA's failure of vehicles on the total emissions of vehicles in certified families is relatively small, and thus none of the strategies analyzed in this study produces a large change in pollution emitted by vehicles in certified families.[2] The primary benefit of the current certification program is that it has helped to compel manufacturers to design vehicles which comply with the Clean Air Act.[3] Any recommended change

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[1] See appendix E for a more detailed description of these results, and appendix F for a description of the methodology used to generate all results presented in this chapter.

[2] The largest percentage saving realized by any strategy considered is only 1.5 percent of the corresponding emissions under EPA's current strategy. (This savings occurs for CO in the case in which only one test is allowed for every EDV, so that retests are not allowed. See section 4.1.2.)

[3] Even failed vehicles generally do not exceed the standards by much. The typical failure can be expected to be about eight percent above the standard on either CO or NO_x.

to EPA's current procedures must therefore be evaluated for its likely effect on this indirect benefit, and should be implemented in such a way that it can be monitored for any resulting undesirable changes in manufacturer behavior.

The impact of the certification process on manufacturers is felt primarily via the rate at which vehicles are failed by the process. It is reasonable to assume the manufacturers respond to changes in the certification process by adjusting the overall emissions of their fleet so as to maintain an acceptable fraction of EDVs failed by the process.[1] Analysis of this type of behavior[2] reveals that an overall increase (or decrease) in total emissions of one percent will cause an increase (or decrease) in the failure rate of approximately one percentage point. Thus, assuming the current failure rate of ten percent is acceptable to the manufacturers, a change in EPA's procedures causing this rate to decrease to eight percent might be expected eventually to cause the manufacturers to allow the overall emissions of their fleets to increase by two percent. This hypothesized effect of EPA's procedures on manufacturer behavior is not explicitly included in the predicted effectiveness of alternative EPA policies considered below, but the possibility of some such effect should be borne in mind in evaluating the overall impact of proposed changes.

4.1.2 Alternative Compliance Criteria

Two alternative criteria for determining whether a single EDV is passed by the certification process emphasize two differences from EPA's

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[1]This assumes that the technology to perform this adjustment is available to the manufacturers, and that the cost or savings of doing so is justified by the corresponding savings (or cost) associated with a decrease (or increase) in the rejection rate.

[2]See section E.2 of appendix E.

current procedures: averaging the results of multiple tests on a single EDV, and changing the total number of tests conducted on a single EDV.

In VRI's preliminary analysis of EPA's certification procedures [VRI, 1976] it was suggested the EPA consider a policy of averaging the results of the two tests conducted whenever a manufacturer requests a retest of a failed EDV. The suggestion was based on the belief that an averaging policy would be more consistent with other EPA policy and with the intent of the Clean Air Act than is the current policy of certifying the EDV if the second test is passed.[1] An averaging policy would impact on the effectiveness of the certification process as follows:[2] adoption of such a policy would cause an increase in the overall failure rate from the current ten percent to approximately 14 percent. A major portion of this increase would be associated with the failure of additional vehicles whose true emissions exceed the standards--approximately 85 percent of such vehicles would fail, compared to the current 62 percent. Overall emissions of certified vehicles would be reduced, but the reduction would be small, for reasons given in the previous section. A few additional test procedures (fewer than 100 per year[3]) would be required to allow for the testing of the increased number of resubmitted vehicles as a result of the higher failure rate. However, the greatest potential disadvantage to this policy is that it would more than double the rate of erroneously failing vehicles, increasing it from two percent to about five percent. In summary, EPA may wish to consider a test averaging policy since it allows detection of more vehicles which exceed the standards than does

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[1]Statistically, the averaging policy would produce an unbiased estimate of the true emissions of the vehicle, while the current policy does not.

[2]See section E.3 of appendix E.

[3]All estimates of changes in testing requirements are based on EPA's projection that 938 EDVs will be submitted for model year 1978 [EPA, undated].

EPA's current policy. However, such a policy also causes an increase in the risk of erroneously failing vehicles which EPA might consider excessive.

As the number of tests on a single EDV increases, the variability of the estimate of the true emissions of the vehicle (taken as an average of the test results) will decrease. As a result, the rates of both erroneously passing and erroneously failing vehicles should decrease with an increase in the number of tests conducted on each vehicle. To investigate this effect, an analysis was conducted of the case in which only one test is conducted on every EDV (so that retests are not allowed), and of the case in which EPA tests every EDV twice and averages the results. As expected, both types of errors (erroneous passing and erroneous failure) were reduced somewhat in switching from a one-test policy to a two-test policy. The one-test case produces a rate of erroneously failing vehicles (seven percent) which is almost certainly unacceptably high, while saving EPA relatively little in resources (fewer than 100 tests per year). The two-test case produces results (in terms of the three types of failure rates) which are essentially identical to those of the previously-analyzed policy of retesting only failed vehicles and averaging the outcomes. This results from the fact that the emissions of most passing vehicles tend to be well below the standards, so that a vehicle which passes one test is highly unlikely to fail a retest. However, the two-test policy would be significantly more costly to EPA than a policy of retesting and averaging only in the event of a failure. Approximately 1,300 more tests per year than are currently conducted would be required to implement a two-test policy. Thus, EPA's current policy of retesting only failed vehicles appears to be an efficient one. A three-test policy would result in a further decrease in the rates of both types of errors, but the increase in the number of tests required to implement such a policy would be prohibitive.

4.1.3 Alternative Testing Strategies

If the engine family classification scheme groups vehicles into families whose emissions are similar, EPA should be able to use this grouping to its advantage in deciding which EDVs to test. This section investigates two general kinds of such testing strategies: sequential testing strategies and judgmental selection of potentially high-emission families.

A sequential testing strategy would base a decision as to how many EDVs to test in a family on the results of earlier tests on a small number of vehicles in the same family.[1] If these preliminary tests indicate that the vehicles in the family are likely to produce emissions close to or in excess of the standards, all EDVs in the family would be tested. Otherwise, only a small number of EDVs would be tested at random.[2] Such a sequential testing strategy would still require the manufacturers to build the same numbers of prototype emission data vehicles. The major difference would be the number of these vehicles which EPA would test at its facility and the number that manufacturers would test to determine certification outcome.

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[1]It should be stressed that EPA must have control over which vehicles are tested first within a given family, in order to avoid basing the testing decision on EDVs effectively selected by the manufacturer through his control of the order in which EDVs are tested. This requirement may produce test scheduling problems which would have to be overcome before a sequential testing strategy could be adopted.

[2]This random testing would allow EPA to monitor manufacturer behavior and to adjust the parameters of the sequential strategy if a change in behavior resulted in a change in the characteristics of the fleet submitted to EPA.

To assess the effectiveness of adoption of a sequential strategy, several such strategies have been analyzed, varying the criteria for deciding whether to test all the EDVs in a family.[1] A broad set of sequential testing strategies was identified which would save certification and testing resources with no increase in the risk of erroneously failing vehicles, and with no increase to a moderate increase in the risk of erroneously passing vehicles, compared with the risks under EPA's current testing procedures.[2]

As an example, one of the more conservative of these strategies requires two vehicles to be tested in each engine family. If the measured emissions on both vehicles are less than 60 percent of the standard for HC and CO, and less than 70 percent of the standard for NO_x, the family is certified.[3] Otherwise all EDVs in the family are tested before a certification decision is made. This strategy produces results (in terms of the three types of failure rates and total lifetime emissions) which are essentially identical to the results under EPA's current procedures, while testing 125 fewer EDVs per year (for a saving of approximately 158 tests, counting voided tests, retests, and tests of resubmitted

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[1]Results for all sequential strategies evaluated can be found in section E.4 of appendix E.

[2]All of the strategies considered are somewhat conservative in that they require no use of manufacturer data in the process of deciding which vehicles to test.

[3]These percentages were selected on the basis of the statistical characteristics of the emissions levels involved. See section E.1.2 (and especially exhibit E-3) of appendix E for a description of these characteristics.

vehicles after a failure).[1] An associated saving of Certification Division personnel time can also be expected, due to a reduction in observation of tests and administrative support of the testing process.[2] Further analysis has indicated that these savings can be more than doubled through adoption of a less conservative sequential strategy (one requiring only one vehicle to be tested in each family) if EPA is willing to accept a moderate increase in the risk of erroneously passing vehicles. Such a strategy would have a negligible direct effect on emissions, but it would decrease the overall failure rate to .08, so it might affect manufacturer behavior somewhat.

The above results are based on the assumption that EPA's current compliance criteria would be employed on those vehicles which would be tested under a sequential strategy. An analysis was also performed of a sequential strategy coupled with a policy of averaging the results of the two tests whenever a retest is conducted on a failed EDV. The particular testing strategy involved would require the testing of only one vehicle in each family unless one or more of the thresholds listed earlier was exceeded. This strategy produces failure rates comparable to those of EPA's current

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[1]The removal of an EDV could "uncover" a fuel economy base level (see appendix G for discussion of the fuel economy testing process). Consequently another vehicle would have to be tested in its place to provide the necessary fuel economy data. The likelihood of such an occurrence is dependent on the probability that a base level has more than one EDV. Data from the current program indicate that about half of the base levels are covered by more than one EDV. Therefore, the chance that the removal of an EDV would "uncover" a base level is at most about 33 percent. As noted previously, EPA's current policy of testing 25 percent of all fuel economy data vehicles (FEDVs) would then require EPA to test one out of every four EDVs (or equivalent) whose removal "uncovered" a base level. Therefore, the fuel economy program would require EPA to test at most eight percent (or one of every 12) EDVs removed.

[2]Exact quantification of this saving is difficult, but a rough approximation is between two and three hours per EDV not tested.

procedures (11 percent of all vehicles fail, 61 percent of vehicles with true emissions above the standards fail, and three percent of vehicles with true emissions below the standards are erroneously failed), while saving EPA roughly 380 tests per year.

In summary, sequential testing strategies are available which would save resources and result in acceptable risks. A comparison of the effectiveness of the alternative sequential strategies described above is summarized in exhibit 3.

A possible alternative to using a small number of tests to identify those families in which all EDVs are to be tested would be to employ the judgment of certification engineers to identify high-emission families. While it is not known how effectively engineers could perform this function, it may be less difficult than the task of selecting high-emitting vehicles within each engine family.[1] Under EPA's current certification procedures, more than 90 percent of the failed vehicles are contained in only 50 percent of the engine families. If engineers were able to preselect these families perfectly and test all EDVs in them (testing only a few randomly-selected vehicles from other families), EPA could test slightly more than half the EDVs currently tested and suffer only a small increase in the risk of erroneously passing vehicles. It is unlikely that engineers have such a high capability to identify these families, however.

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[1]Low mileage durability vehicle tests and/or manufacturer development data might assist in this selection process.

EXHIBIT 3: COMPARISON OF SOME ALTERNATIVE TESTING STRATEGIES

Strategy[1]	Fraction of EDVs Failed			Reduction in Tests Required
	Overall	When True Emissions Exceed Standards	When True Emissions Are Within Standards	
Current strategy	.10	.62	.02	0
Two-vehicle sequential strategy	.09	.62	.02	158
One-vehicle sequential strategy	.08	.46	.02	392
One-vehicle sequential strategy with averaging on failure	.11	.61	.03	380
Judgmental family selection	.08	.50	.02	418
Judgmental family selection and sequential testing	.09	.59	.02	228

[1]These strategies are defined precisely in appendix E.

Using a more realistic (although still arbitrary) representation of the engineers' ability to identify families with high emissions,[1] analysis indicates that a 30 percent reduction could be achieved in the number of EDVs tested (a savings of approximately 418 tests on 281 vehicles) with a moderate increase in the risk of miscertification. In this case, the overall failing rate would be about eight percent, the failure rate of vehicles whose true emissions exceed the standards would be 50 percent and the rate of erroneous failure would remain at about two percent.

A more conservative use of this same assumed capability to identify high-emission families would be to combine the capability with sequential testing in the following way: if engineering judgment indicates a family is likely to contain high-emitting vehicles, apply a conservative sequential strategy to it (e.g., require that two vehicles have emissions below the thresholds in order to certify the family without further testing). Otherwise, apply a less conservative strategy to the family (such as one based on the test of a single vehicle in the family). Analysis of such a mixed strategy reveals that the resulting risks are only slightly greater than under EPA's current procedures (nine percent of vehicles are failed, 59 percent of vehicles whose true emissions exceed the standards are failed, and two percent of vehicles are erroneously failed), while saving EPA approximately 228 tests on 167 EDVs.

It thus appears to be worthwhile for EPA to investigate engineers' ability to select high-emitting families. If such a capability exists, it alone could be used to reduce significantly EPA's testing workload with a

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[1]The exact nature of this representation is described in section E.5 of appendix E.

moderate increase in the risk of erroneously passing vehicles; or it could be used in conjunction with sequential testing to increase the benefits and/or reduce the risks resulting from implementation of a sequential strategy alone. The potential effectiveness of each of these alternative uses of engineering judgment is summarized in exhibit 4-1.

4.2 Analysis of Running Change Testing Strategies

Running change vehicles result from changes to certified vehicle designs proposed by the manufacturer which are additions or modifications to the current product line. EPA engineers determine whether these proposed designs belong in a certified engine family and therefore represent "running changes" to previously certified configurations.[1] Proposed vehicles which are running changes must then be evaluated to determine whether EPA and/or manufacturer testing is required for approval. This testing decision is based on engineering judgment that the effect on emissions of the proposed change is an increase in pollutant levels above the standard, or is unknown. This section is divided into two parts. The first provides an analysis of the emission levels of the running change vehicles tested by EPA. Then, based on the results of this analysis, the second suggests alternative ways of determining whether or not EPA should test these vehicles.

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[1]Closely related to running changes are "additions of vehicles." These additions are changes to a certified vehicle proposed to permit a manufacturer to market a new product. These changes are also reviewed by EPA to determine whether testing is required, however, they are much less frequent and were therefore not analyzed in this study.

4.2.1 Effectiveness of Current Strategy

In order to examine the potentials for reduction in either the amount of engineering analysis or the number of tests performed, it was first necessary to analyze and understand the performance of the present process.[1] This investigation examined EPA test data on 1977 running changes (RCs) proposed by Chrysler, Ford, and General Motors. The running change tests used in this analysis were those which were conducted on modifications to original emission data vehicle (EDV) configurations so that the emission levels before and after the changes could be examined. A total of 66 such test data sets were identified. For each of these sets, the results from the certified vehicle tests were coupled with one or more running change tests.[2]

Because EPA tests were conducted on changes when engineering analysis suggested that they were needed (presumably because of a potential for increased emissions of at least one of the pollutants), it seemed reasonable to expect that the EPA running changes in the 66 test data sets would, in general, have higher emission levels than those of the EDVs. This might be demonstrated by the test results in either of two ways. First, the average emission levels of the RCs for one or more of the pollutants could exceed those for the associated certified EDVs. Second, a high fraction of

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[1]See section D.5 of appendix D.

[2]Many of the running change designs tested skipped one or more of the design sequence numbers indicating that some design changes were not tested by EPA, were not submitted for approval by the manufacturer, or were misnumbered by the computer algorithm (see section D.5 of appendix D).

running change tests could show an increase in at least one pollutant, even though no single pollutant showed an average increase in emission levels.

Statistical tests were performed for both these hypotheses. The first test compared the average emission levels of running changes to those of their previously certified vehicle. The results of this examination revealed no significant difference at the five percent level of significance.[1] The second test examined the frequency with which one or more of the pollutant levels from the running changes were above or below that for the certified EDV.[2] A total of 109 EDV-RC comparisons revealed that the RC emission levels were symmetrically distributed above and below the EDV emission levels. Since it was possible that some of these running change test results represented the unchanged portion of a back-to-back test, a check was made to see if this possible ambiguity in the test results would influence the conclusions of this analysis. The examination revealed that the results of the analysis were indifferent to the interpretation of these test data and that running changes which showed an increase on at least one pollutant were not more frequent than would be expected from random effects.

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[1]The statistical test used in this investigation was a one-way analysis of variance to determine if the mean of the EDVs was significantly different from the mean of the running changes (see section D.5 of appendix D).

[2]A Chi-square test (like that used in comparing the failure rates of type B vehicles to type A vehicles) was used to compare the number of times that one or more RC pollutant levels exceeded those of the EDV with the number of times expected from random effects only (see section D.5 of appendix D).

The above results suggest that, given the present manufacturer behavior in the design and modification process, the running changes selected for testing show no bias toward higher emissions than the originally certified configurations. These analyses only indicate, however, that the running change emissions vary randomly above and below the original certification levels and do not indicate the magnitude of this variation. Since the decision to test a running change may be based on knowledge that the proposed change can significantly affect emissions but the direction of this impact is uncertain, it was necessary to examine the relative variability of running change emissions.

An examination was therefore conducted to measure the variability in the emissions of the original vehicles, as compared to that of their running change counterparts. Since test-to-test errors would introduce some variation even if the running change designs were identical to their original counterparts, the estimate of variability was computed in two steps. First, an estimate of the total variability for each pollutant within each EDV-RC group was computed to get an estimate of the percent of variation around the group averages. This estimate contained both a test-to-test and running change variability components. In the second step, an estimate of test-to-test variability (see appendix B) was subtracted from the total estimate for each pollutant to approximate the amount of variability which could be associated with running changes. The resultant values range from eight percent to 12 percent for HC, 22 percent to 32 percent for CO, and five percent to seven percent for NO_x.

The above RC variability ranges are less than the configuration-to-configuration variabilities found within an engine family.[1] Thus, on

[1]The precise estimate of the configuration-to-configuration coefficient of variation within a family varies depending on the statistical model used, but all estimates run about 20 percent for HC, 30 percent for CO, and 15 percent for NO_x.

the average, the probability that an EPA test will detect an RC whose true emission levels are above the standards (and therefore reject the proposed change) is less than the probability of rejecting a configuration selected at random within the family. In fact, using both the data from the analysis of the EDV emissions in chapter 3.0, and that from this analysis of running changes, one can show that the probability of failing a design on an RC test is between 4 and 40 times smaller than that of failing a randomly selected configuration.[1]

The above findings were further supported by a review of a small sample of proposed changes (five from Ford and five from GM) for which EPA decided to rely solely on the manufacturer's test results rather than to require additional testing by EPA. An analysis of these vehicles revealed that they were as likely to fail certification as those selected for testing by EPA. Thus, EPA's decision to test or not to test a proposed running change is statistically independent of the estimated probability that the change would cause the vehicle to fail the test.

4.2.2 Alternative Running Change Testing Strategies

The primary conclusion of the previous analysis is that EPA reviews and tests a large number of running change vehicles whose emission levels cannot be differentiated from those of the original configurations which are to be modified. The cost to EPA to perform this task is significant. EPA estimates it will take between one and four person years of effort to review

[1]The relatively high variability in the estimated ratio of failure probabilities is due to the data-oriented and statistical uncertainties in all the estimates.

the 1800 running change applications anticipated for the 1978 model year.[1] Further, if the historical RC test rate continues, about half of all RC applications will be tested by EPA, and this testing will consume approximately 50 percent of the exhaust emission testing workload. This suggests that EPA will concentrate a significant amount of time and effort approving many running changes which the above analysis shows are more likely to comply with standards than a randomly selected configuration within the same family.

The small difference in the emissions between the original EDV and the RCs to this configuration (and the generally low probabilities of rejecting a running change[2]) suggests strongly that a great deal of selectivity should be exercised to control the amount of EPA attention and resources which are given to the running changes. While some randomly-selected changes should be reviewed to determine the need for testing, it would appear that most of the selection of changes for testing could be made on a formal basis similar to that suggested in the analysis of sequential testing strategies for emission data vehicles (see section 4.1). In fact, the same policies suggested in section 4.1, in which the choice of whether to test or not is based on the past tests of vehicles in the same family, could be applied directly. That is, if the sequential strategy used in the testing of EDVs suggested that EDVs

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[1] EPA's FY77 Program Plan states that the review of a running change can take from one hour to several days with most changes requiring about one to four hours for review [EPA, undated].

[2] Conversations with EPA engineers indicate that failure of a running change is an extremely rare event. Manufacturers do, however, withdraw some applications for running changes which may indicate their avoidance of an anticipated failure. The data supplied to VRI on running changes indicate all of the running changes examined in this study were accepted by EPA.

in a family should not be tested further, running changes within that family would also not be tested (except on a limited random basis). In addition, a choice based on the certification results of the original EDV, if it was tested, would provide a slight improvement over the use of only family data.

APPENDICES

The purpose of the appendices which follow is to provide the interested reader with further details about the data, analytic methods and results used to develop the conclusions and recommendations presented in the body of the report. For ease of reference, the methods described in the appendices are presented in approximately the same order as they appear in the main text. All figures and tables in the appendices are referred to as exhibits and appear at the end of each appendix.

There are seven technical appendices and one appendix which provides the bibliographic references used in the study. The title of each appendix is given below.

Appendix A: Description of VRI Data Base

Appendix B: Analysis of Emission Test Variability

Appendix C: Analysis of Engine Family Classification

Appendix D: Analysis of Engineering Judgment

Appendix E: Analysis of Alternative Testing Strategies

Appendix F: Methodology for Effectiveness Assessment

Appendix G: Description of EPA Fuel Economy Testing Program

Appendix H: References

APPENDIX A

DESCRIPTION OF VRI DATA BASE

One of the major tasks of the study was the identification, collection and review of emission data vehicle (EDV) test results and associated information. The majority of information contained in VRI's data base was that provided by the Data Branch, Program Management Division, in machine readable form. This data was augmented with emissions data vehicle information maintained by three certification teams within the Light Duty Certification Branch, Certification Division. The following subsections provide a description of the development of this data base and a summary of its content.

A.1 Data Base Development

At project outset, the intent was to analyze EDV test data from model years 1975-1977 for all manufacturers to study the effectiveness of engineering judgment, the engine family classification scheme, and the cost and risk implications of alternative testing strategies. In order to follow such a plan within the project resources, it was necessary to acquire a complete and comprehensive set of machine readable EDV test data. Because portions of the necessary data were not in that form, two operational decisions were made to ensure that the data collection activities of the project would not consume a disproportionate amount of available resources. These decisions were:

(1) to use EDV data from three domestic (Chrysler, Ford, and General Motors) and six foreign (Honda, BMW, Fiat, Datsun, Mazda, and Volvo) manufacturers and

(2) to concentrate on 1977 model year data, using 1976 model year data to provide a larger vehicle sample for certain analyses and to support conclusions derived from the more recent data.

The emissions data vehicles included in the study data base were identified by reviewing manufacturer Part I and Part II applications and comparing this information with the data found in the light duty vehicle summary sheets. This comparison permitted the identification of those EDVs which were tested by EPA to certify the original vehicle fleet of each manufacturer (i.e., vehicles which were withdrawn prior to EPA testing, vehicles tested for purposes other than certification, and vehicles which were "carryovers" from previous years were excluded from the data base). In addition, the review of material maintained by the EPA certification teams provided information necessary to determine whether the high sales or high emissions criterion was used to select each EDV.[1] The description of the engineering specifications and test results[2] for each of these vehicles was then extracted from data contained in the light Duty Vehicle Data System, Phase 2, maintained by the Data Branch.

Information was extracted from four data files in this system. These files contain information detailing vehicle specifications (EPA's 1000D-CURMAS file), the tests performed by EPA (EPA's 1200D file) and manufacturers (EPA's 1202D file) on each EDV, and a locator file to connect information

[1]The criterion for selection is an essential element for the analysis of engineering judgment and is not currently available on the EPA automated data base.

[2]Only those test results which were collected using the 1975 federal test procedure and considered valid by EPA (i.e., not voids) were included in the data base.

in these files (EPA's 1200D-MASLOC file). Since these files are constantly being updated, VRI's information was that found in EPA's files on the date of transfer, November 18, 1976, for domestic manufacturers and February 15, 1977, for foreign manufacturers.

In order to analyze test information for model year 1976,[1] the above files were augmented using information maintained in the previous data system (EPA's file 1030D). Data in this file is much less comprehensive and not compatible with that in the Phase 2 system; thus vehicle information for 1976 EDVs tested prior to January 1977 was less complete than that found for vehicles tested after that date.

A.2 Data Base Content

The study data base consisted of emission data and vehicle specifications collected on 583 emission data vehicles. These vehicles were distributed by year and by manufacturer as shown in exhibit A-1. As noted previously and as can be seen in the exhibit, only 1977 model year vehicles are included for foreign manufacturers.

A review of test data for the 1977 model year vehicles in this data base revealed a number of situations which appeared to contradict VRI's understanding of certification procedures, required further interpretation, or contained potentially erroneous information. The majority of these situations were encountered in an attempt to determine whether vehicles with identical data base specifications were indeed identical and whether multiple tests on such vehicles were conducted under the same procedures.

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[1]Since the recoding of pre-Phase 2 information was not completed at the time of transfer, the files do not contain information on EDVs tested prior to the beginning of the Phase 2 system (approximately January 1976).

Examples of the types of problems encountered in this examination included:

(1) the identification of a failed vehicle versus its "fixed" version (i.e., the modification of a failed vehicle to permit retesting of it under the configuration specified for the proposed replacement),

(2) the determination that manufacturers had not requested retests for vehicles with one failed test (this was necessary to ensure that the single failed test was not a coding error or that there did not exist an additional failed test which was missed),

(3) the identification of low altitude tests performed on high altitude vehicles (the latter set of vehicles being excluded from our analysis),

(4) the identification of detectable coding errors (the most problematic of these being errors in coding test procedure and certification disposition), and

(5) the identification of whether a series of tests on a running change to a certified vehicle were multiple tests on the same running change, back-to-back tests on a proposed change before and after its implementation, or sequential changes with each tested once.

Resolution of the above and similar problems required a reasonable amount of effort by the VRI study team and the participation of the certification team responsible for encoding much of this information since much of the necessary information was not readily available without searching the manuals and personal memories of these groups. The amount of work required by this activity, plus the knowledge that ferreting out the similar information for 1976 vehicles would be a much more demanding task, led the study team to decide to begin by performing most analyses on 1977 vehicle information and test results.[1] The two analyses which used both the 1976 and 1977 vehicle data were the investigations of the correlation between pollutants (described in section D.2.2 of appendix D) and the running change emissions (discussed in section D.5 of appendix D).

All analyses using only 1977 data were either made on the entire collection of 1977 emission data vehicles or on the subset of these vehicles which had more than one test conducted under the same test procedure (i.e., the 1975 Constant Volume Sample, Federal Test Procedure). Where dictated by the design of the statistical analysis, only one test per vehicle[2] was used. The identification of which data set was used is provided in the description of each analysis.

A review of data collected on vehicles for the 1977 model year is provided in exhibit D-2. Of the 335 vehicles in this exhibit, a total of 313 vehicles passed, and 22 vehicles failed certification. Although more type B vehicles than type A vehicles failed certification, the proportion of type B vehicles that failed is not significantly different than the proprotion of type A vehicles.[3] There are a number of retests performed for reasons other than failure. A review of codes for retest and discussions with the Certification Division personnel revealed that most of these retests

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[1] That is, they were performed on the data associated with the 335 vehicles for model year 1977 whose distribution across manufacturers is shown in exhibit A-1. These vehicles represent 88 percent of the 1977 emission data vehicles used to certify light duty vehicle engine families for the nine manufacturers shown (or approximately 60 percent of all such vehicles for all manufacturers).

[2] In order to avoid potential bias introduced by systematic changes to the vehicle between tests, the first test in each series was selected for analysis.

[3] See section D.1 of appendix D for analysis.

are either the consequence of a manufacturer's request[1] or of the need to perform additional fuel economy tests.

Exhibit A-3 provides a listing of the set of vehicles in VRI's data base. To facilitate analysis, each emission data vehicle in the study data base was assigned a unique mnemonic code which permitted rapid segregation of the vehicles by manufacturer, model year, and engine family. The VRI codes shown in exhibit A-3 consist of three separate fields. The first field contains two characters, an alphabetic character for the manufacturer followed by the last digit of the vehicle model year. The remaining two fields provide sequence numbers for the engine family and emission data vehicle, respectively. Alphabetic codes for the manufacturers are given below and at the top of each page of exhibit A-3.

MANUFACTURER	CODE
Chrysler	C*-**-*
Ford	F*-**-*
GM	G*-**-*
BMW	B*-**-*
Datsun	D*-**-*
Honda	H*-**-*
Fiat	I*-**-*
Mazda	M*-**-*
Volvo	V*-**-*

[1]One reason for permitting such retests is to permit vehicles to pass California standards.

EXHIBIT A-1: NUMBERS OF EMISSION DATA VEHICLES IN VRI DATA BASE

MANUFACTURER	MODEL YEAR		
	1976	1977	1976 + 1977
Chrysler	70	72	142
General Motors	146	116	262
Ford	32	64	96
BMW	0	8	8
Datsun	0	25	25
Fiat	0	14	14
Honda	0	12	12
Mazda	0	12	12
Volvo	0	12	12
All Manufacturers	248	335	583

EXHIBIT A-2: SELECTED DATA FROM THE DATA BASE FOR 1977 VEHICLES

Item	Selection Type	Chrysler	Ford	General Motors	BMW	Datsun	Honda	Fiat	Mazda	Volvo
Certified Vehicles	A	15	22	35	4	13	4	6	6	7
	B	51	32	76	4	11	8	8	6	5
Certified Vehicles That Failed One Test	A	2	1	4	0	0	0	0	0	2
	B	3	4	3	0	0	1	0	0	0
Failed Vehicles	A	0	4	1	0	0	0	0	0	0
	B	6	6	4	0	1	0	0	0	0
Vehicles With One Or More Retests	A	5	6	7	1	2	1	1	0	3
	B	22	12	13	1	1	1	3	1	3
Average Number Of Tests Per Vehicle	A	1.53	1.23	1.19	1.25	1.15	1.25	1.17	1.00	1.43
	B	1.40	1.32	1.16	1.25	1.08	1.13	1.38	1.17	1.60
Total Number Of Vehicles	A	15	26	36	4	13	4	6	6	7
	B	57	38	80	4	12	8	8	6	5

EXHIBIT A-3: DATA BASE VEHICLE IDENTIFICATION (C = CHRYSLER)

	Manufacturer Codes	
VRI ID Code	Engine Family	Vehicle
C5- 1-1	FA-360-4-P	2069
C5- 1-2	FA-360-4-P	2074
C6- 1-1	CB-440-4HP-P7S	4171
C6- 1-2	CB-440-4HP-P7S	4180
C6- 1-3	CB-440-4HP-P7S	4188
C6- 2-1	CC-440-4ST-P5L	4169
C6- 2-2	CC-440-4ST-P5L	4170
C6- 2-3	CC-440-4ST-P5L	4172
C6- 2-4	CC-440-4ST-P5L	4225
C6- 3-1	CD-225-1-P5S	4151
C6- 3-2	CD-225-1-P5S	4152
C6- 3-3	CD-225-1-P5S	4154
C6- 3-4	CD-225-1-P5S	4155
C6- 3-5	CD-225-1-P5S	4175
C6- 3-6	CD-225-1-P5S	4182
C6- 4-1	CD-318-2-P5S	4156
C6- 4-2	CD-318-2-P5S	4159
C6- 4-3	CD-318-2-P5S	4176
C6- 4-4	CD-318-2-P5S	4177
C6- 4-5	CD-318-2-P5S	4178
C6- 5-1	CD-360-4-P5S	4158
C6- 5-2	CD-360-4-P5S	4160
C6- 5-3	CD-360-4-P5S	4161
C6- 5-4	CD-360-4-P5S	4162
C6- 5-5	CD-360-4-P5S	4163
C6- 5-6	CD-360-4-P5S	4173
C6- 5-7	CD-360-4-P5S	4174
C6- 6-1	CD-400-4-P5S	4157
C6- 6-2	CD-400-4-P5S	4166
C6- 6-3	CD-400-4-P5S	4168
C6- 6-4	CD-400-4-P5S	4179
C6- 7-1	FA-318-2-P	4057
C6- 7-2	FA-318-2-P	4094
C6- 7-3	FA-318-2-P	4095
C6- 7-4	FA-318-2-P	4096
C6- 7-5	FA-318-2-P	4097
C6- 7-6	FA-318-2-P	4109
C6- 8-1	FB-400-4-P	4065
C6- 9-1	FB-440-4HP-7S	4075
C6- 9-2	FB-440-4HP-7S	4076
C6- 9-3	FB-440-4HP-7S	4103
C6- 9-4	FB-440-4HP-7S	4107
C6-10-1	FC-440-4ST-5L	4063
C6-10-2	FC-440-4ST-5L	4064
C6-10-3	FC-440-4ST-5L	4066
C6-10-4	FC-440-4ST-5L	4074
C6-11-1	FD-225-1-5S	4084
C6-11-2	FD-225-1-5S	4085

EXHIBIT A-3: DATA BASE VEHICLE IDENTIFICATION (C = CHRYSLER) (Continued)

VRI ID Code	Manufacturer Codes Engine Family	Vehicle
C6-11-3	FD-225-1-5S	4093
C6-12-1	FD-225-1-5SS	4053
C6-12-2	FD-225-1-5SS	4055
C6-12-3	FD-225-1-5SS	4060
C6-12-4	FD-225-1-5SS	4067
C6-12-5	FD-225-1-5SS	4068
C6-13-1	FD-318-2-5SS	4058
C6-13-2	FD-318-2-5SS	4061
C6-13-3	FD-318-2-5SS	4062
C6-13-4	FD-318-2-5SS	4069
C6-13-6	FD-318-2-5SS	4091
C6-13-7	FD-318-2-5SS	4092
C6-13-8	FD-318-2-5SS	4100
C6-14-1	FD-360-2-5S	1035
C6-14-2	FD-360-2-5S	4071
C6-14-3	FD-360-2-5S	4072
C6-14-4	FD-360-2-5S	4073
C6-15-1	FD-400-2-5S	4079
C6-15-2	FD-400-2-5S	4089
C6-16-1	FE-400-4-EM	4080
C6-16-2	FE-400-4-EM	4081
C6-16-3	FE-400-4-EM	4082
C6-16-4	FE-400-4-EM	4083
C6-16-5	FE-400-4-EM	4106
C7- 1-1	CD-225-1-EP	9101
C7- 1-2	CD-225-1-EP	9102
C7- 1-3	CD-225-1-EP	9103
C7- 1-4	CD-225-1-EP	9104
C7- 1-5	CD-225-1-EP	9105
C7- 2-1	CD-318-2-GP	9106
C7- 2-2	CD-318-2-GP	9107
C7- 2-3	CD-318-2-GP	9108
C7- 2-4	CD-318-2-GP	9109
C7- 2-5	CD-318-2-GP	9116
C7- 3-1	CD-440-4HP-FP	9114
C7- 3-2	CD-440-4HP-FP	9115
C7- 4-1	CD-440-4ST-GEP	9128
C7- 4-2	CD-440-4ST-GEP	9129
C7- 4-3	CD-440-4ST-GEP	9130
C7- 5-1	CD-360-4-GP	9110
C7- 5-2	CD-360-4-GP	9112
C7- 5-3	CD-360-4-GP	9113
C7- 5-4	CD-360-4-GP	9132
C7- 5-5	CD-360-4-GP	9117
C7- 7-1	FA-400-4-NE	9123
C7- 7-2	FA-400-4-NE	9124
C7- 7-3	FA-400-4-NE	9126
C7- 7-4	FA-400-4-NE	9161

EXHIBIT A-3: DATA BASE VEHICLE IDENTIFICATION (C = CHRYSLER)
(Continued)

VRI ID Code	Manufacturer Codes Engine Family	Vehicle
C7- 7-5	FA-400-4-NE	9179
C7- 8-1	FB-360-4-CE	9051
C7- 8-2	FB-360-4-CE	9052
C7- 8-3	FB-360-4-CE	9053
C7- 8-4	FB-360-4-CE	9086
C7- 9-1	FB-400-4-CE	9069
C7- 9-2	FB-400-4-CE	9089
C7- 9-3	FB-400-4-CE	9091
C7- 9-4	FB-400-4-CE	9134
C7- 9-5	FB-400-4-CE	9135
C7- 9-6	FB-400-4-CE	9155
C7-10-1	FB-440-4HP-DE	9096
C7-10-2	FB-440-4HP-DE	9098
C7-11-1	FB-440-4ST-CE	9093
C7-11-2	FB-440-4ST-CE	9094
C7-11-3	FB-440-4ST-CE	9095
C7-11-4	FB-440-4ST-CE	9099
C7-11-5	FB-440-4ST-CE	9139
C7-12-1	FD-225-1-A	9059
C7-12-2	FD-225-1-A	9060
C7-12-3	FD-225-1-A	9062
C7-12-4	FD-225-1-A	9136
C7-12-5	FD-225-1-A	9149
C7-13-1	FD-225-1-C	9049
C7-13-2	FD-225-1-C	9055
C7-13-3	FD-225-1-C	9056
C7-13-4	FD-225-1-C	9057
C7-13-5	FD-225-1-C	9144
C7-13-6	FD-225-1-C	9150
C7-14-1	FD-225-2-C	9063
C7-14-2	FD-225-2-C	9064
C7-14-3	FD-225-2-C	9065
C7-14-4	FD-225-2-C	9068
C7-14-5	FD-225-2-C	9147
C7-14-6	FD-225-2-C	9153
C7-14-7	FD-225-2-C	9158
C7-15-1	FD-318-2-C	9071
C7-15-2	FD-318-2-C	9074
C7-15-3	FD-318-2-C	9075
C7-15-4	FD-318-2-C	9133
C7-15-5	FD-318-2-C	9138
C7-15-6	FD-318-2-C	9152
C7-16-1	FD-360-2-C	9050
C7-16-2	FD-360-2-C	9081
C7-16-3	FD-360-2-C	9082
C7-16-4	FD-360-2-C	9083
C7-16-5	FD-360-2-C	9151
C7-16-6	FD-360-2-C	9160

EXHIBIT A-3: DATA BASE VEHICLE IDENTIFICATION (F = FORD) (Continued)

VRI ID Code	Manufacturer Codes Engine Family	Vehicle
F6- 1-1	200A(1CEF)	5Q1-200-4-7G
F6- 1-2	200A(1CEF)	5Q2-200-4-11G
F6- 2-1	250(1CEF)	5K1-250-4-4C
F6- 2-2	250(1CEF)	6B1-250-4-4F
F6- 2-3	250(1CEF)	6D2-250-4-1F
F6- 2-4	250(1CEF)	6H1-250-4-6F
F6- 2-5	250(1CEF)	6K2-250-4-5F
F6- 3-1	302(2CMF)	5Z1-302-4-273C
F6- 3-2	302(2CMF)	6Z1-302-4-1F
F6- 3-3	302(2CMF)	6Z1-302-4-3F
F6- 3-4	302(2CMF)	6Z1-302-4-9C
F6- 4-1	302"A"(1CEF)	5Q1-302-4-266G
F6- 5-1	302"A"(1CET)	5Q1-302-4-265D
F6- 6-1	351M/400(2CET)	6A1-351M-4-4R
F6- 6-2	351M/400(2CET)	6A1-400-4-1R
F6- 6-3	351M/400(2CET)	6A1-400-4-17R
F6- 6-4	351M/400(2CET)	6A1-400-4-2R
F6- 6-5	351M/400(2CET)	6A1-400-4-28R
F6- 6-6	351M/400(2CET)	6C1-351M-4-24R
F6- 6-7	351M/400(2CET)	6O1-351M-4-14R
F6- 6-8	351M/400(2CET)	6O1-400-4-21R
F6- 6-9	351M/400(2CET)	6O1-400-4-3R
F6- 7-1	351W(1CEF)	6H1-351W-4-7F
F6- 8-1	460"A"(2CMT)	6A1-460-4-2D
F6- 8-2	460"A"(2CMT)	6L1-460-4-12G
F6- 8-3	460"A"(2CMT)	6L1-460-4-4D
F6- 8-4	460"A"(2CMT)	6L1-460-4-9D
F6- 8-5	460"A"(2CMT)	6O1-460-4-10G
F6- 8-6	460"A"(2CMT)	6O1-460-4-29D
F6- 8-7	460"A"(2CMT)	6S1-460-4-22G
F6- 8-8	460"A"(2CMT)	6S1-460-4-24D
F6- 8-9	460"A"(2CMT)	6S1-460-4-3D
F7- 1-1	F2.3A(1CV1)	7E1-2.3-C-35
F7- 1-2	F2.3A(1CV1)	7E2-2.3-C-23
F7- 1-3	F2.3A(1CV1)	7E2-2.3-C-29
F7- 1-4	F2.3A(1CV1)	7Y1-2.3-C-34
F7- 2-1	F2.3A(1CV5)	7E1-2.3-F-25
F7- 2-2	F2.3A(1CV5)	7E2-2.3-F-33
F7- 2-3	F2.3A(1CV5)	7Y1-2.3-F-43
F7- 2-4	F2.3A(1CV5)	7Z2-2.3-F-22
F7- 2-5	F2.3A(1CV5)	7Z1-2.3-F-26
F7- 4-1	F2.8B(1CV5)	7E1-2.8-F-23
F7- 4-2	F2.8B(1CV5)	7E1-2.8-F-33
F7- 4-3	F2.8B(1CV5)	7Z2-2.8-F-25
F7- 5-1	F2.8BV(1CV1)	7E1-2.8-C-35
F7- 5-2	F2.8BV(1CV1)	7Y1-2.8-C-27
F7- 6-1	F200A(1CV5)	7K1-200-F-11
F7- 6-2	F200A(1CV5)	7K2-200-F-10

EXHIBIT A-3: DATA BASE VEHICLE IDENTIFICATION (F = FORD)
(Continued)

VRI ID Code	Manufacturer Codes Engine Family	Vehicle
F7- 6-3	F200A(1CV5)	7D2-200-F-9
F7- 7-1	F250A(1CV1)	7B1-250-C-28
F7- 7-2	F250A(1CV1)	7D1-250-C-27
F7- 8-1	F250A(1CV5)	7B1-250-F-24
F7- 8-2	F250A(1CV5)	7B1-250-F-43
F7- 8-3	F250A(1CV5)	7D1-250-F-21
F7- 8-4	F250A(1CV5)	7D2-250-F-26
F7- 8-5	F250A(1CV5)	7D2-250-F-42
F7- 8-6	F250A(1CV5)	7K2-250-F-23
F7- 9-1	F302A(1CV5)	7H2-302-F-32
F7- 9-2	F302A(1CV5)	7Z2-302-F-30
F7-10-1	F302AV(1CV1)	7B1-302-C-37
F7-10-2	F302AV(1CV1)	7D1-302-C-36
F7-10-3	F302AV(1CV1)	7Z1-302-C-38
F7-11-1	F302C(2CV4)	7O1-302-F-40
F7-12-1	F302D(1CV5)	7D1-302-F-31
F7-12-2	F302D(1CV5)	7K1-302-F-35
F7-12-3	F302D(1CV5)	7Z1-302-F-33
F7-13-1	F351MA(2CV1)	7O1-400-B-42
F7-14-1	F351MB(2CV1)	7A1-351M-F-57
F7-14-2	F351MB(2CV1)	7A1-351M-F-61
F7-14-3	F351MB(2CV1)	7A1-400-F-32
F7-14-4	F351MB(2CV1)	7O1-351M-F-34
F7-14-5	F351MB(2CV1)	7O1-400-F-33
F7-14-6	F351MB(2CV1)	7O1-400-F-47
F7-14-7	F351MB(2CV1)	7O1-400-F-65
F7-14-8	F351MB(2CV1)	7S1-351M-F-45
F7-15-1	F351MD(2CV4)	7A1-351M-F-91
F7-15-2	F351MD(2CV4)	7A1-400-F-56
F7-15-3	F351MD(2CV4)	7O1-351M-F-54
F7-15-4	F351MD(2CV4)	7O1-400-F-52
F7-15-5	F351MD(2CV4)	7O1-400-F-78
F7-15-6	F351MD(2CV4)	7O1-400-F-85
F7-15-7	F351MD(2CV4)	7W1-351M-89
F7-16-1	F351WC(1CV1)	7D1-351W-F-51
F7-16-2	F351WC(1CV1)	7H1-351W-F-34
F7-16-3	F351WC(1CV1)	7H1-351W-F-42
F7-16-4	F351WC(1CV1)	7D1-351W-F-33
F7-17-1	F351WC(1CV3)	7D1-351W-F-39
F7-17-2	F351WC(1CV3)	7D1-351W-F-46
F7-17-3	F351WC(1CV3)	7H1-351W-F-41
F7-18-1	F351WC(2CV4)	7O1-351W-F-36
F7-19-1	F460A(2CV1)	7A1-460-F-19
F7-19-2	F460A(2CV1)	7M1-460-F-18
F7-19-3	F460A(2CV1)	7V1-460-F-20
F7-20-1	F460B(2CV4)	7A1-460-F-14
F7-20-2	F460B(2CV4)	7M1-460-F-34
F7-20-3	F460B(2CV4)	7V1-460-F-11

EXHIBIT A-3: DATA BASE VEHICLE IDENTIFICATION (F = FORD, G = GM)
(Continued)

VRI ID Code	Manufacturer Codes Engine Family	Vehicle
F7-20-4	F460B(2CV4)	7V1-460-F-22
G6- 1-1	10C1D	841E
G6- 1-2	10C1D	843E
G6- 1-3	10C1D	844E
G6- 1-4	10C1D	845E
G6- 2-1	10C2	811E
G6- 2-2	10C2	813E
G6- 2-3	10C2	814E
G6- 2-4	10C2	815E
G6- 2-5	10C2	816E
G6- 3-1	10FIN	531E
G6- 4-1	10F1	511E
G6- 4-2	10F1	513E
G6- 4-3	10F1	514E
G6- 4-4	10F1	515E1
G6- 4-5	10F1	516E
G6- 5-1	10G2	111E
G6- 5-2	10G2	112E
G6- 5-3	10G2	113E
G6- 5-4	10G2	114E
G6- 5-5	10G2	115E
G6- 5-6	10G2	118E
G6- 6-1	10J2	571E
G6- 6-2	10J2	573E
G6- 6-3	10J2	574E
G6- 6-4	10J2	575E
G6- 7-1	10J4	561E
G6- 7-2	10J4	563E
G6- 7-3	10J4	564E
G6- 8-1	10K4J	131E
G6- 8-2	10K4J	132E
G6- 8-3	10K4J	133E
G6- 8-4	10K4J	134E
G6- 8-5	10K4J	135E
G6- 8-6	10K4J	136E
G6- 9-1	10R4	541E
G6- 9-2	10R4	544E
G6-10-1	10W1	121E
G6-10-2	10W1	122E
G6-10-3	10W1	123E
G6-10-4	10W1	124E
G6-11-1	11B0	831C
G6-11-2	11B0	833C
G6-12-1	11C2	821C
G6-12-2	11C2	823C
G6-12-3	11C2	824C
G6-12-4	11C2	825C
G6-12-5	11C2	826C

EXHIBIT A-3: DATA BASE VEHICLE INDENTIFICATION (G = GM) (Continued)

VRI ID Code	Manufacturer Codes Engine Family	Vehicle
G6-13-1	11F1	521C
G6-13-2	11F1	523C
G6-13-3	11F1	524C
G6-14-1	11G2	501C
G6-14-2	11G2	502C
G6-15-1	11K4	591C
G6-15-2	11K4	592C
G6-15-3	11K4	593C
G6-15-4	11K4	594C
G6-15-5	11K4	595C
G6-15-6	11K4	596C
G6-16-1	11W1V	181C
G6-16-2	11W1V	182C
G6-16-3	11W1V	183C
G6-16-4	11W1V	184C
G6-17-1	20K2	211E1
G6-17-2	20K2	212E1
G6-17-3	20K2	213E
G6-17-4	20K2	214E
G6-18-1	2004	221E
G6-18-2	2004	222E
G6-18-3	2004	223E
G6-18-4	2004	224E
G6-18-5	2004	225E
G6-18-6	2004	226E
G6-19-1	2054E	261E
G6-19-2	2054E	263E
G6-19-3	2054E	264E
G6-20-1	21K4	281C
G6-20-2	21K4	282C
G6-20-3	21K4	283C
G6-20-4	21K4	284C
G6-20-5	21K4	285C
G6-21-1	21S4	271C
G6-21-2	21S4	271C1
G6-21-3	21S4	273C
G6-21-4	21S4	273C1
G6-21-5	21S4	274C
G6-22-1	30H2J	371E
G6-22-2	30H2J	373E
G6-22-3	30H2J	374E
G6-22-4	30H2J	375E1
G6-23-1	30J4	3031E
G6-23-2	30J4	3034E
G6-23-3	30J4	3037E
G6-24-1	30S4	3044E
G6-24-2	30S4	3046E
G6-24-3	30S4	3049E

EXHIBIT A-3: DATA BASE VEHICLE IDENTIFICATION (G = GM)
(Continued)

VRI ID Code	Manufacturer Codes *Engine Family*	*Vehicle*
G6-24-4	30S4	333E
G6-24-5	30S4	334E
G6-25-1	31H2	3081C
G6-25-2	31H2	3083C1
G6-26-1	31H2J	381C
G6-26-2	31H2J	383C
G6-26-3	31H2J	384C
G6-26-4	31H2J	385C
G6-27-1	31J4	3051C
G6-27-2	31J4	3053C
G6-28-1	31S4	3141C
G6-28-2	31S4	3143C
G6-28-3	31S4	3144C
G6-28-4	31S4	3145C-1
G6-29-1	40E2Z	411E
G6-29-2	40E2Z	413E
G6-29-3	40E2Z	414E1
G6-29-4	40E2Z	415E
G6-29-5	40E2Z	416E
G6-30-1	40J2	421E
G6-30-2	40J2	423E
G6-31-1	40J4	441E
G6-31-2	40J4	443E
G6-31-3	40J4	444E
G6-32-1	40S4	461E
G6-32-2	40S4	463E
G6-32-3	40S4	464E
G6-33-1	41E2Z	4019C
G6-34-1	41E22	403C
G6-34-2	41E22	404C1
G6-34-3	41E22	405C
G6-35-1	41J4	451C
G6-35-2	41J4	453C
G6-35-3	41J4	453C1
G6-35-4	41J4	454C
G6-36-1	41S4	471C
G6-36-2	41S4	473C
G6-36-3	41S4	474C
G6-37-1	60J0	601E
G6-38-1	60V0	6021E
G6-38-2	60V0	6022E
G6-39-1	60V4	621E
G6-39-2	60V4	623E
G6-40-1	61J0	611C
G6-40-2	61J0	611C1
G6-41-1	61V0	6021C
G6-41-2	61V0	6022C
G6-42-1	61V4	631C

EXHIBIT A-3: DATA BASE VEHICLE IDENTIFICATION (G = GM)
(Continued)

	Manufacturer Codes	
VRI ID Code	Engine Family	Vehicle
G6-42-2	61V4	633C
G6-42-3	61V4	633C1
G6-43-1	740E2	7402F4
G7- 1-1	710C2	7125C6
G7- 1-2	710C2	7125F1
G7- 1-3	710C2	7125F2
G7- 1-4	710C2	7125F3
G7- 1-5	710C2	7125F4
G7- 1-6	710C2	7125F5
G7- 2-1	710F1H	7143F1
G7- 2-2	710F1H	7143F3
G7- 2-3	710F1H	7143F4
G7- 2-4	710F1H	7143F4-1
G7- 2-5	710F1H	7143F5
G7- 2-6	710F1H	7143F6
G7- 3-1	710F1SMU	7148C1
G7- 3-2	710F1SMU	7148C3
G7- 3-3	710F1SMU	7148C4
G7- 3-4	710F1SMU	7148C5
G7- 4-1	710J4	7160F1
G7- 4-2	710J4	7160F3
G7- 4-3	710J4	7160F4
G7- 4-4	710J4	7160F5
G7- 4-5	710J4	7160F6
G7- 5-1	710J4S	7168C1
G7- 5-2	710J4S	7168C3
G7- 5-3	710J4S	7168C6
G7- 5-4	710J4S	7168F4
G7- 5-5	710J4S	7168F5
G7- 6-1	710W1	7100F1
G7- 6-2	710W1	7100F2
G7- 6-3	710W1	7100F3
G7- 6-4	710W1	7100F4
G7- 7-1	710W1QU	7113C1
G7- 7-2	710W1QU	7113C2
G7- 7-3	710W1QU	7113C3
G7- 7-4	710W1QU	7113C4
G7- 8-1	710Y2	7150F1
G7- 8-2	710Y2	7150F3
G7- 8-3	710Y2	7150F4
G7- 8-4	710Y2	7150F5
G7- 8-5	710Y2	7150F6
G7- 9-1	710Y2V	7156C1
G7- 9-2	710Y2V	7156C3
G7- 9-3	710Y2V	7156C4
G7- 9-4	710Y2V	7156C5
G7-10-1	720K4EH	7243F1
G7-10-2	720K4EH	7243F1-1

EXHIBIT A-3: DATA BASE VEHICLE IDENTIFICATION (G = GM) (Continued)

VRI ID Code	Manufacturer Codes Engine Family	Vehicle
G7-10-3	720K4EH	7243F2
G7-10-4	720K4EH	7243F3
G7-10-5	720K4EH	7243F4
G7-10-6	720K4EH	7243F5
G7-10-7	720K4EH	7243F6
G7-11-1	720S2E	7222F1
G7-11-2	720S2E	7222F3
G7-11-3	720S2E	7222F4
G7-11-4	720S2E	7222F5
G7-11-5	720S2E	7222F6
G7-12-1	720X2E	7211C1
G7-12-2	720X2E	7211C3
G7-13-1	720X2U	7200F1
G7-13-2	720X2U	7200F2
G7-13-3	720X2U	7200F3
G7-13-4	720X2U	7200F5
G7-13-5	720X2U	7200F6
G7-14-1	730H2U	7300F1
G7-14-2	730H2U	7300F3
G7-14-3	730H2U	7300F4-1
G7-14-4	730H2U	7300F5
G7-14-5	730H2U	7300F5-1
G7-14-6	730H2U	7300F6
G7-15-1	730M4AU	7331C1
G7-15-2	730M4AU	7331C2
G7-15-3	730M4AU	7331C3
G7-15-4	730M4AU	7331C4
G7-15-5	730M4AU	7331C5
G7-15-6	730M4AU	7331C6
G7-16-1	730M4U	7321F1
G7-16-2	730M4U	7321F3
G7-16-3	730M4U	7321F4-1
G7-16-4	730M4U	7321F5
G7-16-5	730M4U	7321F6-1
G7-17-1	730P4UY	7341F1
G7-17-2	730P4UY	7341F3
G7-17-3	730P4UY	7341F4
G7-17-4	730P4UY	7341F5
G7-18-1	740E2	7402F1
G7-18-2	740E2	7402F2
G7-18-3	740E2	7402F3
G7-18-4	740E2	7402F5
G7-18-5	740E2	7402F6
G7-18-6	740E2	7402F4
G7-19-1	740E2LU	7410C1
G7-19-2	740E2LU	7410C2
G7-19-3	740E2LU	7410C3
G7-19-4	740E2LU	7410C4

EXHIBIT A-3: DATA BASE VEHICLE IDENTIFICATION

(G = GM, B = BMW, D = DATSUN)
(Continued)

	Manufacturer Codes	
VRI ID Code	Engine Family	Vehicle
G7-19-5	740E2LU	7410C5
G7-19-6	740E2LU	7410C6
G7-20-1	740J2	7420F1
G7-20-2	740J2	7420F3
G7-21-1	740J4U	7440F1
G7-21-2	740J4U	7440F3
G7-21-3	740J4U	7440F4
G7-22-1	760J0U	7600F1
G7-22-2	760J0U	7600F3
G7-23-1	760J0	7601C1
G7-24-1	760V0	7641F1
G7-24-2	760V0	7641F3
G7-24-3	760V0	7641F4
G7-24-4	760V0	7641F5
G7-25-1	760V4S	7631C1
G7-25-2	760V4S	7631C3
G7-25-3	760V4S	7631C4
G7-25-4	760V4S	7631C5
G7-26-1	760V4U	7620F1
G7-26-2	760V4U	7620F2
G7-26-3	760V4U	7620F3
G7-26-4	760V4U	7620F4
G7-26-5	760V4U	7620F5
G7-26-6	760V4U	7620F6
B7- 1-1	BMW 120.8	5 400 001
B7- 1-2	BMW 120.8	5 460 001
B7- 2-1	BMW 120.9	5 420 004
B7- 2-2	BMW 120.9	5 470 002
B7- 3-1	BMW 130.8	4 375 045
B7- 3-2	BMW 130.8	4 375 046
B7- 3-3	BMW 130.8	5 011 506
B7- 3-4	BMW 130.8	5 031 418
D7- 1-1	A140C	AK0434
D7- 1-2	A140C	AK0436
D7- 1-3	A140C	AK0452
D7- 1-4	A140C	A644
D7- 1-5	A140C	A645
D7- 2-1	A140F	AK0433
D7- 2-2	A140F	AK0435
D7- 2-3	A140F	AK0451
D7- 2-4	A140F	A643
D7- 3-1	A141F	AK0472
D7- 4-1	L200C	AK0414
D7- 4-2	L200C	BW0158
D7- 4-3	L200C	BW0159
D7- 4-4	L200C	B1592
D7- 5-1	L200F	AK0415
D7- 5-3	L200F	BK0397

EXHIBIT A-3: DATA BASE VEHICLE IDENTIFICATION

(D = DATSUN, H = HONDA, I = FIAT, M = MAZDA, V = VOLVO)
(Continued)

VRI ID Code	Manufacturer Codes: Engine Family	Manufacturer Codes: Vehicle
D7- 5-4	L200F	BW0157
D7- 6-1	L240C	BW0161
D7- 6-2	L240C	B1596
D7- 7-1	L240F	BW0160
D7- 7-2	L240F	B1594
D7- 8-1	L280C	F565
D7- 8-2	L280C	F567
D7- 9-1	L280F	F566
D7- 9-2	L280F	F568
H7- 1-1	77EB	SBC-5000014
H7- 1-2	77EB	SBD-5000013
H7- 2-2	77ED-1	SG-E3000010
H7- 2-3	77ED-1	SJ-D2000005
H7- 2-4	77ED-1	SJ-E2000006
H7- 2-5	77ED-1	WB-A3000009
H7- 2-6	77ED-1	WB-B3000008
H7- 3-1	77ED-2	SG-E3000007
H7- 3-2	77ED-2	SJ-D2000001
H7- 3-3	77ED-2	SJ-E2000004
H7- 3-4	77ED-2	WB-A3000007
H7- 3-5	77ED-2	WB-B3000001
I7- 1-1	128	0044125
I7- 1-2	128	2122971
I7- 2-1	128-CC1	0049449
I7- 2-2	128-CC1	2088127
I7- 3-2	132	0152508
I7- 3-3	132	0159304
I7- 3-5	132	0605152
I7- 3-6	132	4054941
I7- 4-1	132-CC1	0100101
I7- 4-2	132-CC1	0108238
I7- 4-3	132-CC1	0503001
I7- 4-4	132-CC1	0606502
I7- 4-5	132-CC1	4046477
I7- 4-6	132-CC1	4056032
M7- 1-1	CNAP	77ECNAP-1
M7- 1-2	CNAP	77ECNAP-2
M7- 2-1	CTCP	77ECTCP-1
M7- 2-2	CTCP	77ECTCP-2
M7- 3-1	FNAP	77EFNA-1
M7- 3-2	FNAP	77EFNA-2
M7- 4-1	FTCP	77EFTCP-1
M7- 4-2	FTCP	77EFTCP-2
M7- 5-1	REP	77EREP-1
M7- 5-2	REP	77EREP-2
M7- 5-3	REP	77EREP-3
M7- 5-4	REP	77EREP-4
V7- 1-1	4CA	77:12

EXHIBIT A-3: DATA BASE VEHICLE IDENTIFICATION (V = VOLVO)
(Concluded)

VRI ID Code	Manufacturer Codes Engine Family	Vehicle
V7- 1-2	4CA	77:13
V7- 1-3	4CA	77:14
V7- 1-4	4CA	77:15
V7- 2-1	4FA	77:5
V7- 2-2	4FA	77:6
V7- 2-3	4FA	77:7
V7- 2-5	4FA	77:8
V7- 3-1	6CA	77:16
V7- 3-2	6CA	77:17
V7- 4-1	6FA	77:10
V7- 4-2	6FA	77:9

APPENDIX B

ANALYSIS OF EMISSION TEST VARIABILITY

A prerequisite to performing many of the analyses associated with the study was the selection of an appropriate estimate of exhaust emission test variability. A number of such estimates have been reported by previous investigators [Matula, 1974], [Paulsell and Kruse, 1975], [Juneja, *et al.*, 1976], [Juneja, *et al.*, 1977], and [Ford, undated b]. These studies generally report the test variability in terms of the standard deviation as a percent[1] of the average emission level for each pollutant. Such a percent assumes that test-to-test variability increases in direct proportion to any increase in the average emission level of the vehicle being tested.[2] Since there is evidence[3] which suggests this may not be the case and since the current study had access to multiple test results from a number of vehicles (see the previous appendix), it was decided that this data might be used to provide insight concerning this relationship and further provide estimates of test variability which represent the variability experienced in conducting the certification program.[4]

The benefits of performing this analysis of emission test variability are fourfold. First, the analysis permitted an examination of the functional relationship between test variability and mean vehicle emissions. The outcome of this examination would in part dictate the appropriate statistical

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[1]This percent is generally referred to as the coefficient of variation.

[2]That is, if this were not the case, each vehicle with different emission levels would have a different coefficient of variation.

[3]For example, in Ford [undated-a], the analysis of test variability suggest a nonlinear relationship between the test standard deviation and the mean emission level.

[4]That is, the analyses performed in the study require an estimate of test variability which includes variations not controlled for in EPA's certification testing program.

techniques to be employed in analyzing the results of emission tests on differe vehicles.[1] Second, the results of this analysis might be used to predict the degree of change in test variability with anticipated changes in the emission levels of vehicles as a consequence of new standards.[2] Third, the analysis permits comparison of estimates of test variation recently experienced in EPA's test facility to that of the manufacturers to determine whether the manufacturer's estimates could be adopted for use in this study.[3] Finally, it provides a mechanism to investigate the degree to which the test data used in this study appeared representative and reasonable (i.e., one of the several simple checks to ensure that the test results used here did not contain a significant amount of error).

B.1 Approach

The analysis of emission test variability was conducted in three phases. First, the dependence of test-to-test variability on vehicle emission levels

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[1]That is, if the test variation were determined to be a constant and independent from the average emission level of a vehicle, then the analyses which used multiple vehicle results would not have to be adjusted to account for differences in test variation.

[2]Such changes in test variability would influence the outcome of the effectiveness assessment methodology (discussed in appendix F) in that they would alter the probability of miscertifying a vehicle.

[3]Although some estimates of test variability have been made using the EPA facility data, they are somewhat outdated and for the most part relied on a single vehicle rather than using several vehicles which is more applicable to the current analysis. Therefore, it was considered desirable to be able to use the more recent estimates made by the manufacturers under similar controlled conditions.

was examined by attempting to fit data to several models relating these quantities. Second, using the model selected as appropriate an estimate of test-to-test variance was obtained by combining the estimates of variance from individual vehicles with multiple tests. Finally, the estimates of test-to-test variance were compared with those developed in previous studies and appropriate values for test variability selected. The following paragraphs discuss each of these steps in greater detail.

To examine the relationship between test variability and average emission levels a special data base was created consisting of test results from 1977 emission data vehicles (EDVs), with multiple tests performed on the same vehicle using the same test procedure. The identification of multiple tests was based on a screening of vehicle and test information to ensure that multiple tests recorded for a given vehicle ID were performed on the same vehicle using the same test procedure.[1] The number of vehicles and average number of tests per vehicle passing this screen is given in exhibit B-1.[2]

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[1]Since this screening used data contained in EPA's Light Duty Vehicle Data System which does not record all operations performed on a vehicle between tests (e.g., recalibration), it is possible that the vehicle may have undergone some minor change between tests. On conferring with EPA staff most likely to know about the occurrence of such changes, it was discovered that little, if any, quantitative information (e.g., frequency nature, or predisposing conditions) could be obtained about these changes. It was, however, concluded that their existence could upwardly bias any estimates of test variability if vehicles were systematically altered to reduce emissions levels and possibly downwardly bias the estimates if recalibrated to original specifications.

[2]Out of the 170 tests used to analyze test-to-test variability, the data base codes indicate that 58 were retested because of failure to meet federal emission standards and the remaining vehicles were retested either as a consequence of manufacturer requests or for fuel economy reasons.

For each vehicle in this data base the average and the standard deviation of the measured emission levels for each pollutant (HC, CO, and NO_x) were calculated.[1] Since the number of tests for any one vehicle were small, a reasonable estimate of test variability (i.e., the standard deviation) could only be obtained by combining the population of individual vehicle estimates. To combine these estimates, catalyst vehicles were separated from non-catalyst vehicles and then the relationship between test variability and mean emission levels analyzed for each of these vehicle groupings. This relationship was examined by plotting the vehicle sample standard deviations against the vehicle sample means for each pollutant (as shown in appendix A, section A.1). A number of models which related standard deviation to the average emission level were then tested to determine which model provided the closest fit to the data. The six models tested are shown below (where S denotes the test-to-test standard deviation, $\overline{X}$ denotes the average emission level of a vehicle and a_i, b_i and c_i are constants estimated from the data):

(1) $S^2 = c_1$;

(2) $S^2 = b_1 \overline{X}$;

(3) $S^2 = b_2 \overline{X} + c_2$;

(4) $S^2 = a_1 \overline{X}^2$;

(5) $S^2 = a_2 \overline{X}^2 + c_3$; and

(6) $S^2 = a_3 \overline{X}^2 + b_3 \overline{X}$.

---

[1] The data was further screened for outliers. Since each entry in this data base was checked for validity, the probability of a true outlier is remote. This data was also checked for outliers, but none of the data points could be rejected with justification.

The choice of these models was an attempt to consider combinations of three types of contributions to the total variance which were plausible on theoretical grounds. Constant errors are contributed to many laboratory and other measurement processes, and seemed a plausible type of error to find in the emission measurement process. This possibility was also indicated as probable by the analyses conducted in the earlier study [VRI, 1976]. Additionally, errors contributing variances proportional to the squared emission levels seemed plausible on two bases:

(1) past researchers studying the topic had often presented their results in terms of a constant coefficient of variation, which would make the variance proportional to the squared emission level; and

(2) many variations in dynamometer, driver, and environmental conditions could be expected to have effects of the form

$$\text{emissions} = (1 + \text{effect}) \cdot \text{"normal" emissions}$$

(where "normal" emissions are emission which would be achieved in experiments in which the specific effect involved was controlled). Effects of this kind could also be expected in some aspects of the measurement process proper, where measurement errors or calibration errors would cause measurement effects proportional to the actual emissions.

Beyond both these types of error, there is a third type of variation which could be expected to contribute to the total variability in the measured emissions. This type of variation arises from the addition of a number of independent sources of emissions (produced, for example, by the individual ignitions of the cylinders during the test), each of which might reasonably be modeled as having a random number of molecules of each type of pollutant with the variance of the number proportional to the mean.[1] A summation or averaging of independent variates of this third type produces a variate with the standard deviation proportional to the square root of the mean emissions observed, and the variance proportional to the mean emissions.

The models which were actually examined in this analysis considered these three types of effects taken individually and in pairs, as shown above. It was felt that there was not sufficient data to estimate reasonably a model with all three effects present, and, as discussed in section B.2, the data did not in fact prove sufficient to distinguish these six cases themselves in any conclusive manner.

Each of the above six models was fit to the data by estimating values for a_i, b_i, and c_i which minimized the weighted sums of squares for the corresponding model. The weights for this computation were established to allow data for vehicles with differing numbers of tests to be considered together. The measure used to compare how well each model fits the data was the mean square error between the data and the corresponding model.

The model selected as the best or most appropriate was then used to combine single vehicle estimates of test variability to obtain an estimate of test-to-test variability for the EPA testing facility. This estimate was compared to that reported elsewhere and an appropriate value chosen for use in the subsequent analyses.

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[1]Using a stochastic version of fairly standard chemical rate equation methodology results in Poisson distributions of reaction products for which this property holds.

B.2 Results

Exhibit B-2 displays the square root of the mean square error for each of the models examined. The results are grouped in terms of vehicle manufacturer type (foreign versus domestic) and vehicle emission control system (catalyst versus non-catalyst). Since the data base containing vehicles with multiple tests had only one domestic non-catalyst vehicle, it was not possible to analyze this category.

The results in the table do not select any one of the models for all pollutants and all manufacturers. In fact, the results appear to indicate that there is very little difference among the values of the mean square error for any model of test variability for a given pollutant. The inability to single out clearly the most appropriate model or models is in part explained by looking at the data, which display a wide scatter (see scatter plots in exhibits B-5 through B-13[1]). This scatter is in part attributable to the limited sample of tests per vehicle used to estimate the mean variance.

Even with this scatter, several observations can be made regarding the dependence of the test-to-test variance on the mean. First, the assumption that these quantities are proportional and have a constant coefficient of variation (i.e., model 4) is generally not contradicted by the results in exhibit B-2. The data do not, however, clearly support this model over the others tested. Second, the model of test-variability given by model 6 had consistently lower mean square errors for NO_x emissions from catalyst equipped

[1]The values are plotted for HC, CO, and NO_x separately, and are further differentiated by vehicle category (domestic and foreign with catalyst and non-catalyst distinctions).

vehicles.[1] Finally, the data from vehicles without catalysts (all foreign vehicles in this analysis) did not generally fit the same models as vehicles with catalysts and tended to provide better fits to models 4 and 6 for HC and CO respectively. This is however extremely tenuous since only ten vehicles were not equipped with a catalyst.

In view of the generally inconclusive nature of the results in exhibit B-2 it was decided to duplicate most analyses under two assumptions:

(1) that test variability was independent from mean emission level (model 1); and

(2) that test-to-test standard deviation was directly proportional to the mean (model 4).

The first assumption is supported by the fact that there was little significant difference in the mean square error from one model to the next and the second assumption was selected since it permitted comparison of test variability results from this study to previous estimates. Exhibit B-3 compares this study's estimate of a constant test-to-test standard deviation with that derived from results reported by previous studies.[2] These results show that standard deviation estimates using EPA test data fall within the range of previous estimates. However, the estimate of test-to-test standard deviation for HC and CO is higher than estimated in [Juneja, 1976] for non-catalyst vehicles and in [Juneja, 1977] for both types of vehicles.

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[1]The non-linearity of this relationship is also supported by other analyses [Ford, undated a] which found an exponential best fit curve.

[2]Although the data in this study contained a relatively large number of vehicles which failed at least one certification test, the estimate of test-to-test standard deviation can still be compared to others under the above assumption, if it is conjectured that the only difference between vehicles with test failures and those without is the mean emission level.

This potential upward bias could be attributable to vehicle recalibration to a different but legal standard or differences between the degree to which test conditions were controlled. The effects of such a bias on analysis performed in this study would be to reduce the ability to discriminate the difference among vehicles with different emission levels, and increase the likelihood of presenting a more conservative testing strategy[1] than necessary. The error introduced in both cases is relatively small; however, since any bias is undesirable, analyses designed to differentiate vehicle emission level differences also employed the most recent of the "other" estimates (i.e., [Juneja *et al.*, 1977]).

Under the assumption that test variability is proportional to the mean emission level, exhibit B-4 provides a comparison of this study's estimate[2] of the coefficient of variation with those reported elsewhere. Results in the table show that estimates from this study are in the range of other estimates for HC and CO emissions with the estimated variation of the NO_x emissions slightly above and below the range of estimates being reported elsewhere.

[1]For example, a strategy designed to minimize the probability of miscertifying a vehicle would test more vehicles with increased test variability to assure that certification or failure was not the result of random test error.

[2]Test estimates of the coefficient of variation can again be compared to others since the effect of the higher mean emission level due to failing certification has been accounted for.

EXHIBIT B-1: SAMPLE SIZE AND DISTRIBUTION BY MANUFACTURER OF VEHICLES WITH MULTIPLE TESTS UNDER "IDENTICAL" CONDITIONS

Manufacturer	No. of Vehicles	No. of Tests	Manufacturer	No. of Vehicles	No. of Tests
Chrysler	27	58	Honda	2	4
Ford	18	36	Fiat	4	8
General Motors	20	40	Mazda	1	2
BMW	2	4	Volvo	6	12
Datsun	3	6	TOTAL	83	170

EXHIBIT B-2: SQUARE ROOT OF THE MEAN SUMS OF SQUARES FOR EACH MODEL (MINIMUM VALUES IN EACH VEHICLE CATEGORY ARE UNDERLINED)

MODEL	HC				CO				NO_x			
	Catalyst			Non-Catalyst	Catalyst			Non-Catalyst	Catalyst			Non-Catalyst
	Domestic	Foreign	Both	Foreign	Domestic	Foreign	Both	Foreign	Domestic	Foreign	Both	Foreign
(1) $S^2 = c_1$	.025	.040	.027	.025	9.486	1.408	8.867	3.214	.269	.242	.264	.007
(2) $S^2 = b_1\bar{X}$	.024	.039	.026	.026	9.300	1.138	8.674	3.079	.261	.248	.258	.007
(3) $S^2 = b_2\bar{X} + c_2$	.024	.042	.026	.027	9.361	1.080	8.723	3.236	.253	.255	.256	.007
(4) $S^2 = a_1\bar{X}^2$	.024	.041	.027	.028	9.425	1.008	8.792	3.037	.252	.253	.251	.007
(5) $S^2 = a_2\bar{X}^2 + c_3$	.024	.042	.027	.027	9.447	1.065	8.808	3.272	.246	.251	.249	.007
(6) $S^2 = a_3\bar{X}^2 + b_3\bar{X}$	.024	.041	.026	.022	9.348	1.066	8.719	3.278	.241	.231	.245	.007

EXHIBIT B-3: ESTIMATES OF A CONSTANT TEST-TO-TEST STANDARD DEVIATION (MODEL 1)

	This Study			[Matula, 1974]	[Juneja, 1976]	[Juneja, 1977]
	Catalyst	Non-Catalyst	Both	Non-Catalyst	Non-Catalyst	Both
HC	0.094	0.126	0.101	0.35	0.068	.045
CO	1.442	1.154	1.411	1.90	0.733	.782
NO_x	0.282	0.071	0.267	0.31	0.156	.096

EXHIBIT B-4: ESTIMATES OF THE COEFFICIENT OF VARIATION OF TEST RESULTS FOR EACH POLLUTANT[1]

	This Study			[Matula, 1974]	[Juneja,[2] 1976]	[Juneja,[2] 1977]
	Catalyst	Non-Catalyst	Both	Non-Catalyst	Non-Catalyst	Both
HC	13%	13%	13%	14%	18%	10%
CO	14%	7%	13%	11%	26%	16%
NO_x	9%	4%	9%	6.5%	7%	4%

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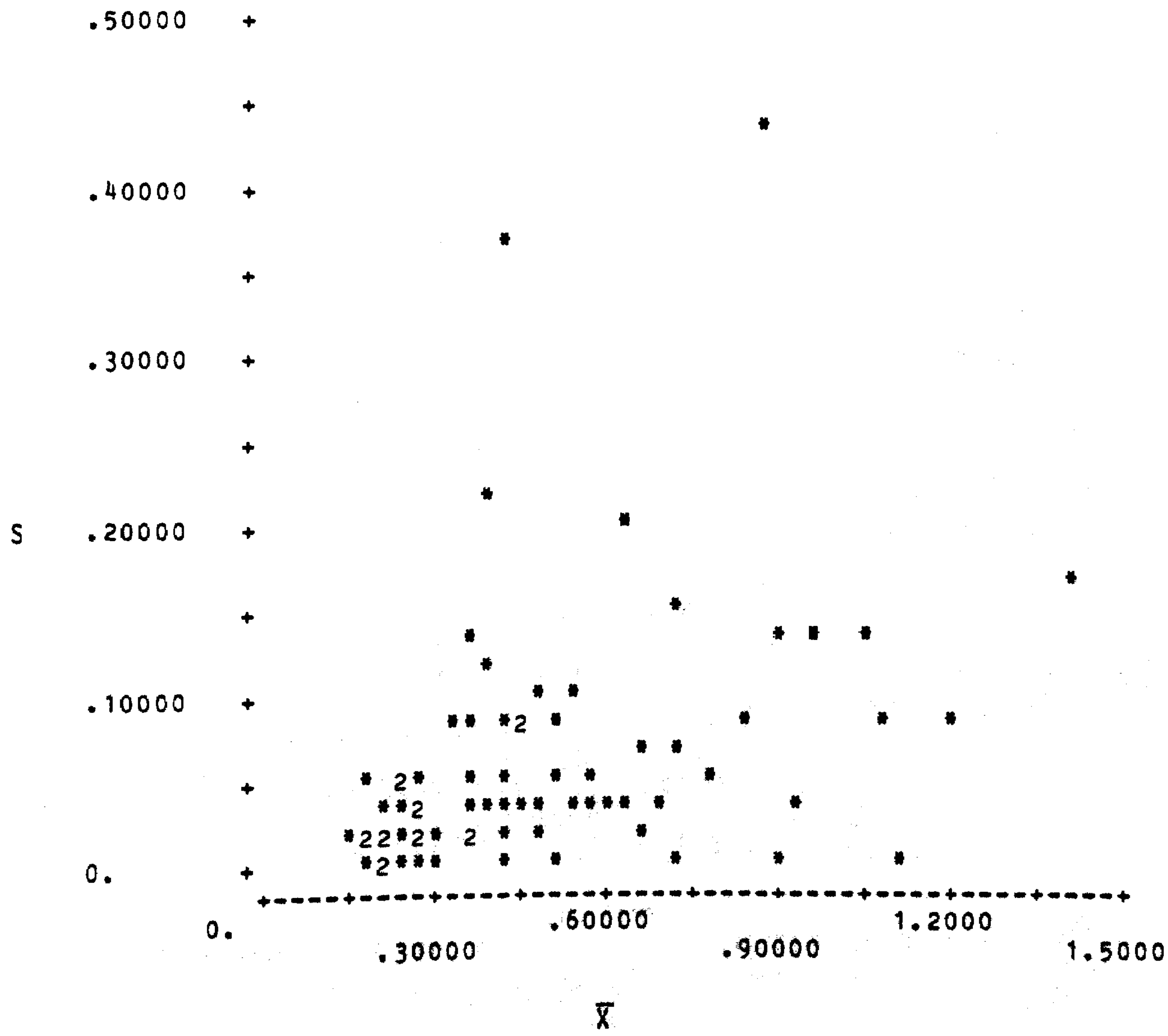
[1] All estimates are the weighted mean of individual vehicle estimates of the coefficient of variation (the standard deviation as a percent of the mean).

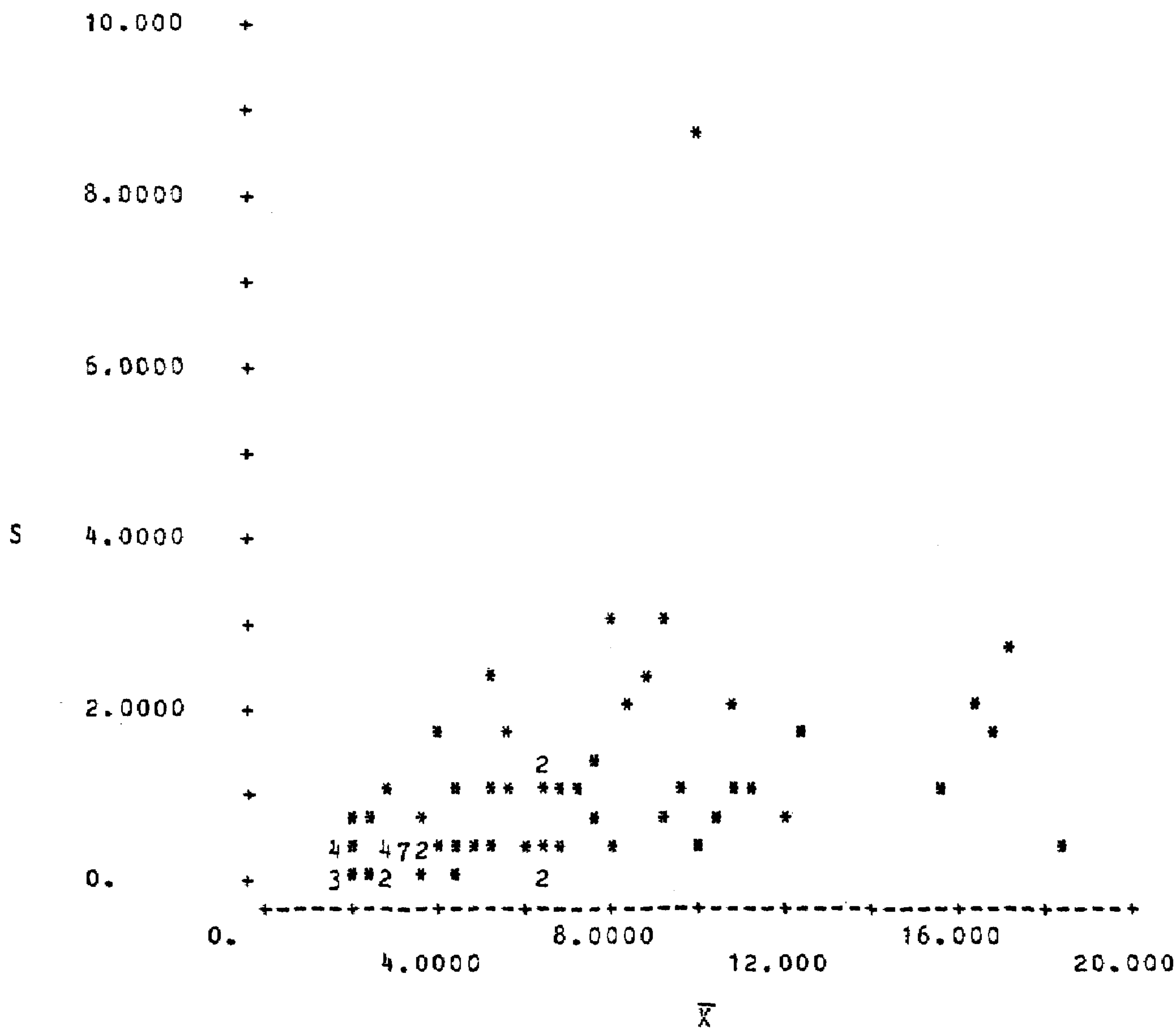
[2] Values are recalculated from data in table 1 of both reports which provide slightly different values due to a difference in definition. (Juneja used the average standard deviation for all vehicles divided by the average emission levels of these vehicles.)

EXHIBIT B-5: PLOT OF TEST-TO-TEST STANDARD DEVIATION VERSUS THE MEAN EMISSION LEVEL FOR HC USING DATA ON 73 DOMESTIC AND FOREIGN MANUFACTURED VEHICLES WITH CATALYSTS



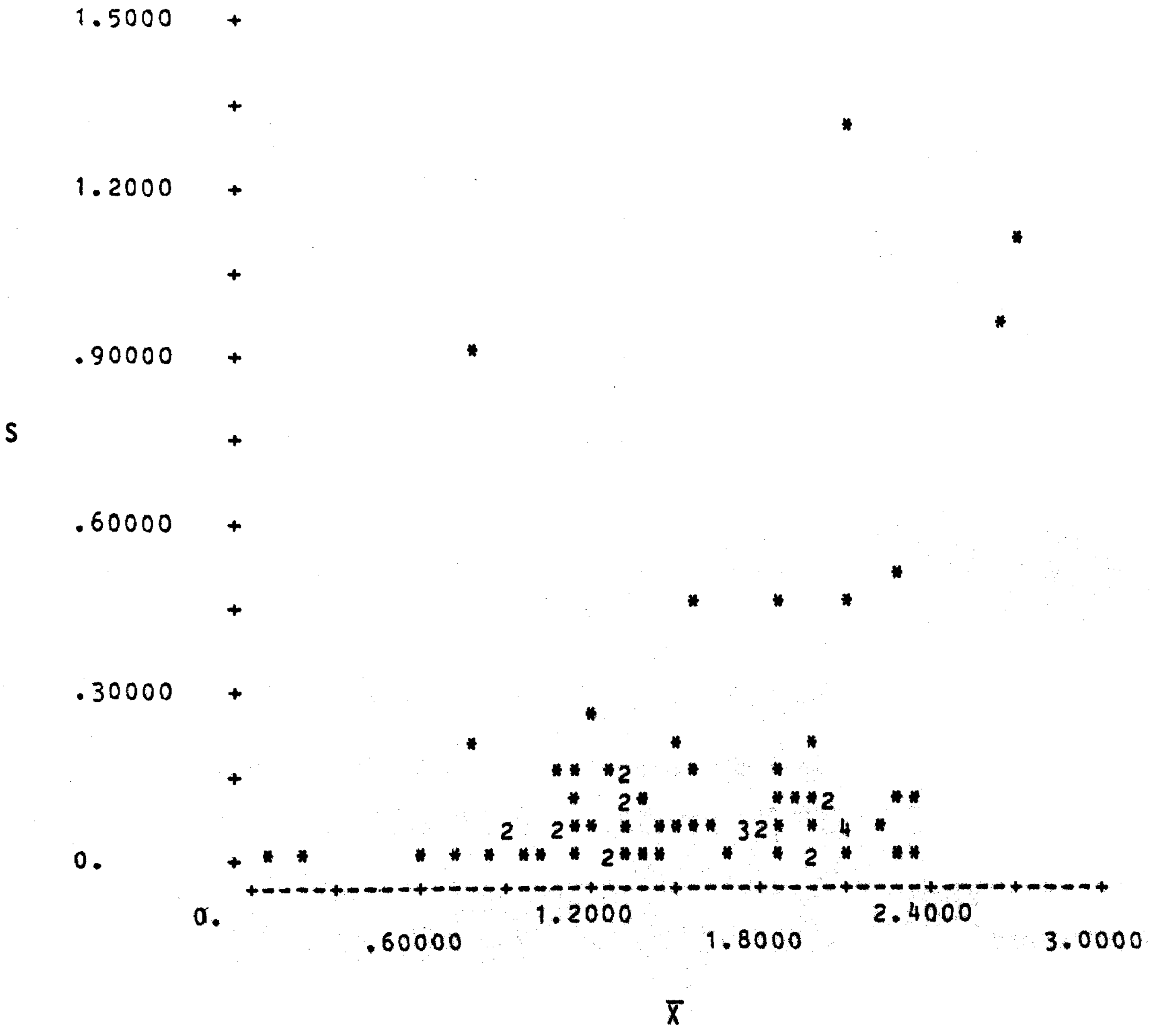
(Single observations are indicated by a *.
Multiple observations are indicated numerically.)

EXHIBIT B-6: PLOT OF TEST-TO-TEST STANDARD DEVIATION VERSUS THE MEAN EMISSION LEVEL FOR CO USING DATA ON 73 DOMESTIC AND FOREIGN MANUFACTURED VEHICLES WITH CATALYSTS



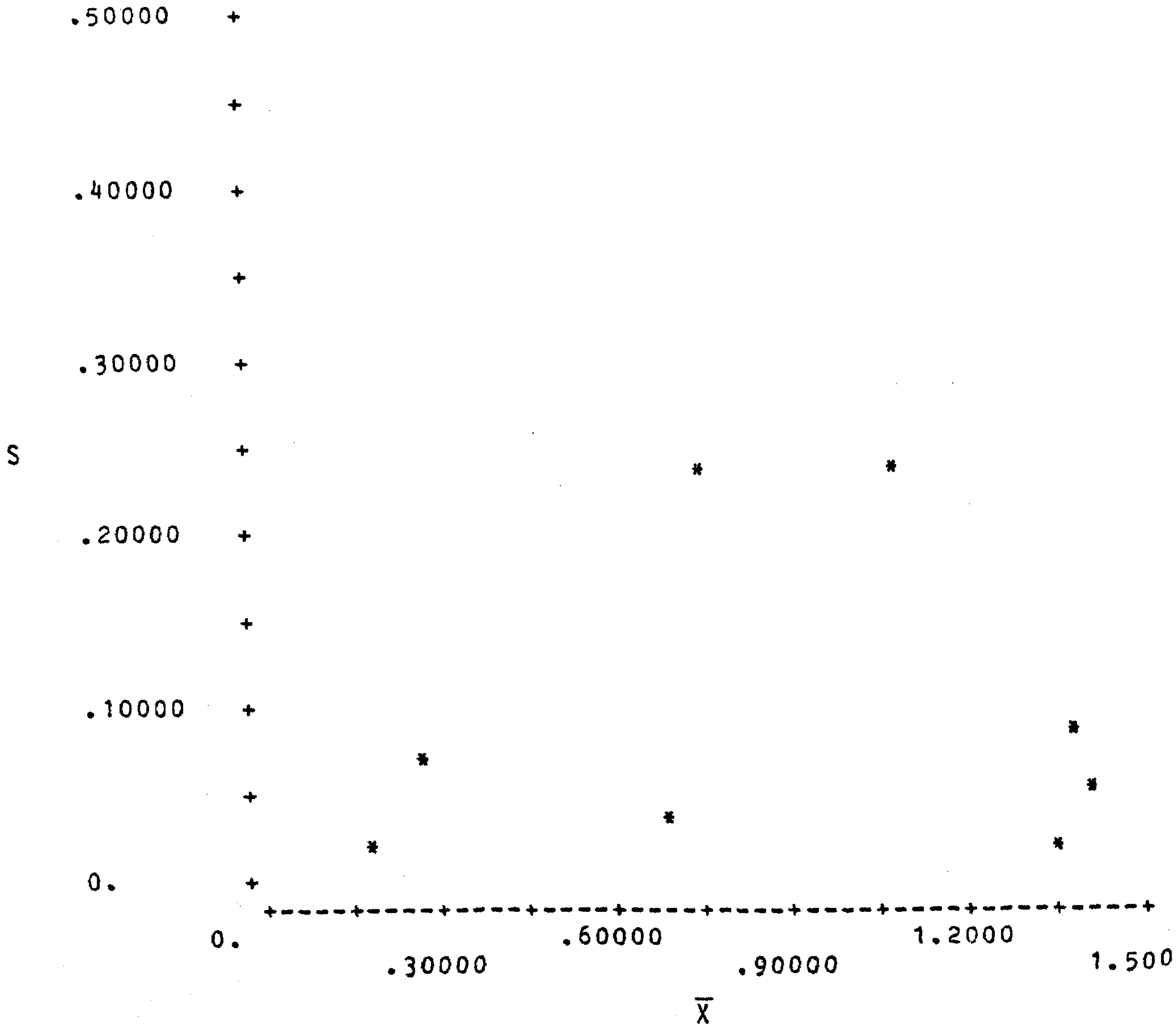
(Single observations are indicated by a *.
Multiple observations are indicated numerically.)

EXHIBIT B-7: PLOT OF TEST-TO-TEST STANDARD DEVIATION VERSUS THE MEAN EMISSION LEVEL FOR NO_x USING DATA ON 73 DOMESTIC AND FOREIGN MANUFACTURED VEHICLES WITH CATALYSTS



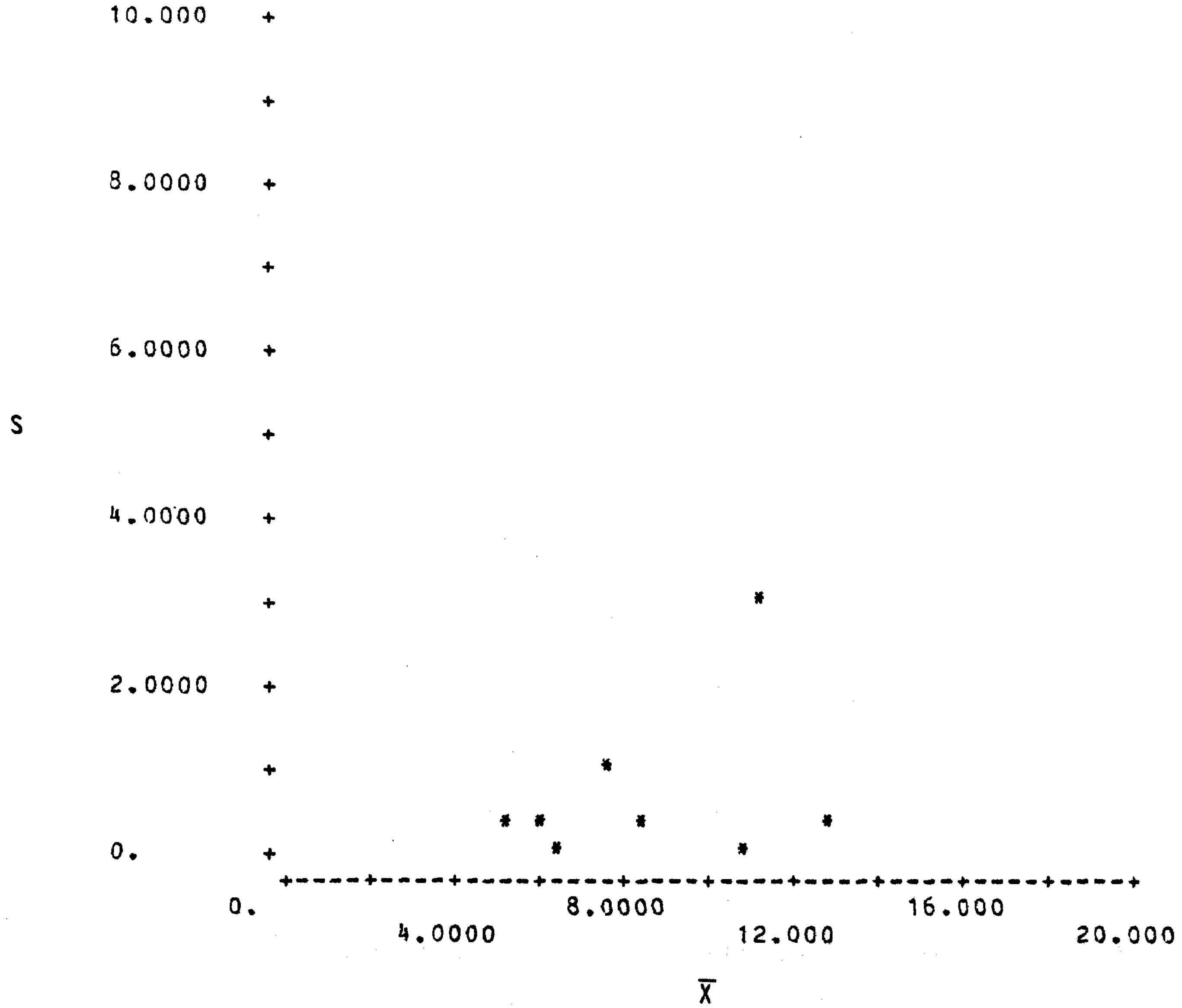
(Single observations are indicated by a *.
Multiple observations are indicated numerically.)

EXHIBIT B-8: PLOT OF TEST-TO-TEST STANDARD DEVIATION VERSUS THE MEAN EMISSION LEVEL FOR HC USING DATA ON 8 FOREIGN MANUFACTURED VEHICLES WITHOUT CATALYSTS



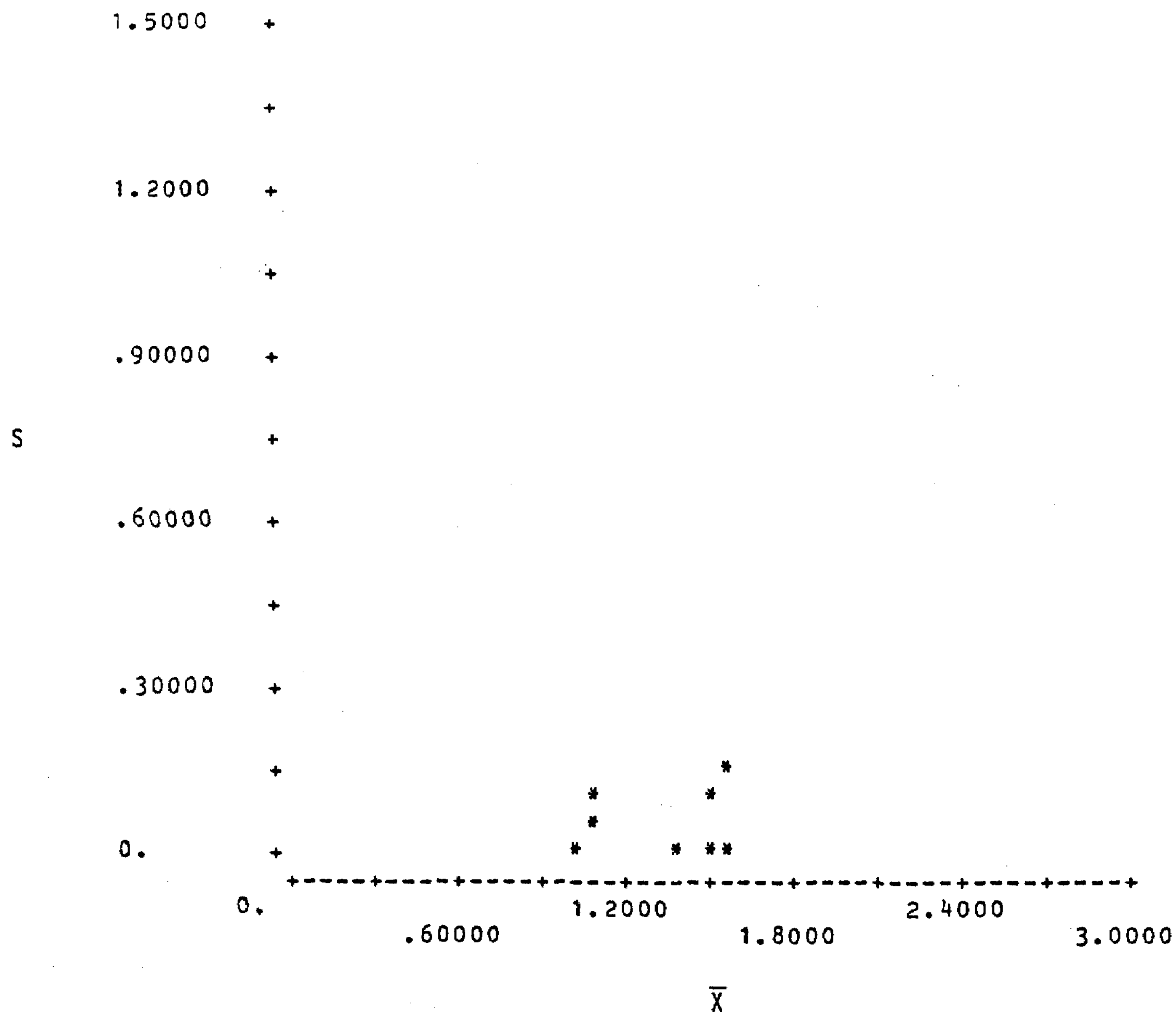
(Single observations are indicated by a *.
Multiple observations are indicated numerically.)

EXHIBIT B-9: PLOT OF TEST-TO-TEST STANDARD DEVIATION VERSUS THE MEAN EMISSION LEVEL FOR CO USING DATA ON 8 FOREIGN MANUFACTURED VEHICLES WITHOUT CATALYSTS



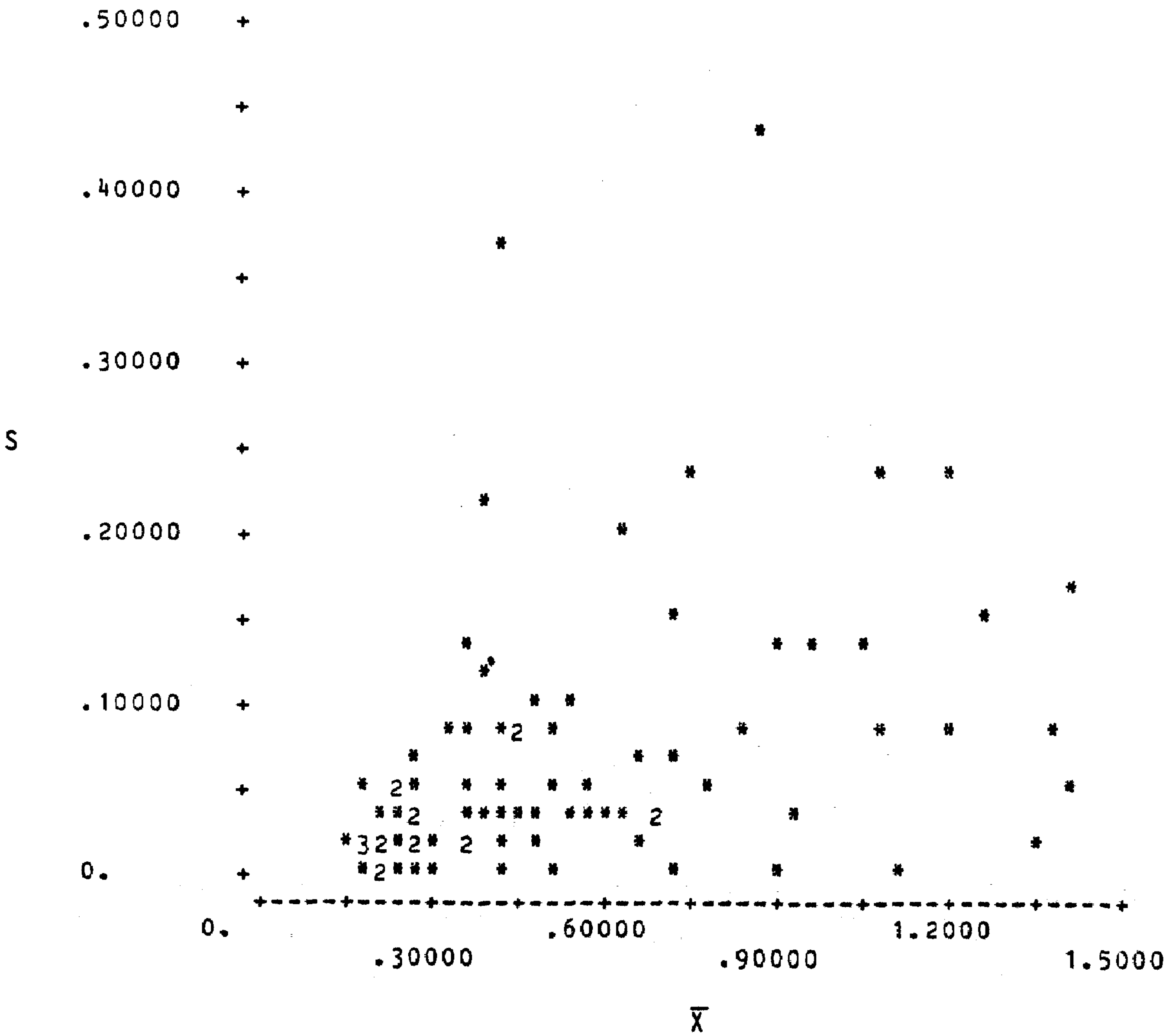
(Single observations are indicated by a *.
Multiple observations are indicated numerically.)

EXHIBIT B-10: PLOT OF TEST-TO-TEST STANDARD DEVIATION VERSUS THE MEAN EMISSION LEVEL FOR NO_x USING DATA ON 8 FOREIGN MANUFACTURED VEHICLES WITHOUT CATALYSTS



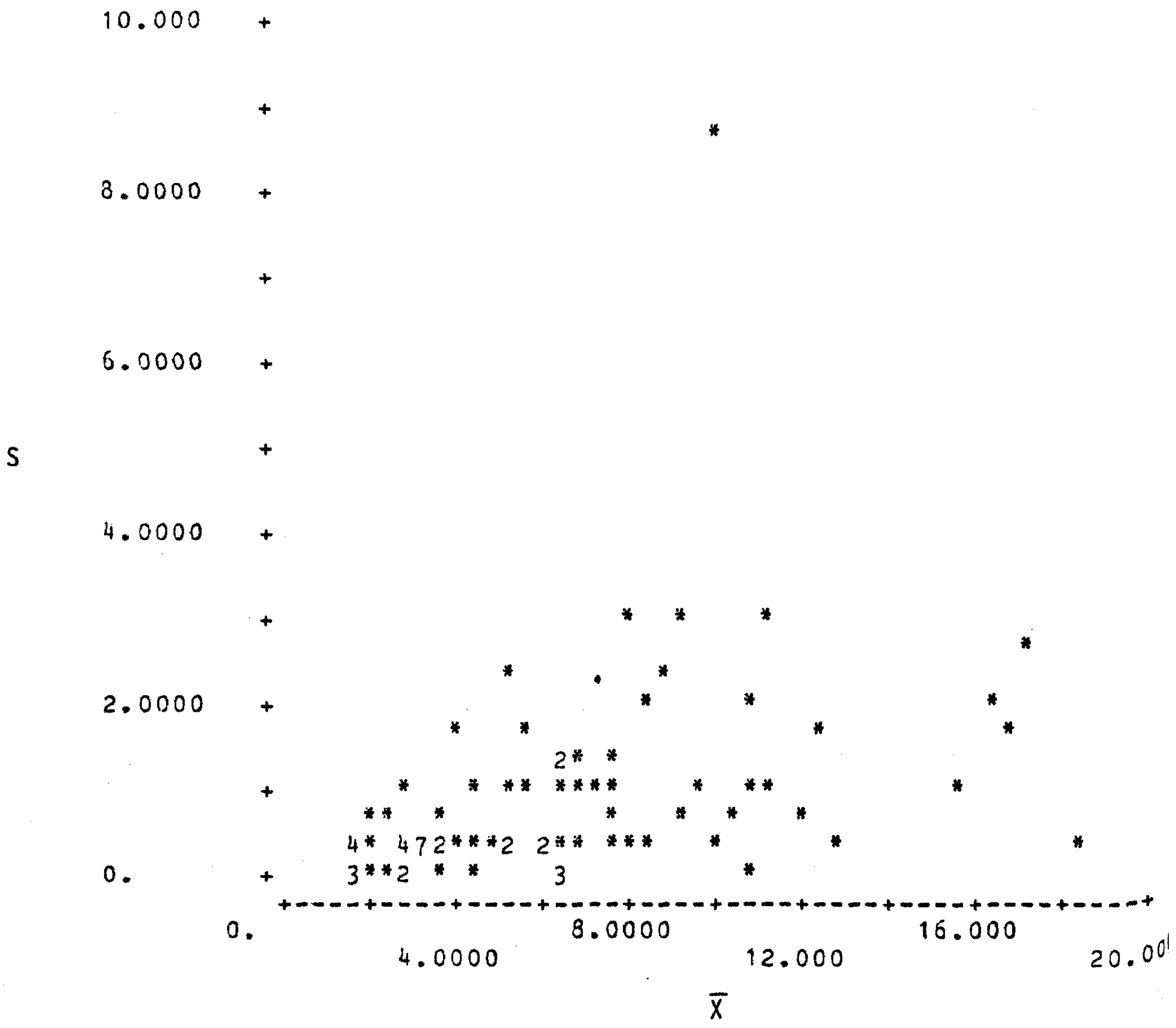
(Single observations are indicated by a *.
Multiple observations are indicated numerically.)

EXHIBIT B-11: PLOT OF TEST-TO-TEST STANDARD DEVIATION VERSUS THE MEAN EMISSION LEVEL FOR HC USING DATA ON 83 DOMESTIC AND FOREIGN MANUFACTURED VEHICLES WITH AND WITHOUT CATALYSTS



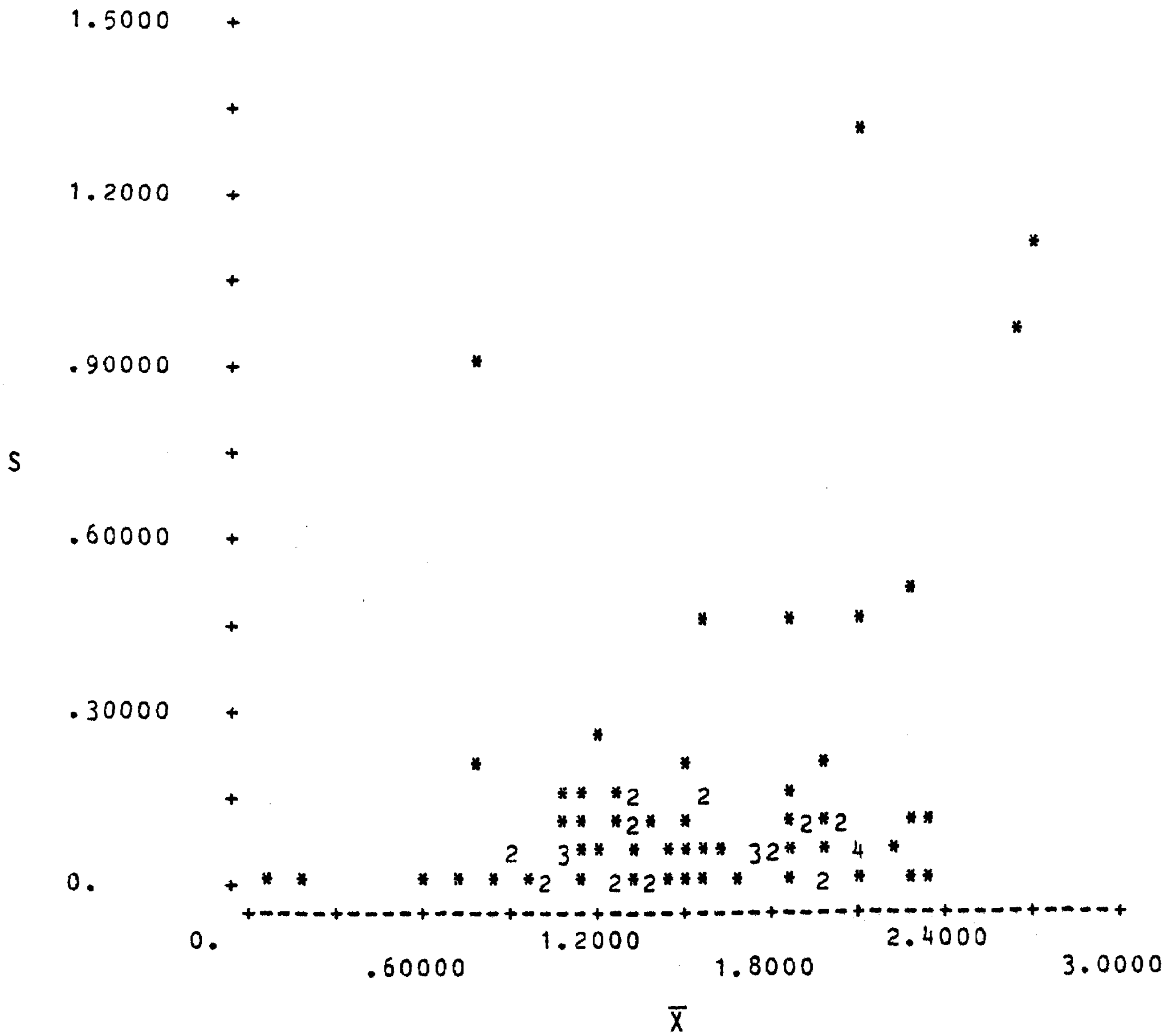
(Single observations are indicated by a *.
Multiple observations are indicated numerically.)

EXHIBIT B-12: PLOT OF TEST-TO-TEST STANDARD DEVIATION VERSUS THE MEAN EMISSION LEVEL FOR CO USING DATA ON 83 DOMESTIC AND FOREIGN MANUFACTURED VEHICLES WITH AND WITHOUT CATALYSTS



(Single observations are indicated by a *.
Multiple observations are indicated numerically.)

EXHIBIT B-13: PLOT OF TEST-TO-TEST STANDARD DEVIATION VERSUS THE MEAN EMISSION LEVEL FOR NO_x USING DATA ON 83 DOMESTIC AND FOREIGN MANUFACTURED VEHICLES WITH AND WITHOUT CATALYSTS



(Single observations are indicated by a *.
Multiple observations are indicated numerically.)

APPENDIX C

ANALYSIS OF ENGINE FAMILY CLASSIFICATION

This appendix contains a description of the analytical methods used to examine EPA's engine family classification and the detailed results of these analyses. It is organized into three sections which parallel the discussion presented in the three sections of chapter 2.0 in the main body of the report. The first section describes the analysis of variance model used to investigate the performance of the current family classification scheme. The second section presents the results of the regression analysis which was used to analyze potential relationships between vehicle parameters and family mean emission levels. The last section provides the information necessary to identify the engine families used in analyzing subjectively-derived family definitions.

C.1 Analyses of Variance

To determine whether the current engine family classification grouped vehicles with similar emission levels the following model was developed for an analysis of variance.[1] Let $Y_{ijk\ell}$ denote the measured emission level of a given pollutant for the ℓ^{th} test on the k^{th} vehicle in family i. Then the model for the analysis of variance is given in the following equation:

$$E_{ik\ell} = \mu + f_i + V_{ik} + e_{ik\ell} \ ,$$

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[1]The model was first developed to include differences in vehicle selection-class. The ANOVA results presented in appendix D showed that the selection-class factor should be removed and that the above model was more appropriate.

where μ = the overall mean of the observations,

f_i = the effect of family i,

V_{ik} = the effect of vehicle k and family i, and

$e_{ik\ell}$ = the error in the ℓ^{th} test on vehicle k in family i.

It is further assumed that $\{f_i\}$, $\{V_{ijk}\}$, and $\{e_{ijk\ell}\}$ are independently normal with zero means and constant variances. The data was analyzed as a random effects completely nested design with unequal numbers of observations.[1] The analysis of variance using this model was performed on emission test results from 1977 emission data vehicles distributed by manufacturers as shown in exhibit C-1.

Exhibit C-2 displays the results of performing the analysis of variance on this model. The analysis was performed on data collected in this study (see exhibit C-1 and appendix A) assuming a constant test-to-test variability (model 1 in appendix B). The ANOVA results in exhibit C-2 confirm the hypothes that there is a significant difference in the mean emission level between famil That is, for every vehicle category and pollutant within that category, the F-ratio exceeds the critical value, with the one exception of NO_x emission in non-catalyst vehicles. When this analysis of variance was repeated assuming the test variability was proportional to the mean (model 4 in appendix B) this one exception disappeared and most F-ratio results increased in value (see exhibit C-3). Finally, for completeness, the analysis was repeated using test variability calculations by [Juneja *et al.*, 1977] under the constant test variability assumption. The results of this analysis (shown in exhibit C-4) were essentially identical to those produced under the same test variability assumption shown in exhibit C-3.

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[1]See appendix D for a slightly more detailed version of the model.

Overall, the consistency of results of these analyses of variance show that there is a significant difference in the emission levels of vehicles in different families which cannot be accounted for by the differences between vehicle configurations within a family. Further, the ANOVA results for configuration-to-configuration differences within a family show a significant difference in emission levels for domestic vehicles with catalyst and foreign vehicles without catalyst[1] which cannot be explained by test-to-test variability.

To analyze whether the above difference in the mean emission levels among families might be explained by the family deterioration factor (df), histograms of these mean emissions were examined with and without application of the df. If the df explained the observed difference, then the emission levels of families with the df applied should be much more similar than those without application of the df. The results (see exhibit C-5 and C-6) indicate that the differences in engine family emission levels are similar under both circumstances. Therefore the ANOVA cannot be solely explained by differences in the deterioration factor.

C.2 Regression Analysis

For each manufacturer, a stepwise multiple linear regression was performed to determine which engine parameters can be used to predict the mean emission level for an engine family. This stepwise algorithm proceeds as follows. The process begins by selecting the one parameter which best predicts the mean emission level. If this regression is not significant at the .05 level, then no variables are selected for the regression. If it is significant,

[1]When the [Juneja *et al.*, 1977] test variability estimates are used all vehicle category results display significant configuration-to-configuration differences within a family.

then the algorithm looks for the next most significant variable. After a variable has been added to the regression, the algorithm examines whether any of the variables in the regression can be eliminated. If the least significant variable renders a significance level of higher than .10, it is removed from the regression. This process continues until the algorithm is unable to add any of the variables not yet included in the regression.

Exhibits C-7 through C-9 display the values of engine parameters and mean emission levels for each engine family in the 1977 model year data base for domestic vehicles. The results of the stepwise regression (see exhibit C-10) on these engine parameters did not consistently select any of the engine parameters to predict the mean emission levels of engine families. Hence, the results of this examination were inconclusive.

C.3 Heuristic Analysis

Two forms of heuristic analysis of engine families were performed: (1) a review of two-way clustering by observing scatter plots of family mean emission levels for one pollutant versus another[1] and (2) an examination of subjective family merging schemes using 1977 certification vehicle summary sheets. The review of the scatter plots did not reveal any significant clustering of families. Minor clustering for CO versus NO_x was found for Chrysler families (see exhibit C-11).

Exhibit C-15 identifies the engine families which were subjectively analyzed to determine whether two or more individual families might be aggregated into

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[1]Several representative scatter plots are presented in exhibits C-11 through C-14

a single family. The exhibit shows the families which were combined on the basis of an aggregation rule specifying that the vehicles in a family should have similar displacements,[1] carburation and engine configurations and identical control systems. As can be seen in this exhibit, the rule only aggregated families from manufacturers with a total of nine or more original family classes.

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[1]Similar displacements were those within 15% or 50 cubic inches of one another.

EXHIBIT C-1: NUMBER OF EMISSION DATA VEHICLES AND ENGINE FAMILIES PER MANUFACTURER

Manufacturer	Catalyst		Non-Catalyst	
	# Vehicles	# Families	# Vehicles	# Families
Chrysler	67	14	5	1
Ford	64	18	0	0
General Motors	116	26	0	0
BMW	0	0	8	3
Datsun	14	5	11	4
Honda	0	0	12	3
Fiat	8	2	6	2
Mazda	6	3	6	2
Volvo	12	4	0	0

EXHIBIT C-2: ANALYSIS OF VARIANCE RESULTS FOR TEST OF FAMILY DIFFERENCES UNDER CONSTANT TEST VARIABILITY ASSUMPTION (MODEL 1)

F-Ratio Test[1] For	Catalyst									Non-Catalyst			Both		
	Domestic			Foreign			Both			Foreign			Both		
	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
Family Differences	8.14 (1.4)	4.64 (1.4)	4.72 (1.4)	14.5 (3.1)	10.6 (2.2)	17.9 (2.9)	8.68 (1.4)	4.83 (1.4)	6.37 (1.4)	6.81 (2.1)	5.12 (2.1)	2.07 (2.1)	11.1 (1.3)	4.98 (1.3)	5.78 (1.3)
Configuration Differences within Family	3.53 (1.4)	4.08 (1.4)	1.48 (1.4)	0.35 (2.7)	1.33 (2.7)	0.38 (2.7)	2.79 (1.4)	3.98 (1.4)	1.34 (1.4)	4.81 (3.1)	3.42 (3.1)	8.52 (3.1)	2.99 (1.4)	3.89 (1.4)	1.41 (1.4)

EXHIBIT C-3: ANALYSIS OF VARIANCE RESULTS FOR TEST OF FAMILY DIFFERENCES UNDER THE ASSUMPTION THAT TEST VARIABILITY IS PROPORTIONAL TO THE MEAN (MODEL 4)

F-Ratio Test[1] For	Catalyst									Non-Catalyst			Both		
	Domestic			Foreign			Both			Foreign			Both		
	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
Family Differences	12.4 (1.4)	6.88 (1.4)	5.62 (1.4)	13.0 (2.9)	7.19 (2.2)	12.17 (2.4)	13.9 (1.4)	7.06 (1.4)	11.3 (1.4)	8.04 (2.1)	7.06 (2.1)	2.16 (2.1)	14.6 (1.3)	7.30 (1.3)	10.2 (1.3)
Configuration Differences within Family	3.23 (1.4)	4.89 (1.4)	2.57 (1.4)	0.39 (2.7)	2.69 (2.7)	0.61 (2.7)	1.98 (1.4)	4.70 (1.4)	1.26 (1.4)	5.61 (3.1)	6.07 (3.1)	8.23 (3.1)	2.28 (1.4)	4.64 (1.4)	1.31 (1.4)

[1] F-ratio results are significant (at the 5% level) when greater than the value in parentheses.

EXHIBIT C-4: ANALYSIS OF VARIANCE RESULTS FOR TEST OF FAMILY DIFFERENCES USING TEST VARIABILITY DATA FROM JUNEJA, *ET AL* [1977], AND ASSUMING CONSTANT VARIABILITY (MODEL 1)

F-Ratio Test[1] For	Catalyst									Non-Catalyst			Both		
	Domestic			Foreign			Both			Foreign			Both		
	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
Family Differences	7.99 (1.4)	4.57 (1.4)	4.47 (1.4)	10.0 (2.2)	10.4 (2.2)	12.7 (2.2)	8.46 (1.4)	4.75 (1.4)	5.98 (1.4)	6.73 (2.1)	5.07 (2.1)	2.08 (2.1)	10.8 (1.3)	4.91 (1.3)	5.47 (1.3)
Configuration Differences within Family	13.4 (1.3)	15.2 (1.3)	12.7 (1.3)	2.76 (1.6)	1.69 (1.6)	3.29 (1.6)	12.1 (1.3)	13.5 (1.3)	11.6 (1.3)	37.7 (1.6)	7.45 (1.6)	4.69 (1.6)	15.0 (1.3)	12.7 (1.3)	10.9 (1.3)

[1] F-ratio results are significant (at the 5% level) when greater than the value in parentheses.

EXHIBIT C-5: HISTOGRAMS OF MEAN ENGINE FAMILY EMISSION LEVELS BY VEHICLE MANUFACTURER (WITH AND WITHOUT APPLICATION OF DETERIORATION FACTOR, df)

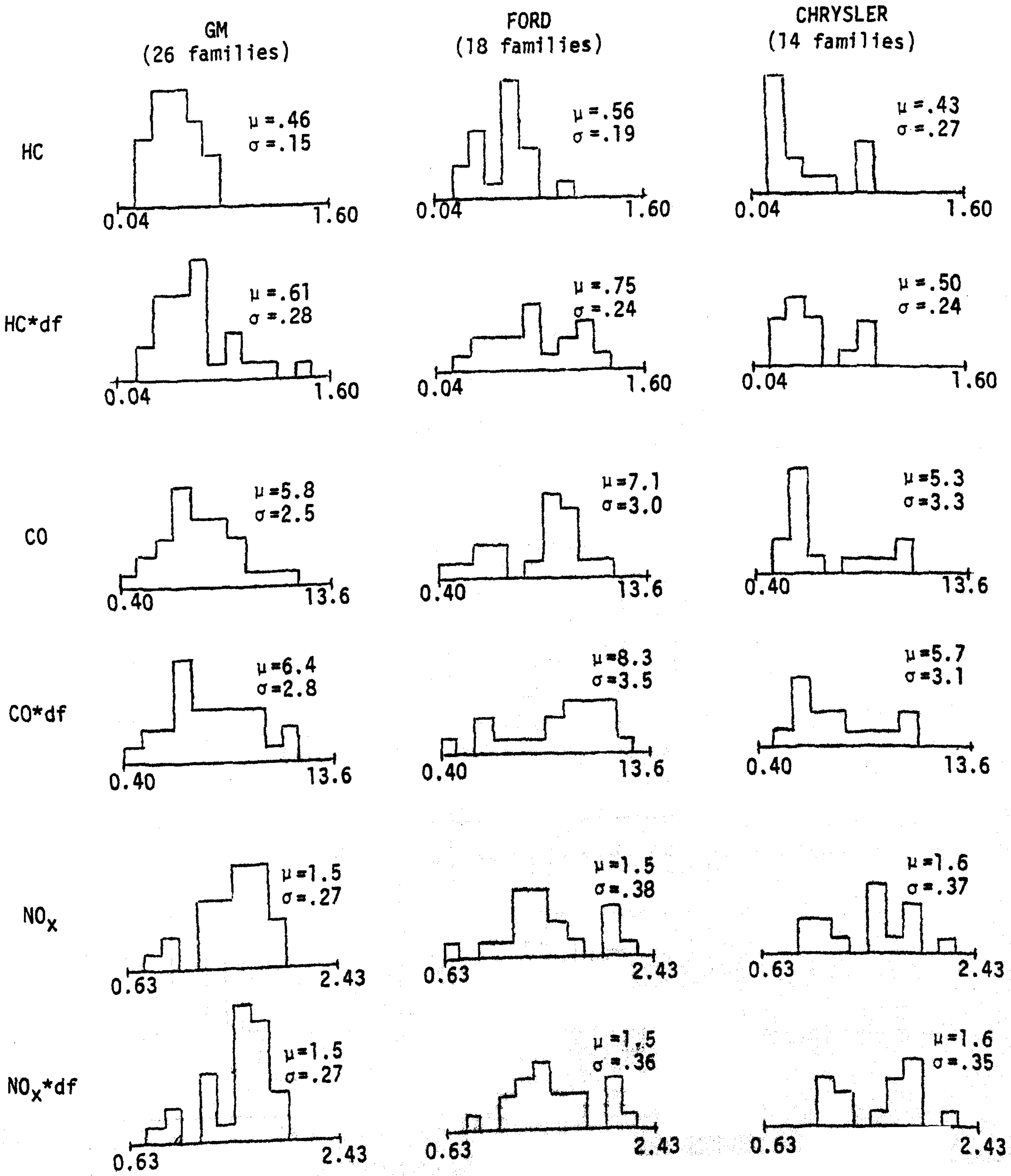

EXHIBIT C-6: HISTOGRAMS OF MEAN ENGINE FAMILY EMISSION LEVELS FOR TOTAL OF THREE MANUFACTURERS (WITH AND WITHOUT APPLICATION OF DETERIORATION FACTOR, df)

GM, FORD AND CHRYSLER

(58 families)

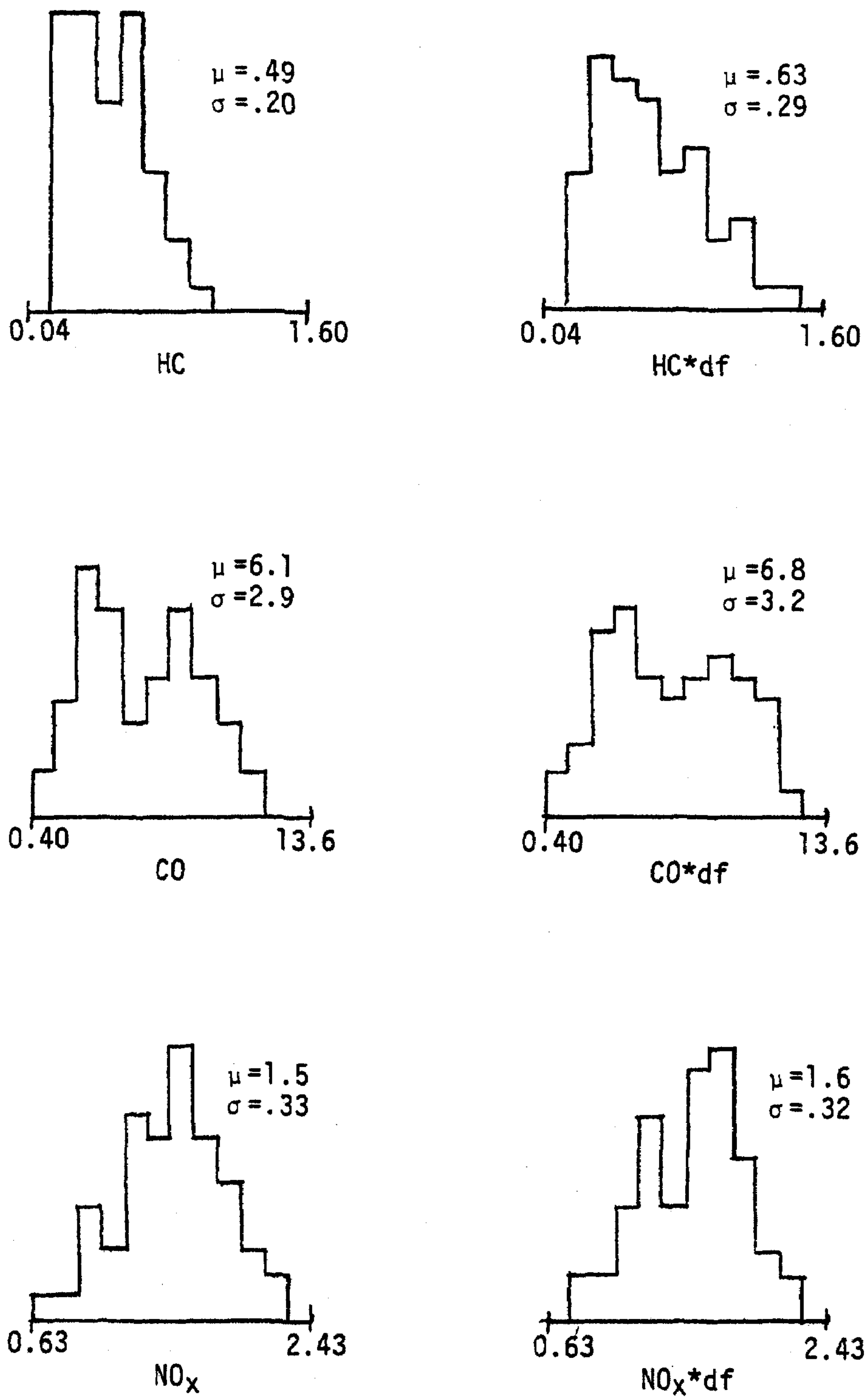

EXHIBIT C-7: MEAN OF ENGINE PARAMETERS FOR CHRYSLER

ENGINE FAMILY	WEIGHT	CID	BORE	STROKE	RHP	CYL	COMP RATIO	TIMING RPM	AXLE RATIO	HC	CO	NO_x
1.	3650.	225.	3.40	4.12	90.	6.	8.4	750.	3.07	.364	2.820	1.200
2.	3956.	318.	3.91	3.31	140.	8.	8.5	650.	2.87	.270	3.440	.938
3.	4555.	440.	4.32	3.75	240.	8.	7.8	750.	2.96	.215	2.800	1.370
4.	5057.	440.	4.32	3.75	190.	8.	8.2	750.	3.04	.190	4.233	1.203
5.	4396.	360.	4.00	3.58	163.	8.	8.2	750.	2.86	.222	3.120	1.070
8.	3971.	360.	4.00	3.58	175.	8.	8.0	750.	3.04	.252	3.825	1.945
9.	4744.	400.	4.34	3.38	195.	8.	8.2	750.	2.79	.247	2.300	1.900
10.	4682.	440.	4.32	3.75	240.	8.	7.8	750.	2.96	.220	1.750	1.630
11.	5111.	440.	4.32	3.75	195.	8.	8.2	750.	2.91	.302	3.380	2.190
12.	3645.	225.	3.40	4.12	95.	6.	8.4	700.	3.02	.900	9.540	1.552
13.	3328.	225.	3.40	4.12	95.	6.	8.4	700.	2.97	.927	8.600	1.873
14.	3700.	225.	3.40	4.12	115.	6.	8.4	750.	3.08	.840	10.743	1.674
15.	4044.	318.	3.91	3.31	145.	8.	8.5	700.	2.79	.660	10.767	1.627
16.	4325.	360.	4.00	3.58	170.	8.	8.4	700.	2.66	.505	6.633	1.790

EXHIBIT C-8: MEAN OF ENGINE PARAMETERS FOR FORD

ENGINE FAMILY	WEIGHT	CID	BORE	STROKE	RHP	CYL	COMP. RATIO	TIMING RPM	AXLE RATIO	HC	CO	NO_x
1.	2606.	140.	3.80	3.10	92.	4.	9.0	625.	3.07	.405	3.150	.725
2.	2693.	140.	3.80	3.10	92.	4.	9.0	580.	3.09	.612	10.480	1.232
4.	2891.	171.	3.66	2.70	93.	6.	8.7	750.	3.06	.733	8.567	1.393
5.	2899.	171.	3.66	2.70	93.	6.	8.7	750.	3.00	.265	3.800	1.060
6.	3159.	200.	3.68	3.13	74.	6.	8.5	750.	2.99	.720	4.667	2.000
7.	3303.	250.	3.68	3.91	104.	6.	8.3	750.	2.79	.295	1.200	1.150
8.	3361.	250.	3.68	3.91	107.	6.	8.6	750.	2.81	.643	8.667	1.497
9.	3510.	302.	4.00	3.00	135.	8.	8.4	500.	3.00	.625	7.850	1.435
10.	3418.	302.	4.00	3.00	135.	8.	8.3	500.	2.75	.247	2.300	1.233
11.	4236.	302.	4.00	3.00	135.	8.	8.4	500.	2.50	.670	8.600	2.030
12.	3436.	302.	4.60	3.00	135.	8.	8.4	500.	2.75	.737	9.367	1.540
14.	4528.	376.	4.00	3.75	167.	8.	8.1	700.	2.61	.517	6.662	1.315
15.	4477.	379.	4.00	3.79	168.	8.	8.0	714.	2.63	.420	7.729	1.714
16.	3763.	351.	3.75	3.75	149.	8.	8.1	625.	2.48	.597	9.775	2.150
17.	3748.	351.	4.00	3.50	149.	8.	8.2	625.	2.48	.617	9.433	1.577
18.	4311.	351.	4.00	3.50	149.	8.	8.4	625.	2.50	1.000	11.600	2.000
19.	4867.	460.	4.36	3.85	198.	8.	8.0	525.	2.83	.393	5.033	1.280
20.	4936.	460.	4.36	3.85	198.	8.	8.4	531.	2.81	.567	8.900	1.420

EXHIBIT C-9: MEAN OF ENGINE PARAMETERS FOR GENERAL MOTORS

ENGINE FAMILY	WEIGHT	CID	BORE	STROKE	RHP	CYL	COMP RATIO	TIMING RPM	AXLE RATIO	HC	CO	NO_x
1.	2829.	140.	3.50	3.63	84.	4.	8.0	660.	3.25	.270	5.583	1.713
2.	3671.	250.	3.88	3.53	105.	6.	8.1	692.	2.85	.593	9.117	1.578
3.	3621.	250.	3.88	3.53	105.	6.	8.0	538.	2.82	.172	1.900	1.260
4.	4029.	350.	4.00	3.48	168.	8.	8.2	520.	3.03	.420	5.120	1.698
5.	3912.	350.	4.00	3.48	183.	8.	8.4	600.	3.02	.384	1.560	1.410
6.	2977.	92.	3.23	2.79	60.	4.	8.2	800.	3.90	.502	8.600	1.535
7.	2115.	98.	3.23	2.98	-0.	4.	8.2	608.	3.90	.300	4.100	1.065
8.	3646.	305.	3.73	3.48	140.	8.	8.4	580.	2.57	.524	5.260	1.568
9.	3508.	305.	3.73	3.49	140.	8.	8.4	500.	2.42	.262	2.525	.972
10.	4097.	386.	4.05	3.75	183.	8.	7.7	594.	2.76	.431	6.686	1.523
11.	3893.	301.	4.00	3.00	135.	8.	8.2	610.	2.77	.562	6.000	1.680
12.	2916.	151.	4.00	3.00	87.	4.	8.4	1000.	3.17	.340	4.000	1.435
13.	2991.	151.	4.00	3.00	85.	4.	8.2	720.	3.28	.748	7.940	1.866
14.	3842.	260.	3.50	3.38	-0.	8.	7.4	1100.	2.64	.527	6.633	1.880
15.	4317.	377.	4.20	3.38	-0.	8.	7.9	1017.	2.57	.333	5.100	1.370
16.	4253.	371.	4.17	3.38	176.	8.	7.9	1100.	2.53	.712	8.060	1.640
17.	4523.	403.	4.35	3.38	193.	8.	7.9	963.	2.57	.550	4.750	1.760
18.	3395.	231.	3.80	3.40	105.	6.	8.0	604.	2.85	.614	7.540	1.298
19.	3347.	231.	3.80	3.40	105.	6.	8.1	696.	3.08	.298	3.233	.857
20.	4084.	350.	3.80	3.85	140.	8.	7.8	520.	2.41	.560	10.250	1.235
21.	4366.	350.	3.80	3.85	155.	8.	8.0	498.	2.74	.480	6.133	1.657
22.	4367.	350.	4.05	3.38	180.	8.	8.0	650.	2.82	.600	7.050	1.560
23.	4398.	350.	4.05	3.38	190.	6.	8.0	650.	2.56	.400	3.500	1.420
24.	4802.	425.	4.08	4.06	180.	8.	8.2	1400.	2.79	.710	11.375	1.722
25.	5107.	425.	4.08	4.06	180.	6.	8.2	1400.	2.92	.282	3.350	1.710
26.	4979.	425.	4.08	4.06	190.	8.	8.2	1400.	2.76	.425	4.217	1.833

EXHIBIT C-10: SUMMARY OF STEPWISE MULTIPLE LINEAR REGRESSION ON ENGINE FAMILY CHARACTERISTICS[1]

MANUFACTURER	DEPENDENT VARIABLE					
	HC	CO	NO_X	ℓn HC	ℓn CO	ℓn NO_X
GMC	None	None	Timing RPM (.194)	None	None	None
Ford	None	None	Axle Ratio (.383)	None	None	Axle Ratio (.376)
Chrysler	Bore Timing RPM (.781)	Displacement Timing RPM (.601)	None	Displacement Timing RPM (.813)	Compression Ratio Timing RPM (.660)	Timing RPM (.322)
All	Bore (.094)	None	Weight (.085)	Rated HP (.171)	None	Weight (.092)

[1]Table indicates variable(s) selected in each case (if any were significant) and corresponding R^2 value (in parentheses). Independent variables considered were weight, displacement, bore, stroke, rated horsepower, number of cylinders, compression ratio, timing RMP, axle ratio, bore divided by stroke, displacement per cylinder, and inertia weight divided by displacement.

EXHIBIT C-11: PLOT OF FAMILY MEANS OF NO_x VERSUS MEANS OF CO FOR CHRYSLER VEHICLES WITH CATALYSTS

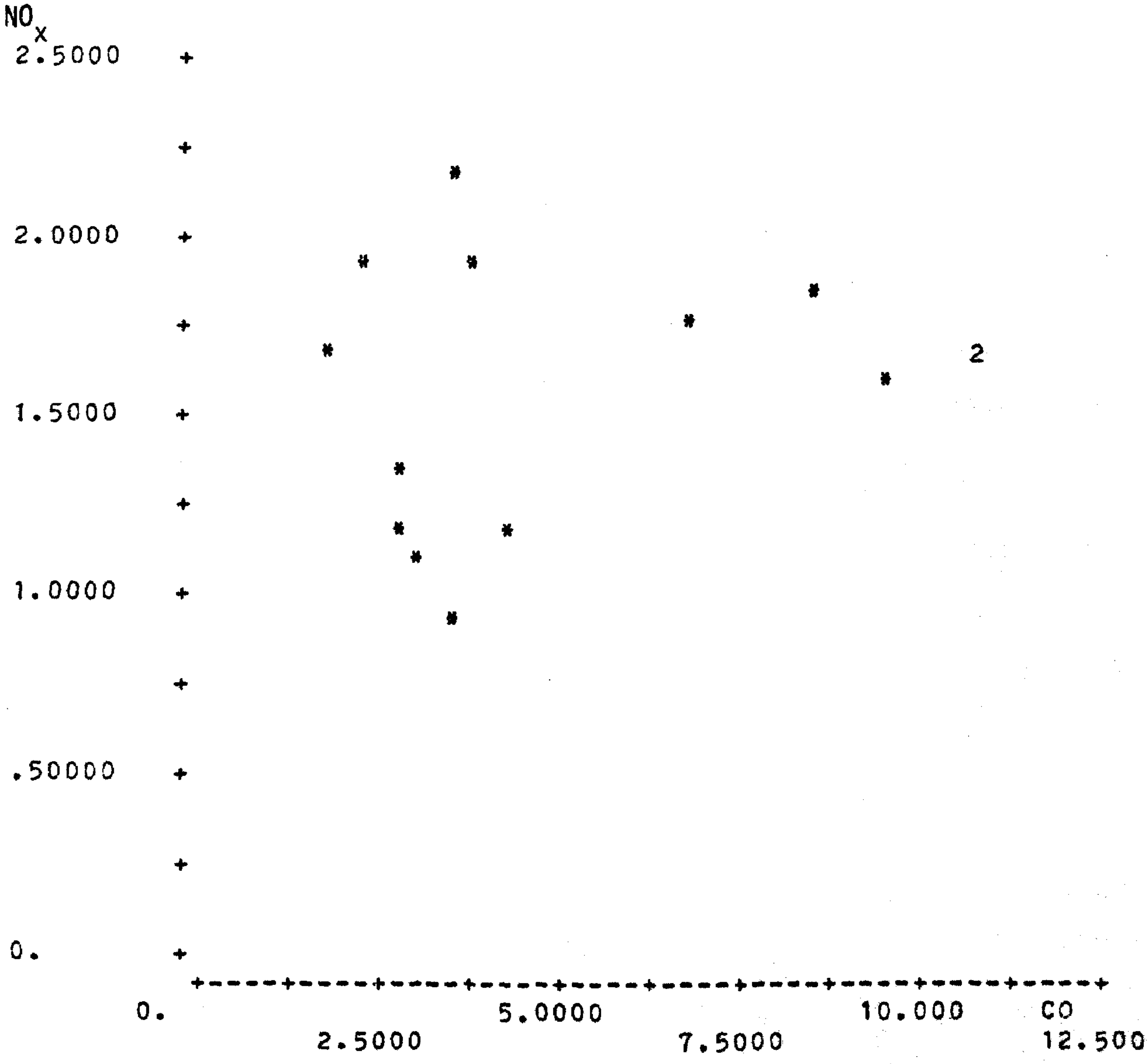

EXHIBIT C-12: PLOT OF FAMILY MEANS OF NO_x VERSUS MEANS OF CO FOR FORD VEHICLES WITH CATALYSTS

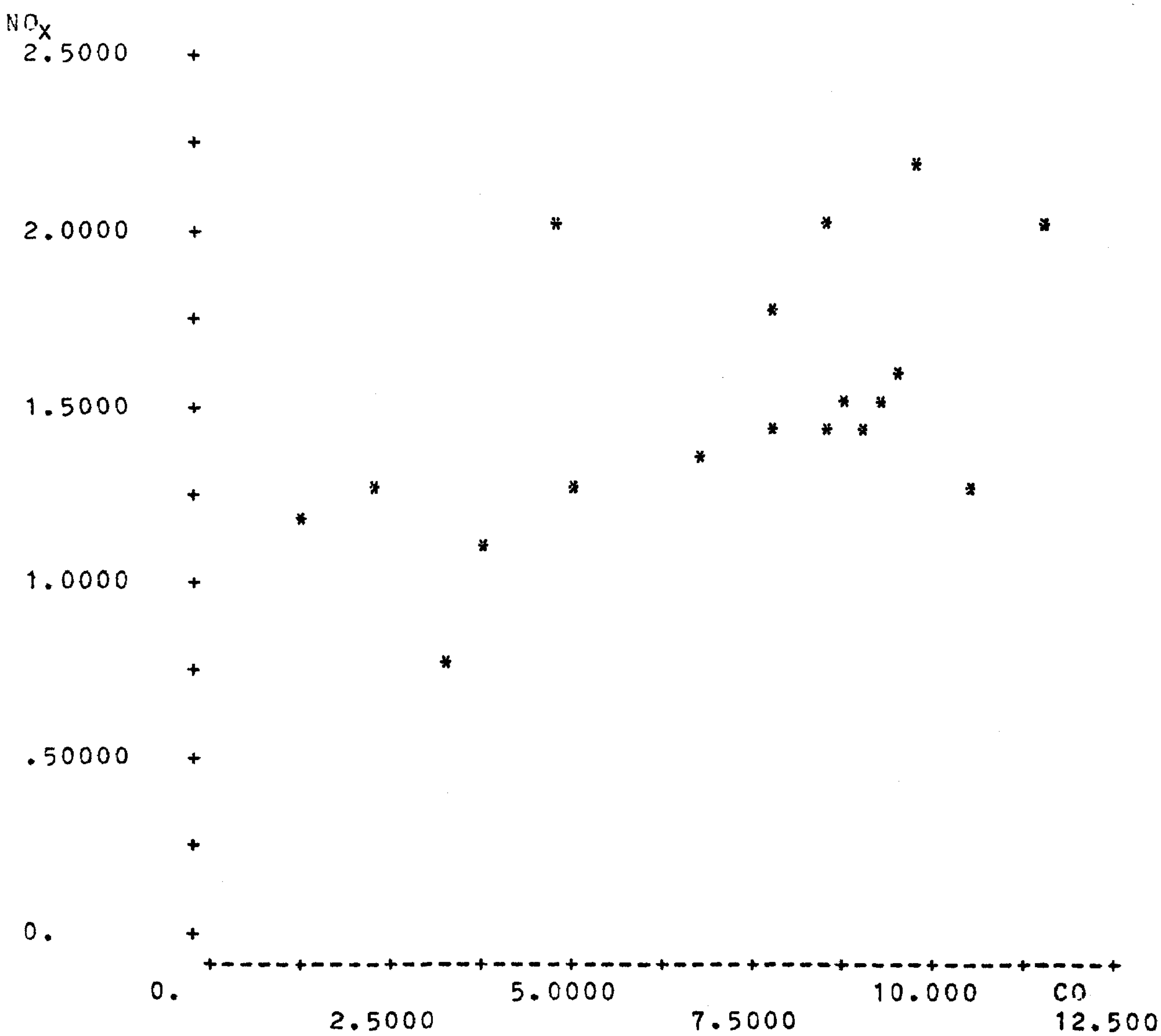

EXHIBIT C-13: PLOT OF FAMILY MEANS OF NO_X VERSUS MEANS OF CO FOR GENERAL MOTORS VEHICLES WITH CATALYSTS

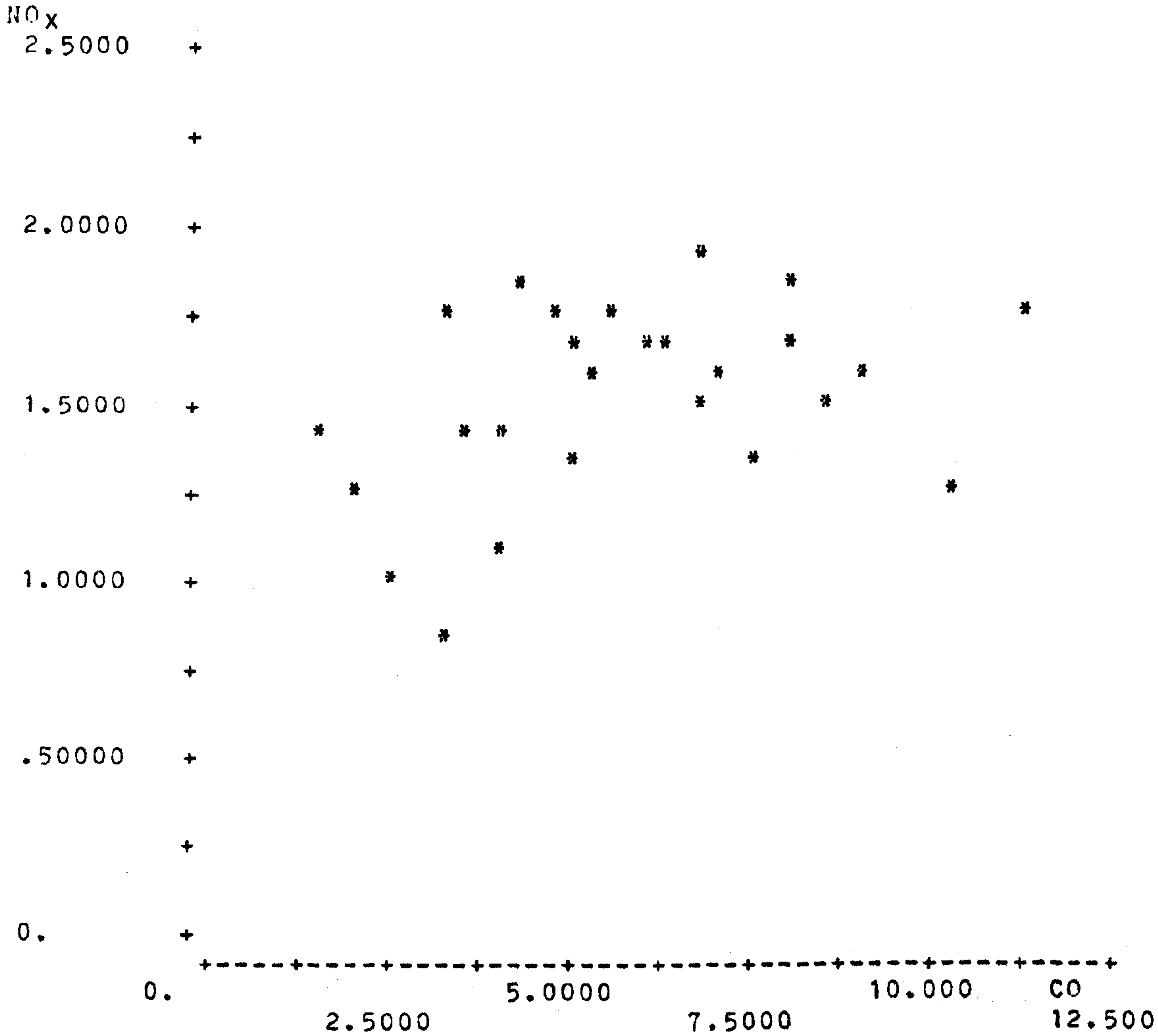

EXHIBIT C-14: PLOT OF FAMILY MEANS OF NO_x VERSUS MEANS OF CO FOR DOMESTIC MANUFACTURED VEHICLES WITH CATALYSTS

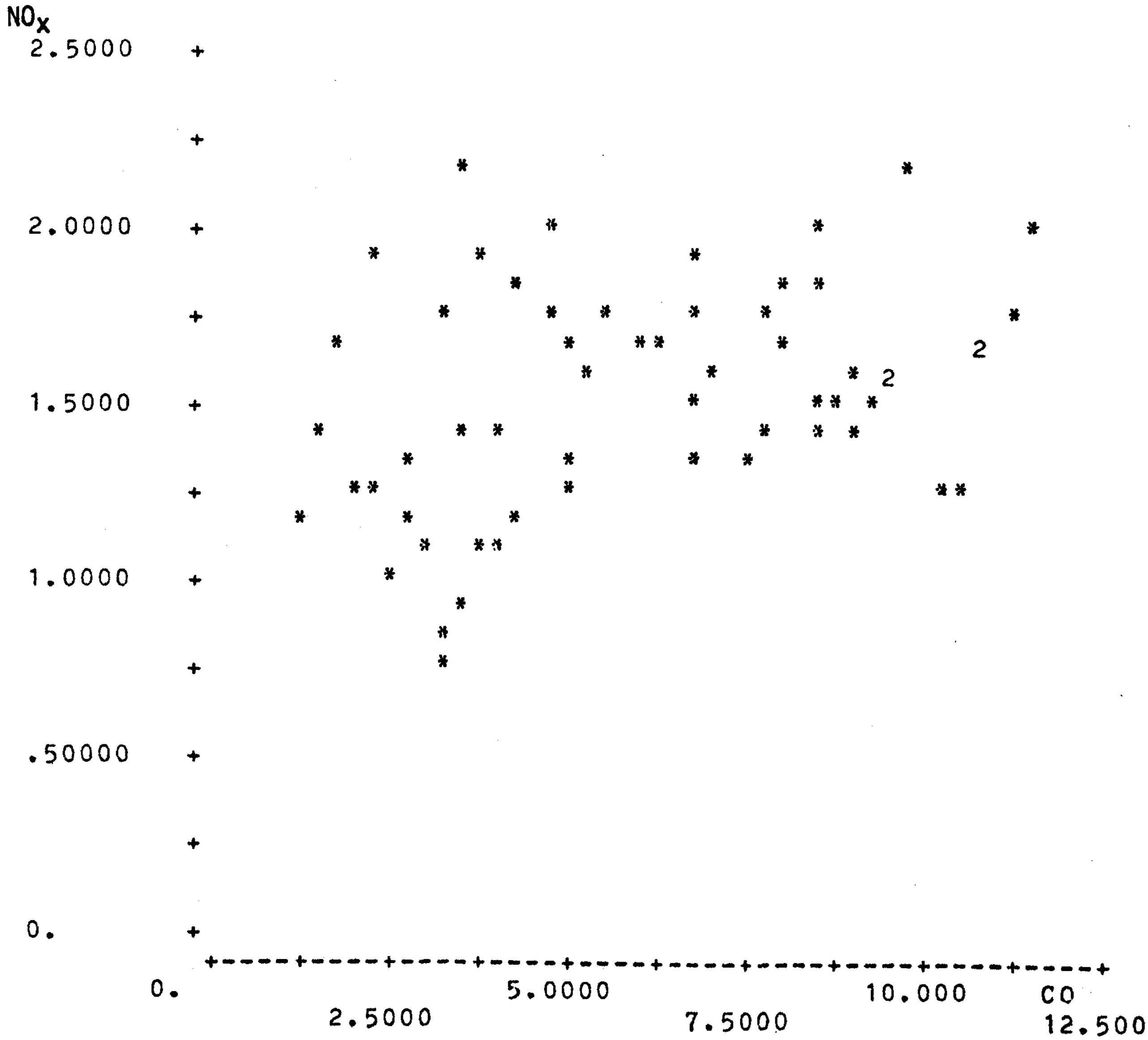

EXHIBIT C-15: GROUPING OF CURRENT FAMILIES USING HEURISTIC CLASSIFICATION CRITERIA

MANUFACTURER	SINGLE FAMILIES	AGGREGATED FAMILIES
CHRYSLER	FA-400-4-NE FB-360-4-CE FB-440-4HP-DE FD-225-2-C CD-225-1-EP CD-318-2-GP CD-360-4-GP CD-440-4HP-FP CD-440-4ST-GEP	FD-225-1-A and FD-225-1-C FD-360-2-C and FD-318-2-C FB-400-4-CE and FB-440-4ST-CE
FORD	F1.6G1CV3 F1.6H1CV5 F2.3A1CV5 F2.3B1CV5 F2.8BV1CV1 F2.8B1CV5 F200A1CV5 F250A1CV1 F250A1CV5 F250B1CV5 F302D1CV5 F302AV1CV1 F351WC2CV4 F351MB2CV1 F351MA2CV1	F302A1CV5 and 302C2CV4 F351MD2CV4 and F351WC1CV1 and F351WC1CV3 F460A2CV1 and F460B2CV4
GENERAL MOTORS	710Y2V 710J4S 710W1QU 710W1 710C2 710F1H 710F1SMU 720K4EH 720X2E 720X2U 730M4AU 730H2U 740E2LU 740E2 760V4U 760V0 760J0U 760V4S 760J0	710J4 and 740J4U 710Y2 and 720S2E 730M4U and 730P4UY

EXHIBIT C-15: GROUPING OF CURRENT FAMILIES USING HEURISTIC CLASSIFICATION CRITERIA

(Concluded)

MANUFACTURER	SINGLE FAMILIES	AGGREGATED FAMILIES
BMW	BMW120.8 BMW120.9 BMW130.8	
FIAT	128 128-CC1 132 132-CC1	
HONDA	77EB 77ED-1 77ED-2	
DATSUN	A140C A141F L200C L240C L280C	L200F and A140F L240F and L280F
VOLVO	4CA 4FA 6CA 6FA	
MAZDA	CNAP FNA CTCP FTCP REP	

APPENDIX D

ANALYSIS OF ENGINEERING JUDGMENT

This appendix describes the analysis methods and results of analyses on the effectiveness of engineering judgment at selecting prototype configurations and identifying the running changes to be tested by EPA. It is organized into five sections. The first section (D.1) describes the analysis comparing certification rejection rates of type B vehicles to type A vehicles. The second section (D.2) presents the results of the analysis of correlation among pollutants. The next two sections then discuss the results of comparing the mean (D.3) and the variance (D.4) of type B vehicle emissions to those for type A vehicle emissions. The final section (D.5) describes the analysis of running change vehicle emissions levels.

D.1 Rejection Rates for Type A and Type B Vehicles

A chi-squared test was performed to determine if the probability that type B vehicles would be rejected during certification was greater than that for type A vehicles. Exhibit D-1 displays the number of vehicles rejected and accepted for each class and also displays the number of vehicles expected to pass or fail the certification criterion if the probability of failing is the same for both classes.

Exhibit D-1 reveals that the number of type A and type B vehicles that actually failed is very close to what one would expect if the probability of failing the certification criterion was the same for vehicles in both classes. A chi-squared test can be used to test the hypothesis that the two probabilities are the same in the case of domestic manufacturers. This test was used on the data shown in exhibit D-1 to determine whether certification disposition was independent from the criteria for selecting an emission data vehicle. The statistic Y used in this test is given by the following equation:

$$Y = \sum_{i=1}^{4} \frac{(O_i - E_i)^2}{E_i} \quad ,$$

where

O_i = the observed number of vehicles in cell i of the matrix in exhibit D-1, and

E_i = the expected number of vehicles in cell i.

Since the statistic in this test has a chi-squared distribution with one degree of freedom, the hypothesis will be accepted at the 5 percent significance level for all values of the statistic less than 3.84. The value in exhibit D-1 for domestic manufacturers of 0.25 shows acceptance of the hypothesis (i.e., the rejection rate of vehicles selected as high emitters is equal to that for those selected on the basis of projected sales).[1]

D.2 Correlation Among Pollutants

VRI's analysis of engineering judgment compared the emissions of type B vehicles with those of type A vehicles to determine whether EPA's engineers were successfully identifying vehicles with high emission levels. In order to determine how to make this comparison, it was first necessary to determine whether the emissions of different pollutants by a vehicle are negatively correlated. If no such negative correlation exists, successful use of engineering judgment should result in the average emissions for one or more

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[1]Although it might be informative to look at this statistic on a manufacturer by manufacturer basis, the number of EDVs for any manufacturer is not sufficiently large to apply the chi-squared test.

pollutants being greater for the B vehicles in an engine family than for the A vehicles in the same family. If, on the other hand, negative correlation exists, as for example between NO_x and CO emissions, a B vehicle selected for potentially high NO_x levels is likely to have low CO levels, and vice versa. If the engineers select roughly equal numbers of vehicles for testing based on each of these two pollutants, the average over all these vehicles of the emission levels for each pollutant may not differ much from the average for randomly selected vehicles.

This phenomenon is illustrated in exhibit D-2, which indicates a hypothetical population of vehicles graphed for their CO and NO_x emission levels. As the exhibit indicates, engineering judgment may not increase the mean of emissions of those vehicles selected over that of vehicles selected at random. However, effective engineering judgment should increase the variance of emissions of selected vehicles, since the selection process should tend to choose to test those vehicles with extreme (high or low) emission levels and ignore vehicles with emissions levels that are about average.

Thus if, on the one hand, an investigation of the correlation of pollution rates were to reveal negative correlations, the subsequent analysis of engineering judgment would attempt to determine whether the variance of emissions of vehicles selected as high emitters (B vehicles) is greater than the variance of emissions of the overall population of vehicles (represented by A vehicles). If, on the other hand, no negative correlations were found, the difference in the mean emissions of type A and type B vehicles would be examined.

The theory of combustion engines indicates that there will be a negative correlation between NO_x and the other two pollutants under certain circumstances. According to the theory, the level of emissions for a given vehicle will change with changes in the air fuel ratio as pictured in exhibit D-3. However, this assumes other factors such as spark timing, engine speed, load level, surface temperature, humidity, exhaust back pressure, intake manifold pressure, valve overlap, combustion chamber deposit buildup, stroke to bore ratio, displacement per cylinder, compression ratio, surface to volume ratio, and combustion chamber design are held constant [Patterson and Henein, 1972]. Although some of these variables would be the same for all vehicles in a family, many of them cannot be assumed to be the same. In discussions with engineers at General Motors Corporation and at Ford Motor Company it was felt that, since each vehicle is calibrated differently and since there are other variables affecting emission levels which are not held constant, the correlation among pollutants for vehicles within an engine family would be nearly zero.

To investigate whether negative correlation between pollutants does in fact exist, a correlation analysis was performed on the emission levels of emission data vehicles for various stratifications of the population, including domestic versus foreign vehicles, catalyst versus non-catalyst vehicles, vehicles stratified by engine family, vehicles stratified by inertia weight, vehicles stratified by manufacturer, vehicles stratified by engine displacement, and some combinations of these stratifications. The possible existence of negative correlation was investigated and linear and quadratic regression analyses were performed.

D.2.1 Vehicles Within An Engine Family

Since each set of B vehicles is selected on an engine family by engine family basis, the possibility of a negative correlation among pollutants was examined within engine families. Under the assumption that the correlation among pollutants within engine families is a constant, but the mean and standard deviation of emission levels is not, two techniques were used to investigate the possibility of negative correlation coefficients.[1] The first was a non-parametric test to determine if any of the correlations were significantly different from zero. The second technique was to use a Bayesian method to estimate the probability distribution of the correlation coefficient.

The correlation coefficients were estimated for those families which had more than two vehicles. Under the assumption that a correlation is zero, the estimated correlation coefficient has a .5 probability of being negative (see page 174, [Jeffreys, 1961]). Exhibit D-4 displays the number of engine families for which the estimated correlation coefficient was negative. Under the assumption that the correlation coefficients are zero, these numbers have a binomial distribution with p equal to 0.5. These numbers were tested to determine if they were significantly larger than would be expected under the assumption of a zero correlation coefficient. At the .05 significance level, the hypothesis of a zero correlation between CO and NO_x was rejected for the categories of domestic manufactured vehicles with catalysts. Since the number of negative estimates was significantly large, there is reason to believe that at least some families in these categories have a

[1]No classical methods were available to estimate the correlation coefficients for vehicles within families since the number of emission data vehicles within a family is at most eight.

negative correlation between CO and NO_x.[1] The next step was therefore to estimate the correlation coefficients.

Since no classical methods for estimating correlation coefficients from multiple, extremely small samples are available, a Bayesian method for estimating the probability distribution of the correlation coefficient was used. This problem of estimating on the basis of several inadequate data sets, each of which provides only limited information about the question of interest, is one of the problems to which Bayesian statistical methods are well-suited (see for example [Box and Tiao, 1973], [Jeffreys, 1961], [Lindley, 1965], or [Savage, 1954] for discussions of Bayesian statistical methods). The first three authors mentioned have described Bayesian methods suitable for dealing with the precise problem analyzed here. The Bayesian method assumes that the researcher has an *a priori* distribution for the parameter in question which reflects his knowledge as to its likely values. The data is then used with this *à priori* distribution to estimate an *à posteriori* distribution for the parameter. The methods described by these authors differ only as to the precise form of the researcher's *à priori* distribution for the correlation coefficient.

Following Jeffreys, the *à priori* distribution of the correlation coefficient was assumed to be uniform on [-1, 1] which reflects the belief that any value in this interval is equally likely. ([Box and Tiao, 1973] and [Lindley, 1965] propose prior distributions that are heavily concentrated on the values +1 and -1, which seems totally inappropriate for this problem. No other

[1]It may be of interest to note that the data revealed a significantly positive correlation between HC and the other two pollutants for these categories.

forms for a non-informative prior distribution have been identified in the literature.) Given an initial state of ignorance so described, the posterior distribution following the result of a single experiment is given in equation 24 on page 177 of [Jeffreys, 1961]. The final posterior belief function, based on a sequence of such experimental observations, is a product of such functions.

Using these techniques a Bayesian 95% confidence interval was constructed for each of the correlation coefficients on the assumption that the intra-family correlations are constant, and that the emission levels for designs within a family have, or are closely approximated by, a multivariate normal distribution. The resulting confidence intervals are displayed in exhibit D-5. A good constant estimate would be the median of the posterior distribution presented in exhibit D-5, which is most negative for the correlation between CO and NO_x (-.22) for foreign vehicles with catalyst. The confidence intervals for this category are, however, much wider than for the categories which include domestic manufactured vehicles. The width of this interval is attributable to the smaller data sample for foreign manufactured vehicles.

The results in exhibit D-5 indicate there is a negative correlation coefficient between CO and NO_x and that a good central estimate of its magnitude would be -.2, or an R^2 of .04. Thus only about 4 percent of the intra-family variance in emissions of NO_x or CO for different designs can be explained by the association between the two pollutants. The results in exhibit D-5 also indicate a positive correlation between HC and CO of about .5 and a weak positive correlation between HC and NO_x of about .1.

D.2.2 Vehicles Stratified in Other Ways

The conclusion from the above analyses is that negative correlation exists between CO and NO_x, but that the magnitude of this correlation is small. Therefore, the linear correlation among emission levels was also computed for other vehicle groupings to see if any negative correlation might be found in these stratifications. The first of these analyses investigated the correlation for all catalyst, non-catalyst, domestic, and foreign vehicles. The results, displayed in exhibit D-6, were that no negative correlation coefficients existed for this stratification.

It was felt that all the data should be stratified by inertia weight and displacement since these appear to be important factors in determining emission levels. The results of the analysis of the correlation among pollutants for vehicles in similar ertia weight classes are shown in exhibits D-7 through D-10. Under this stratification, a few negative values do occur for the estimated correlation coefficients (particularly between CO and NO_x). However, at the .01 significance level none of these negative values is significantly different from zero. The correlation among pollutants is shown in exhibit D-11 for the data stratified by displacement groups with a sample size of 20 or more. The exhibit reveals two displacements (351 and 460) for which the estimated correlation is significantly less than zero.[1] The correlation was recalculated by grouping data from displacements near these two values. When the data are regrouped in this manner, the significance of the negative correlation between NO_x and CO disappears (displayed in exhibit D-12).

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[1]Scatter plots of NO_x versus CO for these two cases revealed that the negative correlation may be driven 2 of 3 data points.

D.3 Emission Level Magnitudes for Type A and Type B Vehicles

The above results which indicate the correlation between vehicles is generally non-negative; however, some negative correlation, albeit minor appears to exist between NO_x and CO. Therefore two types of analyses were performed, one assuming a positive correlation and the other assuming a negative correlation. In this section the emission levels of type A and type B vehicles are compared in terms of the difference between the mean emission levels of each type of vehicle (i.e., assuming a positive correlation). To determine whether the mean of one class is significantly different from that of the other three analyses were performed--an analysis of variance, a Mann-Whitney test and a test of t-statistics. The following three sub-sections discuss the results of each of these analyses.

D.3.1 Analysis of Variance

An analysis of variance was performed on a model explaining the effects of engine family, type of selection, vehicle configuration, and test-to-test differences in the measured emission levels of a particular vehicle. Since these factors are hierarchical or nested in nature (i.e., each engine family contains both type A and type B vehicles which in turn may have different configurations each of which is tested a number of times), the following analysis of variance model was developed

Let $Y_{ijk\ell}$ denote the measured emission level of a given pollutant for the ℓ^{th} test on the k^{th} vehicle of type j in family i. Then the model for the analysis of variance is given in the following equation:

$$E_{ijk\ell} = \mu + f_i + t_{ij} + V_{ijk} + e_{ijk\ell} ,$$

where μ = the overall mean of the observations,

f_i = the effect of family i,

t_{ij} = the effect of type j and family i,

V_{ijk} = the effect of vehicle k of type j and family i, and

$e_{ijk\ell}$ = the error in the 1^{th} test on vehicle k in class j and family i.

It is further assumed that $\{f_i\}$, $\{t_{ij}\}$, $\{v_{ijk}\}$, and $\{e_{ijk\ell}\}$ are independently normal with zero means and constant variances. The data was analyzed as a random effects completely nested design with unequal numbers of observations. The formulas for the analysis of variance are presented on pages 248-258 in [Scheffe, 1963]. Due to the fact that there are unequal numbers of observations the F tests for testing whether the mean emission level for type A vehicles are equal to those of type B vehicles and for testing whether the mean emission levels are the same for all families are approximate F tests. The approximation is discussed on pages 254-255 in [Scheffe, 1963] and in more detail on pages 302-303 in [Ostle, 1963].

Since the results of the analysis of the dependencies between test variability and mean emission level in appendix B were inconclusive and since there is some evidence and rationale that the estimates of test-to-test variance using this study's data base may be biased upwards, ANOVAs were performed using three different test variability assumptions. The first assumption was that test-to-test standard deviation is a constant (model 1 in appendix B). The second assumption was that test-to-test standard deviation is proportional to the mean (model 4 in appendix B). The third

ANOVA was performed using estimates of test-to-test standard deviation as presented in [Juneja *et al.*, 1977].

Analysis results using the first of these assumptions are presented in exhibit D-13. The exhibit presents the computed F-ratio values for each factor in the above model under the assumption that the test-to-test standard deviation is a constant and independent of the mean emission level for a vehicle. The number in parentheses beneath each F-ratio value indicates the critical value for accepting the appropriate hypothesis stated above at the 5 percent significance level. As can be seen from the results in this exhibit, the hypothesis that mean emission levels of type A vehicles differ from those of type B vehicles is rejected for all pollutants in all vehicle categories. On the other hand, the existence of differences in the mean emission levels among families and among configurations within a family are accepted in nearly every case, with the only notable exception occurring for configuration differences in foreign vehicles with catalysts.

The second series of ANOVAs were performed under the assumption that the test-to-test standard deviation was proportional to the mean. Since the analysis of variance model assumes that the test-to-test standard deviation is a constant, test result data were normalized to remove the assumed dependence between mean emission level and test variability. Under the proportional assumption, the logarithm of the data has a constant test-to test standard deviation.[1] To check this transformation a review was made of scatter plots of the test-to-test standard deviation versus mean, after the logarithm of the data was taken, and these did not reveal any apparent trends or relationships which might refute the porportionality assumption.

[1]See page 365, [Scheffe, 1963].

Exhibit D-14 provides the results of the ANOVA on the logarithm of the data. These results are nearly identical to those in exhibit D-13. Minor differences between the specific ANOVA results under these two test variability assumptions do occur; however, both analyses point to the same conclusions, i.e., the mean emission level of vehicles in different families are different, while differences between the mean emissions of type A and B vehicles in these families are not apparent.

Finally, there exists some question concerning the validity (as discussed in appendix B) of any estimate of test variability which is based on data from multiple tests on emission data vehicles. That is, estimates from this data may either contain too much variation due to the few tests available per vehicle or an upward bias due to changes from such recalibrations which alter the conditions between tests. For this reason the analysis was repeated using estimates of test-to-test standard deviation as calculated in [Juneja *et al.*, 1977] assuming test-to-test standard deviation is a constant (model 1 in appendix B).[1] The results of this analysis are presented in exhibit D-15. These results are nearly identical to those in the previous analyses and hence support the same conclusions.[2]

D.3.2 Mann-Whitney Test

A non-parametric method for comparing the rank of the emission levels for type A vehicles to type B vehicles was devised to test the hypothesis that these levels are not significantly different within an engine family.[3]

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[1]This estimate was chosen because it represented the most recent available and because it would produce conclusions which were most conservative (i.e., the lowest test-to-test standard deviation estimate).

[2]Since the results did not differ from those in exhibit D-13, the analysis was not repeated with the data in [Juneja *et al.*, 1977] assuming test-to-test standard deviation is proportional to the mean (model 4).

[3]In this analysis only the first test made on each vehicle was used.

This analysis was performed to determine whether a significant difference between types would be detected without any parametric assumptions on the distribution of emission test results (e.g., the normal distribution assumed in the ANOVA). The non-parametric analysis consisted of calculating a Mann-Whitney statistic on the mean emission level of vehicles in class A versus class B within a family.

The Mann-Whitney statistic for family i, denoted by U_i, is calculated by the following equation:

$$U_i = \sum_{j=1}^{NA} \sum_{k=1}^{NB} \emptyset_{jk} ,$$

where

NA = number of class A vehicles in family i,

NB = number of class B vehicles in family i, and

$$\emptyset_{jk} = \begin{cases} \text{1 if the mean emission level for vehicle k in class B is greater} \\ \text{than or equal to the mean emission level for vehicle j in class} \\ \text{A, and} \\ \text{0 otherwise.} \end{cases}$$

The expected value and variance of U_i are given in the following equations.

$$E(U_i) = NA \cdot NB/2, \text{ and}$$

$$Var(U_i) = NA \cdot NB \cdot (NA+NB+L)/12.$$

Let

$$V_i = \frac{U_i - E(U_i)}{\sqrt{Var(U_i)}}$$

If both NA and NB are at least 10, V_i has a distribution that is approximately normal with a mean of 0 and a variance of 1. Since the values of NA and NB for a given family are not large enough to allow for a good approximation, the V_i were summed over all engine families. Using the central limit theorem, the distribution of the sum of V_i is approximately normal when the number of engine families is at least 20. The standardized sum of the V_i, denoted by V, is presented in the following equation:

$$V = \sum_{i=1}^{I} \frac{V_i}{\sqrt{I}} ,$$

where

I = the number of engine families.

The statistic V has a distribution that is approximately normal with a mean of 0 and a variance of 1 when the number of engine families is at least 20.

Exhibit D-16 displays the normalized sum of the statistic for domestic vehicles by manufacturer and foreign vehicles.[1] To reject the hypothesis that the emission levels of type A vehicles are equal to type B emissions and hence accept the alternative that type B emissions are greater than those for type A, the numbers in the table must be positive and exceed 1.65 for a 5 percent level of significance. Since there are no such values, one cannot conclude the emission levels for type B vehicles are "greater" than the class A vehicles.

D.3.3 Test of t-Statistics

In addition to the Mann-Whitney test a special purpose statistical method was created to permit comparison of type A and type B vehicle emission levels without requiring any specific assumption concerning the pattern of association

[1]Catalyst and non-catalyst distinctions were also examined with the same results; however, the number of non-catalyst vehicles was insufficient to consider the resultant distribution of the statistic approximately normal.

between mean levels within an engine family and variability within that family. In this test a t-statistic was calculated for each family[1] by subtracting the mean emission levels of type B vehicles from those for type A vehicles, and the difference was normalized to account for the pooled variance of emission levels in each family. The t-statistic calculated for a family is presented in the following equation:

$$t = \frac{\bar{A} - \bar{B}}{\left(\frac{1}{NA} + \frac{1}{NB}\right)\sqrt{\dfrac{\sum^{NA} (A_i - A)^2 + \sum^{NB} (B_i - \bar{B})^2}{NA + NB - 2}}} ,$$

where

NA = number of observations in class A,

NB = number of observations in class B,

NA+NB-2 = the degrees of freedom for the t-statistics,

A_i = observation in class A,

$\bar{A}$ = average for class A,

B_i = observation in class B, and

$\bar{B}$ = average for class B.

These calculations produced an array of values (one for each engine family), each of which has a t distribution with the appropriate, family-specific, degrees of freedom. Next, the corresponding cumulative probability was determined for each of these values using the appropriate t distribution. The resulting collection of probabilities was then arranged in ascending order and a sample cumulative distribution constructed.

[1]As in the Mann-Whitney test, the data set used in this analysis included only the first test made on each vehicle.

Under the assumption that the mean emission level of type A vehicles equals that of type B vehicles, each engine family statistic calculated above is a t-distributed random variable. Thus the cumulative probability corresponding to the statistic is distributed uniformly on (0, 1). Therefore, to test the hypothesis that type A and B emission levels are equal against the alternative hypothesis that they are different, the collection of cumulative probabilities is tested to determine if it corresponds to a sample from a random variable uniformly distributed in (0, 1).[1]

The sample cumulative distribution of these probabilities was plotted for vehicles with catalyst, vehicles without catalyst, and a combination of both classes of vehicles. In every case the sample distribution looked approximately uniform on (0, 1). Exhibit D-17 displays the Kolmogorov-Smirnoff test statistic for the test of the goodness of fit of a uniform distribution to the sample cumulative for these cases. The critical values for rejecting the hypothesis at the .05 significance level are also presented. As can be seen, the hypothesis that the mean emission level for type A vehicles is equal to that for type B vehicles cannot be rejected at the .05 level.

D.4 Emission Level Variability for Type A and Type B Vehicles

As noted in section D.2 the selection of type B vehicles which have, in general, greater emission levels than the type A vehicles may result in an observed difference in the variance rather than the magnitude of certain pollutants. That is, if the correlation between pollutant pairs is negative,

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[1]The cumulative probabilities for any continuous, strictly increasing distribution are uniformly distributed on (0, 1) (see page 901, [Wagner, 1969]). Although the probabilities in this case are derived from t distributions with differing degrees of freedom, they are still uniformly distributed on (0, 1) under the null hypothesis.

then the type B vehicle emissions would be expected to demonstrate a greater variance than that for the type A vehicles, under the assumption that the high emitters can be identified.

In order to determine whether the variance of emission levels for type B vehicles is in fact greater than the variance for type A vehicles, a 95 percent confidence interval was constructed for the ratio of these variances for those 1977 engine families with at least two vehicles of each type. If the variance for type B vehicles equals that for type A vehicles (i.e., indicating the emission levels are similar), then the calculated value for the above ratio should fall within this confidence interval 95 percent of the time.

To examine whether this was true, the 95 percent confidence interval for the ratio of the standard deviation of type B vehicles to type A vehicles was obtained as follows. Let g denote the ratio of the variance for type vehicles to the variance of type A vehicles. Then the estimate of g, denoted by g, divided by a g has an F distribution with nB-1 and nA-1 degrees of freedom, where nB denotes the number of type B vehicles in the engine family and nA denotes the number of type A vehicles. Let F_L and F_u denote the end points of a 95 percent confidence interval for the $F_{nB-1,\ nA-1}$ distribution. This confidence interval can then be obtained using the following equations:

$$.95 = P\left[F_L \le \frac{\hat{g}}{g} \le F_u\right] = P\left[\frac{1}{F_u} \le \frac{g}{\hat{g}} \le \frac{1}{F_L}\right], \text{ or}$$

$$.95 = P\left[\sqrt{\hat{g} / F_u} \le \sqrt{g} \le \sqrt{\hat{g} / F_L}\right]$$

Exhibit D-18 displays the confidence intervals using the above equations for all three pollutants. If the ratio of the variances is a constant equal to 1.0 (i.e., type B variance equals type A variance), one would expect the number 1.0 to be outside 3 of the 66 intervals (i.e., 95 percent of the time). The number of times 1.0 is outside these intervals is 4.[1] The confidence intervals for $\sqrt{1/g}$, the standard deviation of type A vehicles divided by the standard deviation for type B vehicles, could be obtained by dividing the values in exhibit D-18 into the number 1. When this was done the confidence interval for $\sqrt{1/g}$ included higher values than those for $\sqrt{g}$ in 47 out of the 66 intervals constructed. This indicated that, if the variances for type A and type B vehicles do differ, then there is a tendency for type A vehicles to have the greater variance (i.e., type A vehicles generally have higher emissions than type B vehicles under the assumption of a negative correlation between pollutants).

There is, therefore, no evidence that the negative correlation between CO and NO_x has caused the variance of emission levels for type B vehicles to exceed the variance for type A vehicles. Thus, the results of this and the preceding analyses indicate that no matter what is assumed about the correlation among pollutants the emission levels of type B vehicles are not significantly different from those of the type A vehicles.

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[1]In 3 out of the 4 cases the interval included values which were all less than 1.0, indicating that where the B variances were not equal to the A variances, the A variances were actually greater.

D.5 Running Change Vehicle Emission Levels

Three types of analyses were conducted to investigate whether the running change vehicles selected for testing by EPA had emission levels which were higher than those measured on the vehicle prior to implementation of the change. The first of these analyses examined the degree to which the mean emission level of sequential running changes was similar to the certified emission levels of the original emission data vehicle (EDV). The second analysis examined the number of times the sequential running change emission levels exceeds the levels of the original EDV. A estimate of the variance of running changes was then obtained in the final analysis to determine the likelihood a tested running change vehicle would fail given the EDV passed the certification test. Each of these analyses are discussed in greater detail below after a brief description of the running change data base.

D.5.1 Running Change Data Base

The data base used in the analysis of running changes was constructed by identifying 66 emission data vehicles (EDVs) in the VRI data base which also had EPA test data on running changes (RCs) to these configurations. The number of RCs per EDV was subject to interpretation because the EPA data base consistently did not differentiate among the following:

(1) a test on one running change and a test on a subsequent change,

(2) two tests on the same running change (the second one, possibly made for the fuel economy testing program),

(3) back-to-back tests to examine emissions before and after implementation of the running change.

The EDV could, however, be easily identified, so most of the analyses discussed below compared the emission levels of all running changes to their original certified EDV. The RC data base used in this analysis contained only EPA test results. It was comprised of 66 EDVs each with one test, and 77 computer differentiated RCs tested a total of 109 times. Fifty of these running changes had one EPA test, 24 had 2 tests, one had 3 tests, and 2 had 4 tests. Exhibit D-19 provides the identification of the vehicles and test results examined in the following analyses.

D.5.2 Mean Emission Levels

One criterion used by EPA in deciding to test proposed running changes is the degree to which the change is expected to increase emissions. Therefore it seemed reasonable to expect that EPA running change tests would have higher emission levels than their corresponding emission data vehicles. This occurence could be observed from the data in exhibit D-19 in one of two forms--as an increase of the mean emission levels for one or more of the pollutants or as an unexpectedly high fraction of RC tests which showed an increase in at least one pollutant, even though no single pollutant showed a consistent increase in the various tests.

An analysis of variance was conducted to test the hypothesis that the mean RC emission levels were above the emissions of their counterpart EPV. The results of this test concluded that, at a five percent level of significance, running changes do not have higher mean emissions in any pollutant than their counterpart original EPVs. A χ^2 test was then performed to compare the frequency that RC emissions exceeded those of the original EDV with the frequency that would be expected where there are no differences in emission levels. Except for the correlation of CO and HC emissions, the distribution of running change test results was statistically indistinguishable from that expected if running changes had no effect on the emission levels of the three pollutants. That is, the effects on each pollutant were symmetrically distributed as to increases and decreases and changes which showed an increase on at least one pollutant were not more frequent than would be expected from random effects.

D.5.3 Emission Level Variability

Given the above result, it became possible to measure the degree of variability between the emissions of the original vehicles and those of their running change counterparts in terms of a variance, rather than a shift in the mean emissions. Because of the fact that test-to-test errors would be expected to cause some variance even if the running change designs were identical to their original counterparts, it was necessary to perform an analysis of variance on the running change data.

This analysis of variance was conducted in two steps, because of the previously mentioned problems in telling whether a test was on a vehicle that had in fact had the running change applied, or an original design vehicle with the test run for back-to-back purposes. These two steps were:

(1) first, the within-group coefficient of variation of each emission level was computed for groups of EDVs and all their identical RC counterparts; and then

(2) the test-to-test variance was eliminated and the change-to-change coefficient of variation was estimated.

The coefficient of variation,[1] including both the effects of test-to-test variation and change-to-change variations, was 18 percent for HC, 34 percent for CO, and 12 percent for NO_x. Eliminating the test-to-test variation[2] left 8 percent for HC, 22 percent for CO, and 5 percent for NO_x. In order to determine the RC-to-RC coefficient of variation from this data, it was necessary to estimate the numbers of tests per RC configuration tested. It was clear that this number could not be less than 1.0. Further an analysis of the data base showed that the number of tests per computer differentiated RCs was 2.07, so that the number of tests per configuration had to lie in the interval 1.0 - 2.07. On this basis, the change-to-change coefficient of variation has a range of 1.0 to $\sqrt{2.07}$ times the above estimate, i.e., 8 percent to 12 percent for HC, 22 percent to 32 percent for CO, and 5 percent to 7 percent for NO_x.

The precise estimate of the EDV-to-EDV coefficient of variation within a family is dependent on the statistical model used, but the results from the ANOVA described in section D.3.1, indicate that all estimates are approximately 20 percent for HC, 30 percent for CO and 15 percent for NO_x. Consequently the variability of RCs is significantly less than the variabilty among the EDV configurations within a family.

The results from this and the previous running change analyses are:

(1) the average of RC emissions cannot be distinquished from the EDV emissions levels,

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[1]Estimated using the logarithmic data transformation discussed in section D.3.1. (See page 365 of [Scheffe, 1963].)

[2]Test-to-test coefficient of variation estimates were taken from the results of this study for catalyst vehicles (see exhibit B-4 in appendix B).

(2) the RC emissions are as likely to be above as below the EDV emission levels, and

(3) the variability of RC-to-RC emissions is less than that for EDV-to-EDV emissions.

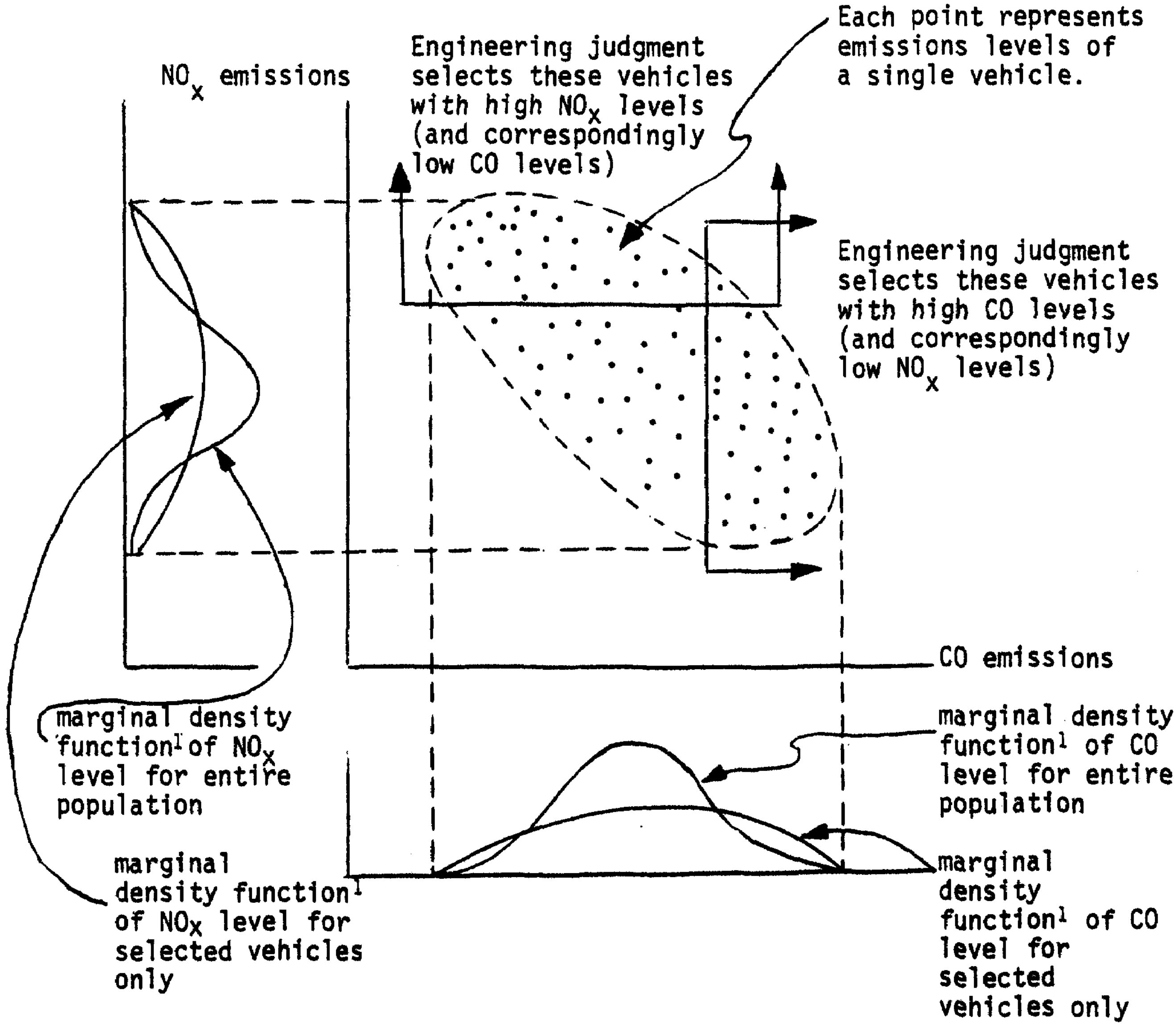
Thus, it is reasonable to assume that given the emission levels of an EDV, the emissions of running changes to the EDV will be approximately the same levels. Therefore the decision to test or not test a proposed running change should, for the most part, be based on the emission levels of the original certified EDV. If the change is proposed to a configuration not originally certified, then the average EDV emissions for the engine family should serve as a good proxy.

EXHIBIT D-1: ACTUAL AND EXPECTED CERTIFICATION DISPOSITION OF 1977 MODEL YEAR VEHICLES IN VRI DATA BASE BY TEST SELECTION CRITERIA

	Domestic		Foreign	
	Type A	Type B	Type A	Type B
Number Passing	72	159	40	42
Number Failing	5	16	0	1
Expected Number to Pass	71	160	40	42
Expected Number to Fail	6	15	0	1
Chi-square Statistic	0.25		*** [1]	

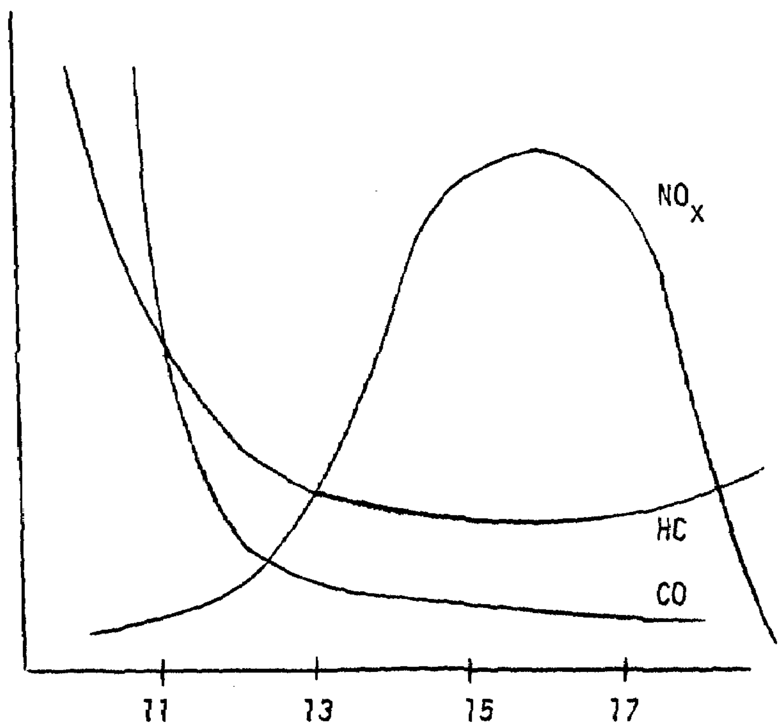
[1]When the expected number of observations in any one cell is less than 5, the distribution of the test statistic cannot be approximated with a chi-square (see page 127, [Ostle, 1963]). An exact test of this hypothesis as described on page 132, [Ostle, 1963] had a significance level of .48.

EXHIBIT D-2: EFFECT OF ENGINEERING JUDGMENT IN DISTRIBUTION OF SELECTED VEHICLES IF EMISSIONS ARE NEGATIVELY CORRELATED



[1]The marginal density function represents the relative frequency of occurrence of vehicles with the given emissions level. In the cases illustrated, the density for the entire population and the density for selected vehicles have the same mean, but the density for the selected vehicles has a larger variance.

EXHIBIT D-3: EFFECT OF AIR FUEL RATIO ON EMISSIONS[1]



[1]Taken from [US Environmental Protection Agency, 1975], p. 7.

EXHIBIT D-4: NUMBER OF ENGINE FAMILIES WITH NEGATIVE ESTIMATES OF THE CORRELATION COEFFICIENT

	CORRELATION			TOTAL NO. OF ENGINE FAMILIES
	HC and CO	HC and NO_x	CO and NO_x	
Domestic Manufactured Vehicles With Catalysts	9	18	33*	48
Foreign Manufactured Vehicles With Catalysts	2	4	3	5
Foreign Manufactured Vehicles Without Catalysts	1	4	5	7
All Vehicles	12	26	41*	60

*Significant at .05 level.

EXHIBIT D-5: 95 PERCENT CONFIDENCE INTERVALS FOR THE CORRELATION COEFFICIENTS

	Number of Engine Families	Correlation Between								
		HC and CO			HC and NO_x			CO and NO_x		
		Lower Point	Median	Upper Point	Lower Point	Median	Upper Point	Lower Point	Median	Upper Point
Domestic Manufactured Vehicles With Catalysts	48	.39	.53	.71	-.04	.13	.30	-.35	-.19	-.03
Foreign Manufactured Vehicles With Catalysts	5	-.35	.17	.61	-.56	-.11	.37	-.63	-.22	.26
Foreign Manufactured Vehicles Without Catalysts	7	.22	.62	.85	-.56	-.12	.34	-.58	.00	.44
All Vehicles	60	.39	.52	.64	-.07	.09	.24	-.32	-.18	-.03

EXHIBIT D-6: CORRELATION AMONG POLLUTANTS

	Catalyst			Non-Catalyst	Both
	Domestic	Foreign	Both	Foreign	Both
HC and CO	.76	.69	.77	.34	.65
HC and NO_x	.27	.42	.36	.48	.29
CO and NO_x	.11	.32	.20	.25	.18

EXHIBIT D-7: CORRELATION AMONG POLLUTANTS BY INERTIA WEIGHT (DOMESTIC VEHICLES WITH CATALYSTS)

INERTIA WEIGHT	CORRELATION BETWEEN			.01 Critical Value
	HC and CO	HC and NO_x	CO and NO_x	
2250	.95	.14	.33	.83
2750	.35	.80	-.10	.92
3000	.45	.13	-.16	.54
3500	.79	.59	.21	.38
4000	.82	.42	.32	.26
4500	.82	.31	.30	.33
5000	.81	-.06	-.16	.35
5500	.84	-.17	-.37	.51

EXHIBIT D-8: CORRELATION AMONG POLLUTANTS BY INERTIA WEIGHT (FOREIGN VEHICLES WITH CATALYSTS)

INERTIA WEIGHT	CORRELATION BETWEEN			.01 Critical Value
	HC and CO	HC and NO_x	CO and NO_x	
2250	.66	.13	.21	.68
2500	.53	.09	.80	.99
2750	.97	-.26	-.06	.99
3000	.61	.43	.56	.62
3500	.71	.61	.36	.68

EXHIBIT D-9: CORRELATION AMONG POLLUTANTS BY INERTIA WEIGHT (FOREIGN VEHICLES WITHOUT CATALYSTS)

INERTIA WEIGHT	CORRELATION BETWEEN			.01 Critical Value
	HC and CO	HC and NO_x	CO and NO_x	
2000	.17	.48	.37	.96
2250	.71	.33	.09	.62
2500	.60	.67	.39	.64
3000	-.02	.58	.62	.80
3500	.85	.26	.52	.99

EXHIBIT D-10: CORRELATION AMONG POLLUTANTS BY INERTIA WEIGHT (DOMESTIC AND FOREIGN VEHICLES WITH CATALYSTS)

INERTIA WEIGHT	CORRELATION BETWEEN			.01 Critical Value
	HC and CO	HC and NO_x	CO and NO_x	
2250	.78	.22	.40	.55
2500	.53	.09	.80	.99
2750	.59	.30	-.21	.76
3000	.58	.39	.21	.41
3500	.79	.62	.28	.34
4000	.82	.42	.32	.26
4500	.82	.31	.30	.33
5000	.81	-.06	-.16	.35
5500	.84	-.17	-.37	.51

EXHIBIT D-11: CORRELATION AMONG POLLUTANTS
BY DISPLACEMENT (DOMESTIC VEHICLES)

DISPLACEMENT	SAMPLE SIZE	CORRELATION BETWEEN			.01 CRITICAL VALUE
		HC&CO	HC&NO_x	CO&NO_x	
140	42	.21	-.04	-.01	.39
225	61	.81	.44	.28	.33
231	36	.67	.22	.37	.42
250	54	.80	.04	-.11	.35
260	22	.78	.00	.00	.54
302	27	.49	.00	-.28	.49
318	41	.40	.74	.42	.40
350	87	.60	.27	.06	.27
351	40	.45	.04	-.40	.40
360	40	.56	.20	.15	.40
400	77	.61	.41	.28	.29
425	33	.86	.11	-.23	.44
440	44	.40	.08	.02	.38
455	29	.78	.24	.15	.47
460	46	.41	.12	-.40	.38

EXHIBIT D-12: CORRELATION AMONG POLLUTANTS BY DISPLACEMENT GROUP (DOMESTIC VEHICLES)

Displacement Group	Sample Size	Correlation Between			.01 Significance Level
		(HC, CO)	(HC, NO_x)	(CO, NO_x)	
440, 454[1], 455, 460	121	.50	.07	-.17	23
350, 351	127	.60	.17	-.13	.23

[1]This displacement does not appear in exhibit D-11 because the sample size is less than 20.

EXHIBIT D-13: ANALYSIS OF VARIANCE RESULTS INCLUDING TYPE A VS B DIFFERENCES UNDER CONSTANT TEST VARIABILITY ASSUMPTION (MODEL 1)

F-Ratio Test[1] For	Catalyst									Non-Catalyst			Both		
	Domestic			Foreign			Both			Foreign			Both		
	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
Family Differences	8.79 (1.9)	4.44 (1.9)	14.5 (4.2)	9.59 (3.8)	28.1 (5.2)	13.5 (3.9)	9.82 (1.8)	5.09 (1.7)	17.7 (2.8)	9.79 (3.1)	6.18 (3.0)	1.46 (2.7)	12.2 (1.6)	5.50 (1.6)	13.4 (2.2)
Type A vs. Type B Differences within Family	0.94 (1.4)	1.04 (1.4)	0.53 (1.4)	1.82 (3.4)	0.35 (2.6)	1.47 (3.2)	0.90 (1.4)	0.95 (1.4)	0.53 (1.4)	0.61 (2.4)	0.76 (2.5)	1.94 (2.4)	.91 (1.4)	.91 (1.4)	.56 (1.4)
Configuration Differences within Type and Family	3.56 (1.4)	4.00 (1.4)	1.71 (1.4)	0.29 (2.9)	1.82 (2.9)	0.34 (2.9)	2.86 (1.4)	4.00 (1.4)	1.57 (1.4)	5.58 (3.2)	3.66 (3.2)	5.53 (3.2)	3.05 (1.4)	3.96 (1.4)	1.64 (1.4)

[1]F ratio results are significant (at the 5% level) when greater than the value in parentheses.

EXHIBIT D-14: ANALYSIS OF VARIANCE RESULTS INCLUDING TYPE A VS B DIFFERENCES UNDER THE ASSUMPTION THAT TEST VARIABILITY IS PROPORTIONAL TO THE MEAN (MODEL 4)

F-Ratio Test[1] For	Catalyst									Non-Catalyst			Both		
	Domestic			Foreign			Both			Foreign			Both		
	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
Family Differences	11.9 (1.9)	5.70 (1.8)	13.3 (3.0)	8.41 (3.6)	16.8 (4.2)	8.21 (3.2)	13.0 (1.7)	6.59 (1.7)	11.6 (1.8)	11.8 (3.2)	6.20 (2.9)	1.52 (2.7)	14.4 (1.6)	7.06 (1.6)	10.6 (1.6)
Type A vs. Type B Differences within Family	1.04 (1.4)	1.18 (1.4)	0.58 (1.4)	1.92 (3.3)	0.38 (2.5)	1.90 (2.9)	1.06 (1.4)	1.07 (1.4)	0.98 (1.4)	0.60 (2.4)	1.24 (2.4)	1.99 (2.4)	1.01 (1.4)	1.03 (1.4)	0.97 (1.4)
Configuration Differences within Type and Family	3.17 (1.4)	4.59 (1.4)	2.91 (1.4)	0.31 (2.9)	3.62 (2.9)	0.46 (2.9)	1.93 (1.4)	4.55 (1.4)	1.26 (1.4)	6.55 (3.2)	5.13 (3.2)	5.26 (3.2)	2.26 (1.4)	4.54 (1.4)	1.32 (1.4)

[1] F ratio results are significant (at the 5% level) when greater than the value in parentheses.

EXHIBIT D-15: ANALYSIS OF VARIANCE RESULTS INCLUDING TYPE A VS B DIFFERENCES FROM USING JUNEJA *ET AL.* [1977] TEST VARIABILITY ESTIMATES UNDER MODEL ASSUMPTION

F-Ratio Test[1] For	Catalyst									Non-Catalyst			Both		
	Domestic			Foreign			Both			Foreign			Both		
	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
Family Differences	8.72 (1.9)	4.41 (1.8)	13.5 (3.7)	8.13 (3.0)	27.2 (4.8)	11.4 (3.0)	9.68 (1.8)	5.05 (1.7)	16.3 (2.6)	9.87 (3.2)	6.22 (3.0)	1.46 (2.7)	12.1 (1.6)	5.46 (1.6)	12.7 (2.1)
Type A vs. Type B Differences within Family	0.93 (1.4)	1.03 (1.4)	0.52 (1.4)	1.42 (2.6)	0.35 (2.6)	1.19 (2.6)	0.89 (1.4)	0.95 (1.4)	0.51 (1.4)	0.60 (2.4)	0.75 (2.4)	1.99 (2.5)	0.90 (1.4)	0.91 (1.4)	0.54 (1.4)
Configuration Differences within Type and Family	13.5 (1.3)	14.9 (1.3)	14.7 (1.3)	2.30 (1.8)	2.32 (1.8)	2.98 (1.8)	12.4 (1.3)	13.6 (1.3)	13.5 (1.3)	43.8 (1.7)	7.97 (1.7)	3.05 (1.7)	15.3 (1.3)	12.9 (1.3)	12.7 (1.3)

[1] F-ratio results are significant (at the 5% level) when greater than the value in parentheses

EXHIBIT D-16: NORMALIZED SUM OF MANN-WHITNEY TEST STATISTIC TO COMPARE TYPE A TO TYPE B VEHICLE EMISSIONS

	Domestic				Foreign	All
	Chrysler[1]	Ford[1]	GM	All		
HC	.97	-2.60	1.43	-.07	-.57	-.26
CO	-.13	-.95	.57	-.19	.39	.05
NO_x	.53	-.56	-.11	-.10	-1.53	-.92

EXHIBIT D-17: KOLMOGOROV-SMIRNOFF TEST OF THE SAMPLE CUMULATIVE DISTRIBUTION

	HC	CO	NO_x	.05 Critical Value
Catalyst	.09	.10	.15	.19
Non-Catalyst	.27	.23	.29	.40
Both	.09	.11	.13	.17

[1]The numbers of samples in these categories fall slightly below the necessary minimum to consider the distribution of the statistic approximately normal.

EXHIBIT D-18: 95 PERCENT CONFIDENCE INTERVAL ON THE STANDARD DEVIATION OF TYPE B VEHICLES DIVIDED BY THE STANDARD DEVIATION OF TYPE A VEHICLES

Domestic Manufactured Vehicles With Catalysts

Engine Family	Number Type "A" Vehicles	Number Type "B" Vehicles	HC		CO		NO_x	
			Lower Point	Upper Point	Lower Point	Upper Point	Lower Point	Upper Point
F7- 2	2	3	0.04	7.13	0.02	3.58	0.03	6.07
F7-14	3	5	0.04	0.77	0.08	1.57	0.09	1.73
F7-15	2	5	0.22	22.53	0.01	1.44	0.74	77.65
F7-16	2	2	0.03	16.66	0.11	74.58	0.08	54.75
F7-20	2	2	0.01	9.79	0.00	1.30	0.07	47.03
G7- 1	2	4	0.01	1.25	0.02	2.69	0.06	6.80
G7- 6	2	2	0.05	31.35	0.04	28.17	0.03	18.34
G7- 7	2	2	0.02	9.93	0.05	34.43	0.01	7.38
G7-10	3	4	0.21	5.15	0.09	2.26	0.08	2.02
G7-13	2	3	0.04	7.54	0.02	4.22	0.01	0.89
G7-15	2	4	0.01	1.47	0.29	36.02	0.03	3.87
G7-18	2	3	0.06	10.40	0.11	19.11	0.02	3.89
G7-19	2	4	0.03	3.96	0.01	1.09	0.04	4.42
G7-26	2	4	0.05	6.33	0.02	2.08	0.08	9.41
Foreign Manufactured Vehicles With Catalysts								
D7- 4	2	2	0.02	15.89	0.23	150.62	0.03	17.81
I7- 4	2	4	0.03	4.25	0.00	0.44	0.59	72.87
V7- 1	2	2	0.02	12.91	0.01	3.69	0.01	5.03
V7- 2	2	2	0.22	142.03	0.32	213.01	0.02	10.24
Foreign Manufactured Vehicles Without Catalysts								
B7- 3	2	2	0.01	7.04	0.01	3.83	0.07	46.80
H7- 2	2	3	0.15	26.80	0.15	25.70	0.06	9.83
I7- 3	2	2	1.30	855.66	0.02	13.64	0.03	20.66
M7- 5	2	2	0.57	372.54	0.01	8.26	0.02	10.83

EXHIBIT D-19: VEHICLE EMISSION DATA USED IN ANALYSIS OF RUNNING CHANGES

Vehicle ID	Change No.	Type	HC	CO	NOX
C6- 1-3	0	EDV	0.26600	2.43000	1.14000
C6- 1-3	0	RC	0.37000	2.68000	1.22000
C6- 1-3	0	RC	0.33200	1.93000	1.25000
C6- 2-1	0	EDV	0.21100	1.89000	1.49000
C6- 2-1	0	RC	0.27300	3.67000	1.60000
C6- 2-1	0	RC	0.21400	3.16000	1.29000
C6- 4-5	0	EDV	0.35400	1.47000	1.30000
C6- 4-5	0	RC	0.35400	1.78000	1.21000
C6- 6-4	0	EDV	0.27600	5.47000	1.60000
C6- 6-4	0	RC	0.32000	4.38000	1.75000
C6- 6-4	0	RC	0.32000	4.78000	1.59000
C6- 9-3	0	EDV	0.43700	3.60000	2.00000
C6- 9-3	0	RC	0.57600	4.11000	2.30000
C6- 9-3	0	RC	0.47000	3.32000	1.97000
C6-11-2	0	EDV	1.04000	11.20000	1.92000
C6-11-2	0	RC	0.46100	2.79000	2.41000
C6-12-4	0	EDV	0.63200	5.14000	1.89000
C6-12-4	1	RC	0.85700	2.56000	2.84000
C6-12-5	0	EDV	0.93600	9.87000	2.86000
C6-12-5	2	RC	1.38000	11.00000	2.99000
C6-12-5	2	RC	0.83500	9.18000	3.44000
C7- 5-5	0	EDV	0.31000	3.20000	1.07000
C7- 5-5	1	RC	0.20000	2.80000	1.08000
F6- 6-1	0	EDV	0.46400	5.68000	2.14000
F6- 6-1	0	RC	0.41400	2.75000	2.17000
F6- 6-1	0	RC	0.43600	7.17000	1.45000
F6- 6-3	0	EDV	0.52200	3.75000	2.26000
F6- 6-3	1	RC	0.73000	8.23000	1.92000
F6- 6-7	0	EDV	0.75500	3.18000	2.55000
F6- 6-7	0	RC	0.92700	4.31000	2.38000
F6- 6-7	0	RC	0.91400	8.11000	1.95000
F6- 6-8	0	EDV	0.71900	1.96000	1.96000
F6- 6-8	0	RC	0.80300	3.21000	2.26000
F6- 8-4	0	EDV	0.60000	4.58000	1.29000
F6- 8-4	0	RC	0.66400	5.87000	2.09000
F6- 8-4	0	RC	0.50400	4.28000	1.77000

EXHIBIT D-19: VEHICLE EMISSION DATA USED IN ANALYSIS OF RUNNING CHANGES

(Continued)

Vehicle ID	Change No.	Type	HC	CO	NOX
F6- 8-5	0	EDV	0.36300	1.50000	2.03000
F6- 8-5	0	RC	0.61500	2.26000	2.23000
F7- 1-1	0	EDV	0.25000	3.10000	0.76000
F7- 1-1	1	RC	0.27000	3.90000	0.72000
F7- 2-1	0	EDV	0.56000	14.80000	0.85000
F7- 2-1	1	RC	0.54000	13.00000	0.99000
F7- 2-2	0	EDV	0.74000	4.90000	1.78000
F7- 2-2	1	RC	0.55000	3.70000	1.57000
F7- 2-2	1	RC	0.63000	3.80000	1.77000
F7- 2-4	0	EDV	0.78000	5.50000	1.56000
F7- 2-4	1	RC	0.63000	4.10000	1.09000
F7- 2-4	2	RC	0.76000	4.90000	1.34000
F7- 2-4	2	RC	0.67000	5.00000	1.07000
F7- 4-1	0	EDV	0.74000	8.00000	1.47000
F7- 4-1	2	RC	0.55000	6.40000	0.83000
F7- 6-1	0	EDV	0.56000	2.90000	1.56000
F7- 6-1	2	RC	0.61000	2.50000	1.92000
F7- 6-2	0	EDV	0.64000	3.60000	1.79000
F7- 6-2	1	RC	0.61000	2.90000	1.88000
F7- 6-3	0	EDV	0.92000	5.60000	1.95000
F7- 6-3	1	RC	0.94000	4.60000	2.05000
F7- 7-1	0	EDV	0.28000	0.80000	0.96000
F7- 7-1	0	RC	0.28000	0.60000	0.94000
F7- 8-2	0	EDV	0.58000	3.10000	1.82000
F7- 8-2	1	RC	0.52000	2.30000	2.01000
F7- 8-3	0	EDV	0.60000	8.40000	1.56000
F7- 8-3	2	RC	0.47000	4.90000	1.68000
F7- 8-3	3	RC	0.43000	4.70000	1.88000
F7- 9-2	0	EDV	0.62000	5.30000	1.60000
F7- 9-2	1	RC	0.67000	5.70000	1.50000
F7-11-1	0	EDV	0.67000	8.60000	2.03000
F7-11-1	1	RC	0.68000	6.10000	1.70000
F7-11-1	1	RC	0.72000	6.60000	1.63000

EXHIBIT D-19: VEHICLE EMISSION DATA USED IN ANALYSIS OF RUNNING CHANGES

(Continued)

Vehicle ID	Change No.	Type	HC	CO	NOX
F7-12-1	0	EDV	0.88000	14.80000	1.16000
F7-12-1	2	RC	0.89000	12.30000	1.21000
F7-12-1	2	RC	0.72000	8.70000	1.36000
F7-12-1	3	RC	0.78000	9.00000	1.56000
F7-12-1	4	RC	1.00000	17.70000	1.03000
F7-12-1	4	RC	0.79000	12.80000	1.13000
F7-14-1	0	EDV	0.55000	7.30000	1.48000
F7-14-1	1	RC	0.56000	10.00000	1.79000
F7-14-1	1	RC	0.60000	9.10000	1.52000
F7-14-3	0	EDV	0.43000	5.00000	1.20000
F7-14-3	0	RC	0.53000	5.20000	1.46000
F7-14-3	0	RC	0.40000	2.30000	1.25000
F7-14-4	0	EDV	0.48000	6.70000	1.23000
F7-14-4	0	RC	0.34000	5.70000	1.30000
F7-14-6	0	EDV	0.41000	4.50000	1.53000
F7-14-6	1	RC	0.27000	1.40000	1.45000
F7-14-8	0	EDV	0.51000	8.10000	1.37000
F7-14-8	1	RC	0.56000	5.90000	1.50000
F7-16-3	0	EDV	0.67000	13.40000	1.52000
F7-16-3	0	RC	0.63000	8.70000	1.88000
F7-20-1	0	EDV	0.64000	7.00000	1.07000
F7-20-1	1	RC	0.41000	7.50000	0.95000
F7-20-2	0	EDV	0.55000	8.40000	1.32000
F7-20-2	1	RC	0.44000	9.90000	1.33000
F7-20-2	2	RC	0.33000	7.10000	1.37000
F7-20-2	9	RC	0.29000	2.60000	1.40000
F7-20-4	0	EDV	0.57000	6.50000	1.64000
F7-20-4	1	RC	0.57000	7.40000	1.51000
F7-20-4	2	RC	0.51000	6.30000	1.74000
G6- 1-4	0	EDV	1.02000	11.80000	2.44000
G6- 1-4	0	RC	1.45000	9.07000	2.26000
G6- 3-1	0	EDV	0.46500	7.28000	2.38000
G6- 3-1	0	RC	0.37800	4.88000	1.98000
G6- 3-1	0	RC	0.36200	1.74000	2.62000
G6- 4-1	0	EDV	0.25400	1.71000	2.72000
G6- 4-1	0	RC	0.37700	2.12000	2.33000
G6- 4-1	0	RC	0.47400	4.96000	2.55000
G6- 4-1	0	RC	0.31700	2.51000	2.39000

EXHIBIT D-19: VEHICLE EMISSION DATA USED IN ANALYSIS OF RUNNING CHANGES

(Continued)

Vehicle ID	Change No.	Type	HC	CO	NOX
G6- 4-3	0	EDV	0.74800	2.54000	1.94000
G6- 4-3	0	RC	0.41100	1.92000	2.34000
G6-13-1	0	EDV	0.53200	2.60000	1.42000
G6-13-1	0	RC	0.46900	0.97000	1.35000
G6-13-2	0	EDV	0.43300	1.69000	1.20000
G6-13-2	0	RC	0.40100	1.70000	1.29000
G6-15-2	0	EDV	0.45200	3.84000	1.91000
G6-15-2	0	RC	0.41600	3.47000	1.42000
G6-26-3	0	EDV	0.50800	7.26000	1.58000
G6-26-3	0	RC	0.57200	6.61000	2.04000
G6-37-1	0	EDV	0.55100	7.36000	2.16400
G6-37-1	0	RC	1.41200	9.00000	2.37200
G6-37-1	0	RC	0.84700	8.84000	2.39400
G6-37-1	0	RC	0.85400	8.91000	2.18300
G6-40-2	0	EDV	0.40600	5.74000	1.34000
G6-40-2	0	RC	0.46300	5.13000	1.33900
G6-40-2	0	RC	0.45700	6.04000	1.24800
G6-43-1	0	EDV	0.35000	3.70000	1.76000
G6-43-1	2	RC	0.46000	7.10000	1.93000
G6-43-1	2	RC	0.57000	10.00000	1.99000
G6-43-1	3	RC	0.47000	7.40000	1.77000
G6-43-1	3	RC	0.35000	5.70000	1.79000
G7- 8-4	0	EDV	0.62000	5.40000	1.47000
G7- 8-4	1	RC	0.76000	6.40000	1.45000
G7- 8-4	1	RC	0.71000	5.50000	1.77000
G7-12-1	0	EDV	0.29000	3.50000	1.66000
G7-12-1	1	RC	0.25000	2.50000	1.30000
G7-12-2	0	EDV	0.42000	4.50000	1.25000
G7-12-2	1	RC	0.38000	4.60000	0.93000
G7-12-2	1	RC	0.34000	4.60000	1.02000
G7-12-2	2	RC	0.24000	2.70000	0.98000
G7-14-1	0	EDV	0.53000	8.20000	2.02000
G7-14-1	1	RC	0.53000	8.00000	1.87000
G7-14-5	0	EDV	0.48000	4.60000	1.56000
G7-14-5	1	RC	0.62000	5.40000	1.43000

EXHIBIT D-19: VEHICLE EMISSION DATA USED IN ANALYSIS OF RUNNING CHANGES

(Concluded)

Vehicle ID	Change No.	Type	HC	CO	NOX
G7-15-3	0	EDV	0.34000	4.40000	1.56000
G7-15-3	1	RC	0.28000	2.60000	1.56000
G7-15-3	1	RC	0.30000	2.60000	1.42000
G7-15-6	0	EDV	0.35000	8.90000	1.35000
G7-15-6	2	RC	0.34000	6.50000	1.67000
G7-15-6	2	RC	0.34000	5.70000	1.69000
G7-15-6	2	RC	0.36000	5.90000	1.68000
G7-15-6	2	RC	0.38000	8.30000	1.38000
G7-16-5	0	EDV	0.50000	4.30000	1.67000
G7-16-5	1	RC	0.54000	5.70000	1.39000
G7-17-4	0	EDV	0.64000	5.10000	1.80000
G7-17-4	2	RC	0.45000	2.00000	1.45000
G7-18-1	0	EDV	0.48000	9.90000	1.77000
G7-18-1	1	RC	0.59000	12.90000	1.70000
G7-18-1	1	RC	0.55000	10.40000	1.92000
G7-18-3	2	EDV	0.38000	4.90000	1.44000
G7-18-3	2	RC	0.62000	8.90000	1.51000
G7-18-3	3	RC	0.59000	9.30000	1.44000
G7-19-1	0	EDV	0.36000	4.50000	0.87000
G7-19-1	1	RC	0.37000	5.20000	0.98000
G7-21-3	0	EDV	0.41000	9.90000	1.42000
G7-21-3	1	RC	0.40000	3.60000	1.81000
G7-25-2	0	EDV	0.29000	4.80000	1.69000
G7-25-2	1	RC	0.23000	5.30000	1.09000
G7-25-3	0	EDV	0.24000	3.50000	1.42000
G7-25-3	1	RC	0.25000	2.50000	1.06000
G7-26-1	0	EDV	0.38000	3.40000	1.58000
G7-26-1	1	RC	0.40000	4.80000	1.78000
G7-26-1	2	RC	0.39000	1.50000	1.82000
G7-26-1	4	RC	0.42000	4.40000	1.58000
G7-26-5	0	EDV	0.45000	5.20000	2.00000
G7-26-5	1	RC	0.46000	3.90000	2.12000
G7-26-5	1	RC	0.49000	6.70000	2.16000

APPENDIX E

ANALYSIS OF ALTERNATIVE TESTING STRATEGIES

This appendix discusses the application of the effectiveness methodology described in appendix F to alternative procedures for EPA's conduct of the certification program. Four general types of strategies were analyzed using this methodology. Following a summary description of the approach and results of this analysis in section E.1, the analysis of each of these four areas is described in turn:

(1) Application of the methodology to EPA's current procedures is described in section E.2.

(2) Analysis of alternative criteria for deciding whether a single emission data vehicle (EDV) exceeds the standards is considered in section E.3.

(3) Analysis of sequential testing strategies (in which the number of EDV's to be tested in an engine family depends on the results of tests on a portion of the family) is described in section E.4.

(4) Consideration of the potential effectiveness of modified uses of engineering judgment in testing decisions is discussed in section E.5.

E.1 Approach and Summary

This section summarizes the application of the effectiveness methodology to the evaluation of the types of strategies listed above. The effectiveness measures computed are defined and discussed in section E.1.1. The basic assumptions and data employed in the analysis are included in section E.1.2. Finally, section E.1.3 presents a summary of the results of the analysis which is described in greater detail in the remainder of this appendix.

E.1.1 Effectiveness Measures Used

For each strategy evaluated by the effectiveness methodology, several measures of the effectiveness and risk of the strategy were computed. These included averages of the following probabilities:

(1) the probability an EDV is failed by the certification process;

(2) the probability an EDV whose true emission rates exceed the standards is failed by the process;[1] and

(3) the probability an EDV whose true emission rates are within the standards is failed by the process.[2]

To obtain a more direct measure of the effectiveness of a given strategy, an attempt was also made to predict differences in pollution emitted by vehicles certified under various strategies. In particular, the decrease from current levels in lifetime emissions of all vehicles certified in a given model year was computed for each strategy analyzed.

In addition to the above effectiveness and risk measures, the cost impacts of the alternative strategies were evaluated. For each strategy,

[1]One minus this probability is referred to elsewhere in this report as the probability of erroneously passing a vehicle.

[2]This is referred to elsewhere in this report as the probability of erroneously failing a vehicle.

changes in EPA testing requirements from those of current procedures were estimated, and the effects on EPA personnel requirements were explored.

E.1.2 Assumptions and Data Used

This section provides a brief summary of the assumptions and data used in this analysis. Additional details appear in appendix F.

The effectiveness analysis was conducted using certification data for 1977 model year vehicles. The 1977 emission standards of 1.5 grams per mile for HC, 15 grams per mile for CO, and 2.0 grams per mile for NO_x were therefore assumed to be in effect.[1] While most of the analysis was conducted on VRI's data base for domestic vehicles with catalysts, some analysis of the major types of strategies investigated was also performed on VRI's foreign non-catalyst data base to assure that recommendations resulting from the analysis would be generally applicable. Unless otherwise specified, results presented in this appendix are those associated with the domestic data base. Actual family means from this data base for each pollutant (including deterioration effects) were used to compute effectiveness results for an empirical distribution of family means. Values of these means before deterioration, and the corresponding deterioration factors, are presented in exhibit E-1 for both the domestic and foreign data bases. The data base was used to develop estimates of design-to-design differences within a family. The pollutant level for a given design within a family was assumed to be a normally-distributed random variable with mean equal to the family mean and standard deviation as shown in exhibit E-2. The levels for the three pollutants were assumed to be uncorrelated.

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[1] In actual computations, standards of 1.55, 15.5, and 2.05 were used to allow for the effects of EPA's round-off procedures.

A portion of the analysis alternatively represented the pollutant level of a vehicle selected at random from the entire domestic fleet as a random sample from a mixture of two normal distributions, where each distribution was weighted by a factor of 0.5. The means (θ_1 and θ_2) and standard deviations (γ_1 and γ_2) of these distributions for each of the three pollutants are presented in exhibit E-3. These parameter values were developed from the data of exhibit E-1, as described in appendix F.

The results of a test on a single vehicle were assumed to be normally distributed with means equal to the actual pollution levels for that design and standard deviations as shown in exhibit E-2. Pollutant levels were again assumed to be uncorrelated.

E.1.3 Summary of Results

Exhibit E-3 summarizes the results of the cost and effectiveness analysis of representative examples of the testing strategies considered. These examples include the following:

(1) EPA's current strategy;

(2) EPA's current strategy except that, when a manufacturer requests a retest, the results of the two tests are averaged to determine whether the vehicle is passed.

(3) EPA's current strategy except that retests are not allowed (i.e., a one-test strategy);

(4) a strategy in which every vehicle is tested twice and the results of the two tests are averaged (a two-test strategy);

(5) a sequential strategy in which considerable evidence is required

before a decision is made whether to test the remaining EDVs in the family[1] (a conservative sequential strategy);

(6) a sequential strategy based on less evidence per family[1] (a non-conservative sequential strategy);

(7) a strategy in which engineering judgment is used to identify high-emitting families, which are then tested more extensively than other families; and

(8) a strategy in which engineering judgment and a sequential testing strategy are used in conjunction with one another to identify high-emitting families.[2]

The table presents results in terms of the effectiveness and cost measures described earlier. The following sections develop in more detail the material summarized in the table.

E.2 Current Procedure Effectiveness

Use of the effectiveness methodology to analyze EPA's current certification procedures provides both a check of the methodology and a set of "baseline" effectiveness values against which to judge alternative strategies. A summary of the results for this strategy was presented previously in exhibit E-4. A frequency distribution of failure probabilities by engine family is shown in exhibit E-5. More than 90 percent of all failed vehicles are concentrated in 50 percent of the families .

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[1]See section E.4 for detailed specifications of this strategy.

[2]See section E.5 for detailed specifications of this strategy.

It is of interest to note that the overall percent of EDVs predicted by the methodology to be failed is 9.8 percent, whereas the actual percent failed from these families was 8.3 percent. The effectiveness computations thus produce a reasonably accurate estimate of total failure in the fleet.[1] In addition, the estimate generated from the analysis of the expected number of tests required per EDV tested is very close to that used by EPA in its planning. Using EPA's assumption of a test void rate of .175, and assuming two EDVs are submitted by the manufacturer after modifications associated with a failed EDV, the failure rates predicted by the methodology result in an average of 1.64 tests conducted per EDV tested. EPA's estimate used for internal planning [EPA, undated] is 1.69 tests per EDV.

It is assumed that the effect on total emissions of EPA's failure of vehicles is that the vehicles are redesigned so that their emissions allow them to be passed. Under this assumption, the current certification process has a direct benefit of reducing the emissions of the average vehicle by approximately 0.4 percent for HC, 3.0 percent for CO, and 1.4 percent for NO_x (e.g., the NO_x saving equals 9.8 percent times the average improvement of NO_x emissions of failed vehicles of approximately 14.3 percent). This benefit is as small as it is because most vehicles (approximately 87 percent,[2] according to the analysis) submitted for certification have already been designed to meet the standards. Furthermore, even those EDVs failed by the certification process doe not generally

[1]Application of the methodology to the foreign families in VRI's data base resulted in a prediction that 5 percent of the EDVs would be failed, compared to slightly over 1 percent which actually were failed. Considering the small sample size in this case, the predicted result is still reasonably close to the true failure rate.

[2]This estimate includes an unknown error caused by the fact that the methodology assumes that deterioration factors are predicted without error by EPA.

exceed the standards by much. The average excess over the standard for such vehicles is approximately 0.5 percent of the standard for HC, 3.4 percent for CO, and 4.5 percent for NO_x. Failures are more than 90 percent due to excessive CO and NO_x emissions, so the typical failed vehicle can be expected to have its true emissions about 8 percent above the standard on either CO or NO_x.

A change in the certification process might be expected to have an effect on these true emission rates resulting from manufacturer response to the new procedures. To evaluate the impact of such a change, the effectiveness methodology was applied to a fleet of vehicles whose average emissions for each pollutant were 10 percent lower than the emissions of the empirical fleet. The result was that the failure rate dropped by approximately 8 percentage points. A family-by-family study of these results led to the conclusion that this change in the failure rate could be achieved by reducing the emissions of only half of the families), producing an overall decrease in emissions of about 7.5 percent. On this basis, one can predict that a one percent increase (or decrease) in emissions would result in approximately a one percent increase (or decrease) in the failure rate. This result can be used as an approximate representation of the extent to which a manufacturer would have to change the emissions of his fleet in order to maintain an acceptable over-all failure rate as EPA's certification procedures changed.

E.3 Alternative Compliance Criteria

EPA's current criterion for passing of an EDV by the certification process is that the vehicle's measured emissions must be below the standard for each pollutant (after adjustment for projected deterioration) on at least one of a possible two tests. An analysis was conducted of alternative criteria to this one, emphasizing differences in two areas:

(1) the possibility of averaging the results of multiple tests on a single vehicle, and

(2) the possibility of changing the number of tests conducted on each vehicle.

Three strategies were analyzed to gain insights into these two areas:

(1) EPA's current strategy except that the results of any retests are averaged with the results of the first valid test on the vehicle,

(2) a strategy in which one test is conducted on every EDV (and retests are not allowed), and

(3) a strategy in which every vehicle is tested twice and the results of the two tests are averaged.

The results for each of these strategies were summarized in exhibit E-4. The savings in emissions tests shown in the exhibit (for these and other strategies) were computed from the previously-stated assumptions that the test void rate is .175 and that a failure results in the later resubmission and testing of two modified EDVs. The totals were based on projected numbers of EDVs for the 1978 model year given in [EPA, undated].

E.4 Sequential Testing Strategies

A sequential testing strategy can be defined as follows:

In each engine family, test n EDVs. If the emission level of pollutant i (i = 1, 2, 3) for at least k of the n vehicles ($k \leq n$)

is less than a threshold t_i for all i, certify the family without further testing. Otherwise, test all EDVs in the family. (The values of t_i will generally be somewhat below the standard for pollutant i.)

Results of application of the effectiveness methodology to several sequential testing strategies are summarized in exhibit E-6. The exhibit defines each strategy in terms of the parameters n, k, t_1, t_2, and t_3. Values of the thresholds were selected heuristically based on an analysis of the representation of the distribution of fleet emissions as a mixture of two normal distributions (see section E.1.2). Additional results for two representative examples of these five strategies were displayed in exhibit E-4, where the "conservative" sequential strategy corresponds to the case in which $n = 2$ and $k = 2$, while the "non-conservative" strategy corresponds to the case in which $n = k = 1$, $t_1 = .7$, $t_2 = .7$, and $t_3 = .75$. For both of these strategies, 57 percent of all families were tested completely (so that 43 percent of the families had only one or two vehicles tested).[1]

In addition to the sequential strategies discussed above, one sequential strategy was analyzed in conjunction with a certification policy of averaging test results whenever a manufacturer requests a retest. The particular sequential strategy used had $n = k = 1$, $t_1 = .6$, $t_2 = .6$, and $t_3 = .7$. The result was that 11 percent of all vehicles were failed, 3 percent of vehicles whose true emissions levels met the standards were erroneously failed, and 61 percent of vehicles whose true emissions exceeded the standards were failed. Approximately 380 tests would be saved annually by adoption of such a combined strategy.

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[1]Comparable results were obtained from application of a sequential strategy in which $n = k = 1$ to the foreign families in VRI's data base. In this case, 60 percent of all families were tested completely, and 90 percent of failures under the current strategy were tested under the sequential strategy (compared to 80 to almost 100 percent for the domestic fleet).

E.5 Strategies Involving Modified Use of Engineering Judgment

Some analysis was conducted to determine the potential effectiveness of the use of engineering judgment to identify high-emission families, which could then be tested more extensively than other families. To obtain an upper bound on this effectiveness, a case was analyzed under the assumption that EPA's certification engineers could identify the 50 percent of engine families having the highest average rejection probabilities. (Earlier analysis indicated that these families contain 91 percent of all vehicles rejected under EPA's current procedures.) If only vehicles in these families were tested, the average failure probability (for the entire fleet) would be .09, the probability of erroneously failing a vehicle would be less than .02, and the probability of failing a vehicle whose true emissions exceed the standards would be .58. These results are quite close to those for EPA's current procedures, and would be achieved with a 50 percent reduction in the number of EDVs tested.

Probably a more realistic representation of the capability of engineers to identify families with high failure rates is outlined in exhibit E-7. The exhibit hypothesizes a probability that each family in the domestic data base is selected as a function of that family's rank by average failure probability. Application of these probabilities resulted in selection of 70 percent of all families. The average probability that a vehicle in a selected family exceeds one or more standards is .16 (compared to .13 for the fleet as a whole). Results were presented in exhibit E-4 for the strategy in which all EDVs are tested in families selected by engineering judgment (with these probabilities), and no other EDVs are tested.

This same assumed capability to identify families with high emissions was combined with two previously-introduced sequential strategies in the following way:

> For families selected by engineering judgment (using the probabilities given in exhibit E-7), apply the sequential strategy in which $n = k = 2$. For all other families, use the sequential strategy in which $n = k = 1$, and $t_1 = .7$, $t_2 = .7$, and $t_3 = .75$.

Results for this case were also presented in exhibit E-4.

EXHIBIT E-1: FAMILY MEAN EMISSIONS AND DETERIORATION FACTORS USED IN EFFECTIVENESS ANALYSIS

		HC		CO		NOX	
Family ID	#EDVs	Mean	DF	Mean	DF	Mean	DF
C7- 1	5	0.388	1.412	3.180	1.000	1.223	1.000
C7- 2	5	0.254	1.276	3.337	1.186	0.950	1.199
C7- 3	2	0.215	1.524	2.800	1.105	1.370	1.000
C7- 4	3	0.180	1.824	4.117	1.286	1.200	1.088
C7- 5	5	0.216	1.259	3.090	1.354	1.063	1.015
C7- 7	5	1.134	1.216	5.990	1.685	1.644	1.000
C7- 8	4	0.230	1.000	3.733	1.420	1.771	1.000
C7- 9	6	0.244	1.512	2.325	1.649	1.914	1.000
C7-10	2	0.220	1.000	1.750	1.000	1.630	1.018
C7-11	5	0.297	1.590	3.430	1.000	2.038	1.000
C7-12	5	0.900	1.000	9.540	1.000	1.552	1.080
C7-13	6	0.901	1.000	8.467	1.000	1.870	1.021
C7-14	7	0.854	1.005	10.800	1.038	1.685	1.092
C7-15	6	0.661	1.099	10.817	1.000	1.618	1.095
C7-16	6	0.507	1.000	6.908	1.000	1.786	1.000
F7- 1	4	0.402	1.580	3.112	1.288	0.726	1.161
F7- 2	5	0.594	1.034	9.490	1.000	1.244	1.000
F7- 4	3	0.733	1.695	8.567	1.284	1.393	1.124
F7- 5	2	0.265	1.000	3.800	1.027	1.060	1.023
F7- 6	3	0.713	1.524	4.350	1.372	1.883	1.000
F7- 7	2	0.295	1.273	1.200	1.086	1.150	1.043
F7- 8	6	0.652	1.453	8.600	1.442	1.629	1.000
F7- 9	2	0.632	1.167	7.550	1.571	1.587	1.000
F7-10	3	0.240	1.212	2.150	1.305	1.237	1.000
F7-11	1	0.670	1.168	8.600	1.000	2.030	1.000
F7-12	3	0.743	1.316	9.467	1.000	1.503	1.107
F7-14	8	0.515	1.426	6.456	1.656	1.322	1.063
F7-15	7	0.419	1.182	7.714	1.000	1.714	1.000
F7-16	4	0.634	1.426	10.325	1.008	1.924	1.000
F7-17	3	0.633	1.799	9.917	1.000	1.535	1.000
F7-18	1	1.000	1.004	11.600	1.000	2.000	1.000
F7-19	3	0.393	1.162	5.033	1.091	1.280	1.000
F7-20	4	0.650	1.323	9.612	1.412	1.384	1.000
G7- 1	6	0.270	1.112	5.583	1.000	1.713	1.000
G7- 2	6	0.589	1.000	9.142	1.000	1.577	1.066
G7- 3	4	0.173	1.471	1.925	1.078	1.270	1.000
G7- 4	5	0.420	1.217	5.120	1.000	1.698	1.000
G7- 5	5	0.384	1.113	1.560	1.000	1.410	1.000
G7- 6	4	0.502	1.221	8.600	1.000	1.535	1.004
G7- 7	4	0.300	1.000	4.100	1.238	1.065	1.000
G7- 8	5	0.524	1.000	5.260	1.000	1.568	1.000
G7- 9	4	0.262	1.000	2.525	1.000	0.972	1.011
G7-10	7	0.434	1.306	6.779	1.000	1.516	1.008
G7-11	5	0.566	1.000	5.980	1.000	1.668	1.000
G7-12	2	0.348	1.301	4.000	1.124	1.445	1.129
G7-13	5	0.759	1.145	8.070	1.059	1.801	1.042
G7-14	6	0.532	1.161	6.792	1.024	1.873	1.000
G7-15	6	0.331	1.015	5.117	1.000	1.366	1.000

EXHIBIT E-1: FAMILY MEAN EMISSIONS AND DETERIORATION FACTORS USED IN EFFECTIVENESS ANALYSIS

(Concluded)

		HC		CO		NOX	
Family ID	#EDVs	Mean	DF	Mean	DF	Mean	DF
G7-16	5	0.673	1.908	7.780	1.018	1.648	1.017
G7-17	4	0.550	1.669	4.750	1.059	1.760	1.000
G7-18	5	0.614	1.853	7.540	1.440	1.298	1.028
G7-19	6	0.282	1.103	3.175	1.000	0.852	1.000
G7-20	2	0.560	1.649	10.250	1.174	1.235	1.076
G7-21	3	0.480	2.217	6.133	1.476	1.657	1.000
G7-22	2	0.600	1.000	7.050	1.316	1.560	1.000
G7-23	1	0.365	1.300	3.200	1.416	1.415	1.074
G7-24	4	0.699	1.118	11.150	1.001	1.731	1.052
G7-25	4	0.277	1.210	3.275	1.112	1.702	1.000
G7-26	6	0.414	1.374	3.867	1.593	1.829	1.000
B7- 1	2	0.220	1.000	6.975	1.000	1.047	1.000
B7- 2	2	1.065	1.000	8.550	1.000	1.400	1.000
B7- 3	4	0.320	1.000	8.850	1.000	1.275	1.000
D7- 2	4	1.245	1.050	9.650	1.000	1.360	1.000
D7- 5	3	1.312	1.164	10.567	1.156	1.620	1.000
D7- 7	2	1.155	1.157	7.550	1.210	1.385	1.000
D7- 9	2	1.230	1.011	6.000	1.000	1.555	1.002
H7- 1	2	0.695	1.000	9.650	1.000	1.525	1.000
H7- 2	5	0.260	1.000	3.060	1.000	1.226	1.000
H7- 3	5	0.911	1.000	5.040	1.000	1.583	1.000
I7- 1	2	0.867	1.089	8.675	1.061	1.467	1.000
I7- 3	4	0.699	1.204	10.962	1.000	1.324	1.000
M7- 3	2	0.565	1.000	10.150	1.000	1.550	1.118

EXHIBIT E-2: TEST-TO-TEST AND DESIGN-TO-DESIGN VARIABILITY ASSUMED IN EFFECTIVENESS ANALYSIS

Pollutant	Design Standard Deviation[1]		Test Standard Deviation[1]	
	Domestic (With Catalyst)	Foreign (Non-Catalyst)	Domestic (With Catalyst)	Foreign (Non-Catalyst)
HC	.20	.20	.13	.13
CO	.30	.15	.14	.07
NO_x	.16	.10	.09	.04

[1]Expressed as a fraction of the family mean for the corresponding pollutant.

EXHIBIT E-3: PARAMETERS OF DISTRIBUTION OF VEHICLE EMISSION LEVELS

Parameter / Pollutant	θ_1	γ_1	θ_2	γ_2
HC	.25	.15	.60	.20
CO	.25	.20	.60	.25
NO_x	.65	.20	.85	.15

[1]Each value is expressed as a fraction of the corresponding standard.

EXHIBIT E-4: SUMMARY OF RESULTS OF EFFECTIVENESS ANALYSIS

STRATEGY	AVERAGE PROBABILITIES			SAVINGS IN POLLUTION[1] (LIFE-TIME TONS PER VEHICLE IN CERTIFIED FAMILIES)			REDUCTION IN EDVs TESTED[1] (VEHICLES PER YEAR)	SAVINGS IN EMISSIONS TESTS[1] (TEST PROCEDURES PER YEAR)
	FAILURE	FAILURE GIVEN WITHIN STANDARDS	FAILURE GIVEN EXCEEDS STANDARDS	HC	CO	NO_x		
1. Current	0.10	0.02	0.62	0.0	0.0	0.0	0	0
2. Current with averaging on failure	0.14	0.05	0.85	.00016	.0121	.00105	0	-94
3. One test always	0.16	0.07	0.77	.00013	.0126	.00094	0	84
4. Two tests always	0.15	0.05	0.85	.00016	.0121	.00105	0	-1332
5. Conservative sequential testing	0.09	0.02	0.62	0.0	0.0	0.0	125	158
6. Non-conservative sequential testing	0.08	0.02	0.46	-.0006	-.0056	-.00058	265	392

[1]Savings are in comparison with current strategy. A negative value indicates an increase over the current strategy. Values assume no change in manufacturer behavior in response to new strategy.

EXHIBIT E-4: SUMMARY OF RESULTS OF EFFECTIVENESS ANALYSIS

(Concluded)

STRATEGY	AVERAGE PROBABILITIES			SAVINGS IN POLLUTION[1] (LIFETIME TONS PER VEHICLE IN CERTIFIED FAMILIES)			REDUCTION IN EDVs TESTED[1] (VEHICLES PER YEAR)	SAVINGS IN EMISSIONS TESTS[1] (TEST PROCEDURES PER YEAR)
	FAILURE	FAILURE GIVEN WITHIN STANDARDS	FAILURE GIVEN EXCEEDS STANDARDS	HC	CO	NO_x		
7. Judgmental family selection[2]	0.08	0.02	0.50	-.00006	-.0046	-.00047	281	418
8. Judgmental family selection and sequential testing[2]	0.09	0.02	0.59	-.00002	-.0015	-.00014	167	228

[1]Savings are in comparison with current strategy. A negative value indicates an increase over the current strategy. Values assume no change in manufacturer behavior in response to new strategy.

[2]Results for this case are hypothetical in that they are based on an assumed capability to identify high-emission families (see section E.5 for details).

EXHIBIT E-5: FREQUENCY DISTRIBUTION OF FAILURE PROBABILITIES BY ENGINE FAMILY FOR EPA'S CURRENT CERTIFICATION PROCEDURES

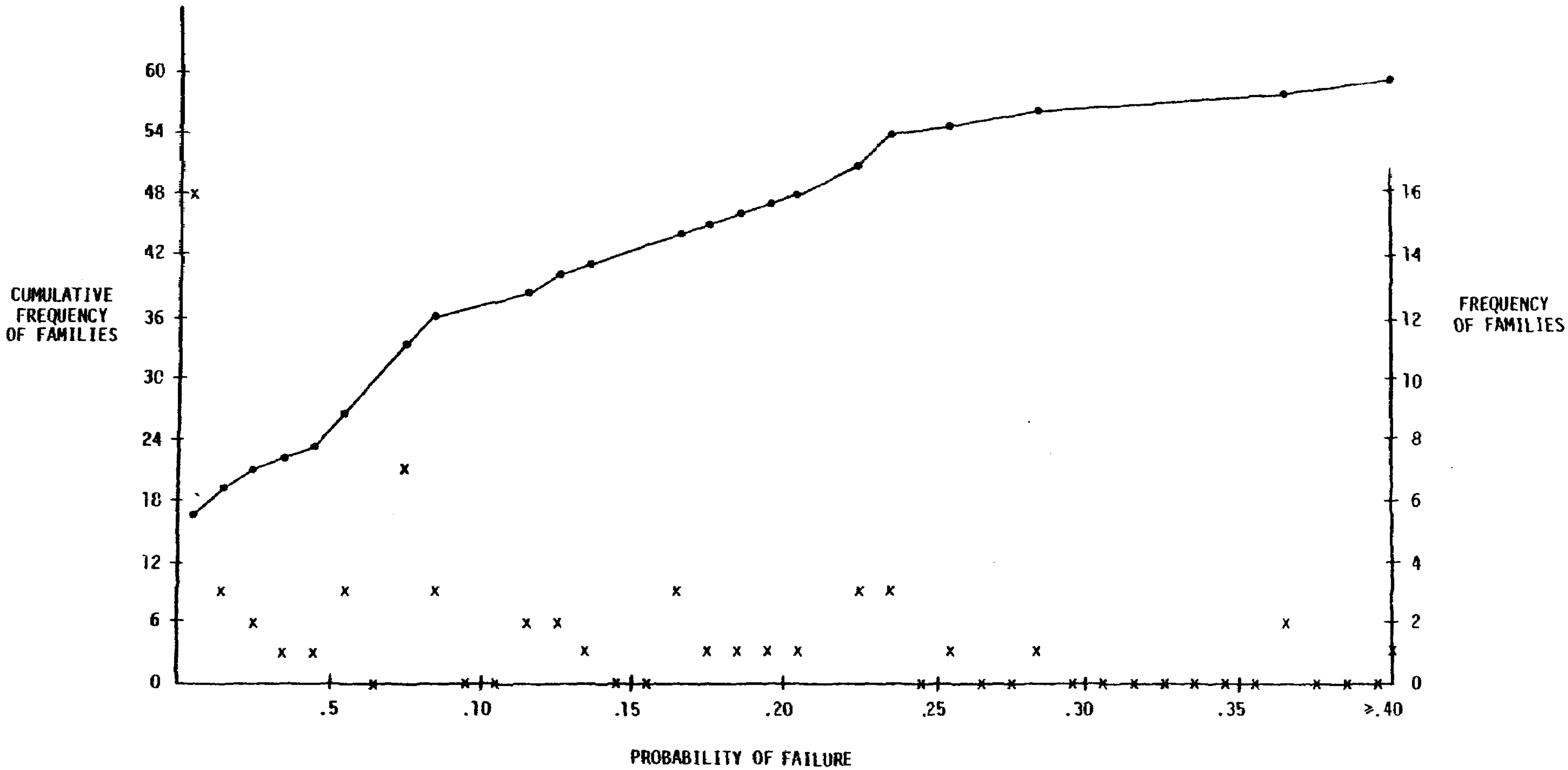

EXHIBIT E-6: RESULTS FOR SEVERAL SEQUENTIAL TESTING STRATEGIES

STRATEGY					RESULTS		
NUMBER OF VEHICLES TESTED (n)	NUMBER WHICH MUST BE WITHIN THRESHOLDS (k)	THRESHOLDS (FRACTION OF CORRESPONDING STANDARD)			AVERAGE PROBABILITY OF FAILURE	PROBABILITY OF FAILURE GIVEN WITHIN STANDARDS	PROBABILITY OF FAILURE GIVEN EXCEED STANDARDS
		HC (t_1)	CO (t_2)	NO_x (t_3)			
1	1	.7	.7	.75	0.08	0.02	0.46
1	1	.6	.6	.7	0.08	0.01	0.46
2	2	.6	.6	.7	0.09	0.02	0.62
3	2	.6	.6	.7	0.08	0.01	0.54
3	3	.6	.6	.7	0.10	0.02	0.62

EXHIBIT E-7: REPRESENTATION OF HYPOTHETICAL CAPABILITY TO IDENTIFY FAMILIES WITH HIGH FAILURE RATES

FAMILY RANK[1]	PROBABILITY FAMILY IS SELECTED
1, 2, ..., 12	.9
13, ..., 24	.8
25, ..., 36	.7
37, ..., 48	.6
49, ..., 59	.5

[1]Ranked in descending order of average failure probability.

APPENDIX F
METHODOLOGY FOR EFFECTIVENESS ASSESSMENT

This appendix describes a methodology used to assist in predicting the effectiveness of modifications to EPA's Light-Duty Vehicle certification process.[1] A set of probabilistic models has been developed to predict EPA's certification decisions associated with a fleet of vehicles submitted by manufacturers, and to compute the effectiveness of such decisions in terms of several effectiveness measures selected for the analysis. Data for the models were taken from EPA's records of emission test results and other records maintained by EPA.

The effectiveness methodology can be conceptually divided into four parts, as follows:

(1) A fleet representation predicts the probabilistic characteristics of the vehicles which will be submitted to EPA for certification.

(2) A representation of the vehicle selection process describes how EPA processes information submitted by manufacturers so as to select emission data vehicles for testing.

(3) A representation of the emissions testing and certification process predicts the outcome of EPA's testing process on the emission data vehicles within each engine family. Several representations of this process are required to represent different types of policies for certifying engine families based on emissions test results.

[1]The methodology excludes that part of the certification process dealing with EPA's procedures to predict emissions deterioration, since VRI's current study is not addressing deterioration estimation.

(4) An effectiveness analysis is performed to compute the values of selected effectiveness measures resulting from certification decisions.

Exhibit F-1 illustrates the inputs, outputs, and interactions of the four parts of the methodology. The following sections describe the details of each of the four parts in turn.[1]

F.1 The Manufacturers' Fleet

The fleet representation is used to predict characteristics of the vehicles submitted to EPA for certification. Historical certification data have been used to generate probabilistic descriptions of

(1) family mean emission levels for HC, CO, and NO_x, including the effects of deterioration, and

(2) configuration-to-configuration differences in emission levels within a family, given the family means.

The nature of these two types of descriptors is outlined in the following paragraphs.

For most uses of the effectiveness methodology, an empirical distribution of family means was used. The effectiveness computations were performed for each of a set of families having the same mean emission levels as the families in the VRI 1977 model year data base. In addition, for some sensitivity analyses sets of various hypothetical family means were also used in the computations.

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[1]Implementation of some of these models has involved certain numerical approximations which are not reflected in the text.

Design-to-design emission differences within an engine family are represented by three independent[1] normal distributions centered at the family mean for each pollutant. Estimates of the standard deviation of this distribution for each pollutant were generated from an analysis of variance on the data base. In each case, the standard deviation was assumed to be proportional to the family mean with coefficients of variation which were presented in appendix E.

A portion of the analysis has used an alternative representation of the true emissions of vehicles in the fleet. A heuristic fit was made to the overall distribution of vehicle emissions. The result was a mixture of two normal distributions, allowing the true emissions of pollutant i, μ_i, of a vehicle selected at random from the entire fleet to be represented as

$$\Pr[\mu_i \leq a] = .5P\left(\frac{a - \Theta_1}{\gamma_1}\right) + .5P\left(\frac{a - \Theta_2}{\gamma_2}\right)$$

where

P(a) = cumulative standard normal distribution

$$= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{a} e^{-t^2/2}\, dt ,$$

$\Theta_1 \Theta_2$ = empirically-determined means of the two normal distributions, and

$\gamma_1 \gamma_2$ = empirically-determined standard deviations of the two normal distributions.

[1]Actually, HC and CO emissions are positively correlated, but this correlation is sufficiently small that it may be neglected for these purposes. A description of an analysis of the correlation among pollutant levels within an engine family can be found in appendix D.

The parameters of this distribution were selected to give the same percent of vehicles above and below the standard for designs which are near the standard as does the full empirical distribution above. In addition, use of this distribution produces the same percent of vehicles failed by the certification process as does the full empirical distribution for each of three very different strategies to which it was applied. The parameter values actually used were presented in appendix E.

F.2 EPA's Prototype Vehicle Identification

The analysis of EPA's current vehicle identification scheme described in appendix D was used to characterize the vehicle identification process as represented in the effectiveness methodology. As a result, it is assumed in most of the effectiveness analyses that each emission data vehicle is a randomly selected configuration from the engine family to which it belongs.

F.3 EPA's Emissions Testing and Certification Process

Given a vehicle has been selected for testing, the representation of the emissions testing and certification process predicts probabilistic results of testing that vehicle and specifies a probability that the vehicle passes the certification process. The results of a single emissions test on a vehicle (after application of the appropriate deterioration factor[1]) are assumed to be three independent normally-distributed random variables (one for each pollutant) with means equal to the corresponding true emission levels for the configuration being tested. Development of estimates of the standard deviation for this

[1]Because the scope of this study was limited to the emissions measurement program, estimation of deterioration was assumed to be exact in this analysis. Thus, the effects of variability due to the deterioration estimation process are not reflected in the results of the analysis.

distribution was described in appendix B. The standard deviation for each pollutant is assumed to be proportional to the mean with coefficients of variation described in appendix B (and also presented in appendix E). The assumption of independence among pollutants was developed from an analysis of data presented by [Paulsell and Kruse, 1974].[1]

To express this distribution notationally, let

μ_i = *true emission level of pollutant i for the EDV being tested*,[2]

σ_i = test-to-test standard deviation for pollutant i, and

P(a) = cumulative standard normal distribution.

Then the probability that x_i, a vehicle's measured emissions for pollutant i after application of the appropriate deterioration factor, is less than or equal to a is given by

$$Pr[x_i \leq a] = P\left(\frac{a-\mu_i}{\sigma_i}\right).$$

---

[1] This was the most recent data available for which a sufficient number of tests had been conducted on a single vehicle to allow for an analysis of correlation among pollutants.

[2] Note that μ_i is itself assumed to be a random variable whose distribution was described in section F.1. The randomness of μ_i is treated numerically as described in section F.4.

Given the above characterization of the results of a single test, prediction of a decision as to whether a vehicle is in compliance with the Clean Air Act is a function of the emission standards and the specific policy by which EPA compares test results to these standards. Five types of policies have been investigated in this study:

(1) EPA's current policy, in which a vehicle passes the certification process only if the measured emission levels of all pollutants fall within the standard on at least one of two tests conducted on the vehicle;[1]

(2) a policy which allows only one test to be conducted;

(3) a policy by which every vehicle is tested twice and the results of the two tests are averaged;

(4) EPA's current policy except that, when the vehicle exceeds one or more standards on the first test, a retest is conducted and the results of the two tests are averaged; and

(5) policies involving sequential testing, in which a vehicle may be passed without testing if the results of testing one or more other vehicles in the same engine family fall within acceptable limits.[2]

Procedures to predict the probability a vehicle is failed by the certification process under each of the above types of policies are described in the following sections.

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[1]EPA's actual procedure allows the manufacturer to request a retest if the vehicle exceeds one or more standards on the first test. The representation of the procedure described here assumes the manufacturer always exercises this option.

[2]In this case, EPA's current policy is applied to those vehicles which are tested. One case was also run in which the policy of averaging results in case of a retest is applied to vehicles tested.

F.3.1 EPA's Current Policy

Under EPA's current policy, a vehicle fails the certification process if the measured levels of its three pollutants (including deterioration) are not all within the standard on at least one of two tests. Assuming that the results of the two tests are independent, the probability a vehicle is failed under this policy can be expressed in previously-introduced notation as

$$\Pr[F] = \left[1 - \prod_{i=1}^{3} P\left(\frac{s_i - \mu_i}{\sigma_i}\right)\right]^2 ,$$

where F is the event that the vehicle is failed and s_i is the emissions standard for pollutant i.

F.3.2 Single-Test Policy

A policy which does not allow the manufacturer to request a retest but which simply accepts the result of a single test (and rejects the vehicle if any pollutant exceeds the standard) results in the following simple expression for the probability the vehicle is failed.

$$\Pr[F] = 1 - \prod_{i=1}^{3} P\left(\frac{s_i - \mu_i}{\sigma_i}\right)$$

F.3.3 Two-Test Policy

A policy which requires every vehicle to be tested twice and then averages the results of the two tests also produces a simple expression for the probability the vehicle is failed. For a given pollutant i, the average result of two tests is normally distributed with mean equal to μ_i and standard deviation equal to $\frac{\sigma_i}{\sqrt{2}}$ Therefore, the probability a vehicle fails the certification process is simply

$$\Pr[F] = 1 - \prod_{i=1}^{3} P\left(\frac{\sqrt{2}(s_i - \mu_i)}{\sigma_i}\right)$$

F.3.4 Current Policy With Averaging on Failure

Consider a variant of EPA's current policy in which a failure of a single test results in a retest, but the results of this retest are averaged with those of the first test to produce the values which are compared with the standards. To derive the expression for the probability of failure for this situation, some additional notation is needed. Let

(x_1, x_2, x_3) = the result of the first test on the vehicle (a random vector consisting of the measured emission level for each of the three pollutants), and

(r_1, r_2, r_3) = the result of the second test (if it is conducted).

Note that, as before, x_i and r_i are independent, normally-distributed random variables each with mean μ_i and standard deviation σ_i. Define

$$y_i = \frac{x_i + r_i}{2} \quad ,$$

the average result of the first and second tests. Then y_i is normally-distributed with mean μ_i and standard deviation $\sigma_i/\sqrt{2}$. Further, the joint distribution of x_i and y_i is a bivariate normal whose correlation coefficient can be shown to be equal to $1/\sqrt{2}$ for any i.

The probability a vehicle is failed by the certification process can thus be expressed as a sum of products of normal and bivariate normal distribution functions. The exact expression is one minus the expression given in exhibit F-2 for the probability a vehicle is accepted. The exhibit uses the following notation (adopted from [Abramowitz and Stegun, 1970]):

$L(h,k,\rho)$ = standard bivariate normal distribution function

$$= \int_h^\infty \int_k^\infty g(b,c,\rho)\ db\,dc,$$

where

$$g(b,c,\rho) = \frac{1}{2\Pi\sqrt{1-\rho^2}} \exp - \frac{1}{2}\left(\frac{b^2-2\rho bc+c^2}{1-\rho^2}\right) .$$

The distribution functions in the exhibit are expressed in terms of the parameters u_i, v_i, and ρ, where

$$u_i = \frac{s_i-\mu_i}{\sigma_i} ,$$

$$v_i = \sqrt{2}\left(\frac{s_i-\mu_i}{\sigma_i}\right) ,$$

and

$$\rho = \text{correlation coefficient} = \frac{1}{\sqrt{2}} .$$

F.3.5 Policies Involving Sequential Testing

A particular sequential testing strategy can be characterized by the following parameters:

t_i = threshold for pollutant i, and

n = number of EDVs to which the thresholds are applied.

The strategy then can be expressed as follows. In each engine family, test n EDVs, where $n \leq N$, the total number of EDVs in the family. If the emission level of pollutant i for all n vehicles is less than t_i for all i, certify the family without further testing. Otherwise, test all EDVs in the family.[1] The following paragraphs develop an approximate form for computing $\overline{Pr[F]}$, the average probability a vehicle is failed by the certification process, in the special case in which n = 1. Similar approximations can be used for calculating $\overline{P[F]}$ for other classes of sequential strategies.

Assuming $t_i \leq s_i$ (i=1,2,3) in the case in which n = 1, the value of $\overline{Pr[F]}$ can be expressed as the sum of (1) the probability a given vehicle is selected as the first vehicle tested in the family and is rejected, plus (2) the probability another vehicle is selected as the first vehicle and exceeds one or more of the thresholds (so that the given vehicle must be tested) and the given vehicle is then tested and rejected. Assuming the first vehicle to be tested is selected uniformly randomly from among the N EDVs in the family, the probability the given vehicle is rejected is

[1]Strategies could also be devised for which testing of a family is stopped if tests on k of the n vehicles produce results less than t_i for some k less than n.

$$\Pr[F] = \frac{1}{N}\Pr[F] + \frac{N-1}{N}\Pr[\varepsilon]\Pr[F],$$

where ε is the event that the first tested vehicle in the family exceeds at least one of the thresholds t_i. The probability of the event ε is computed as:

$$\Pr[\varepsilon] = 1-\prod_{i=1}^{3} P\left(\frac{t_i-\mu_i}{\sigma_i}\right) ,$$

using earlier notation. The value of Pr[F] is computed as described in section F.3.1.

F.4 Effectiveness Computations

This section describes how the mathematical structures developed in the previous three sections are combined to compute the values of effectiveness measures under the various testing strategies examined. As discussed in appendix E, the methodology is used to compute various average failure probabilities for the EDVs submitted to EPA. The effectiveness methodology directly computes the following probabilities, which are then used to generate the failure probabilities presented in appendix E:

(1) the probability an EDV from a particular family is failed by the certification process,

(2) the probability the EDV's true emissions exceed the standard for at least one pollutant,

(3) the joint probability the vehicle is failed and exceeds one or more standards, and

(4) the joint probability the vehicle is failed and is within all standards.

In addition to these probabilities, estimates are made of the total lifetime emissions of vehicles certified under most of the strategies investigated. To develop these latter estimates it was necessary to adopt several assumptions:

(1) Emission rates and deterioration rates as measured by EPA provide a reasonable proxy for true in-use emissions of certified vehicles.

(2) The average life of a certified vehicles is 100,000 miles.

(3) The ultimate effect of a failure of an EDV is to cause the manufacturer to modify the vehicles in the portion of the engine family associated with the failure in such a way that the average emission of the pollutant on which the failure was based is reduced in these vehicles to the mean emission level of the family as a whole. These modified vehicles are then submitted and certified.

(4) The average fraction of an engine family modified as the result of a failed EDV is equal to 1/N, where N is the number of EDVs in the family.

(5) The manufacturer's projected sales for a family are an adequate approximation of the true sales realized by the family.

The first of these assumptions recognizes that many considerations will cause in-use emissions and deterioration to differ from emissions and deterioration predicted by the certification process, but asserts that changes in the predicted values resulting from a change in the certification process would be accompanied by a similar change in the in-use values. This is an assumption inherent in the certification process itself. The second assumption is generally accepted and has been used by EPA in other analyses. The third assumption is a simplified representation of the extremely complex events which follow the failure of an EDV. It is VRI's understanding that most failed vehicles are eventually modified to the extent that they can be certified, and that this simplified representation therefore reasonably reflects the ultimate impact of a failure. The fourth assumption is consistent with the earlier assumption that each EDV is randomly selected from its engine family. For any portion of the analysis which does not assume vehicles to be randomly selected, corresponding estimates of lifetime emissions have not been generated. Finally, the assumption concerning projected sales is consistent with information provided verbally to VRI by members of the EPA staff.

The following two sections describe, in turn, the computation of the above probabilities and the computation of projected emissions.

F.4.1 Computation of Probabilities

Recall that the true emission levels μ_i ($i=1,2,3$) for a given EDV are assumed to be normally-distributed random variables with means and standard deviations dependent on the family from which the vehicle was selected. To compute the probability a vehicle selected at random from a given family is failed by the certification process under a given testing strategy, the effectiveness methodology must use this distributional assumption to compute the expected value of Pr[F] for that strategy.[1] It does this via a numerical integration over all possible values of the μ_i of the product of Pr[F] and the joint probability density function of the μ_i. Similarly, the joint probability that the vehicle is failed and that its true emission levels are within the three standards is computed by means of the same numerical integration over values of the μ_i less than s_i. The difference between the values of these two integrations provides the joint probability that the vehicle is failed and exceeds one or more of the standards. Finally, the simple probability that the vehicle exceeds one or more of the standards is just the probability that one or more of the normally-distributed μ_i is greater than the corresponding s_i.

F.4.2 Computation of Projected Emissions

The total tons of pollutant i emitted by all vehicles in an engine family throughout their lives is given by

$$W_i = G_i C \bar{\nu} \qquad (i=1,2,3),$$

---

[1]And the expected value of Pr[ε] in the case of a sequential strategy.

where

G_i = average emissions in grams per mile of pollutant i by a vehicle in the family during its 100,000 mile life,

C = a proportionality constant to convert grams per mile to tons per 100,000 miles, and

ν = projected sales of vehicles in the family

Because deterioration is assumed to be a linear function of mileage, the value of G_i is given by the average emissions of the family at 50,000 miles. That is, it is equal to the mean emission level $E[\mu_i]$, adjusted to account for the reduced emissions of vehicles which have been modified as the result of a failed EDV. Thus, the value of G_i is approximately given by

$$G_i = E[\mu_i] - P[F]\ (E[\mu_i|F] - E[\mu_i]),$$

where $E[\mu_i|F]$, the conditional expectation of the true emission level μ_i given a failure, can be determined by a means of a numerical integration similar to those used to compute failure probabilities.

EXHIBIT F-1: STRUCTURE OF EFFECTIVENESS METHODOLOGY

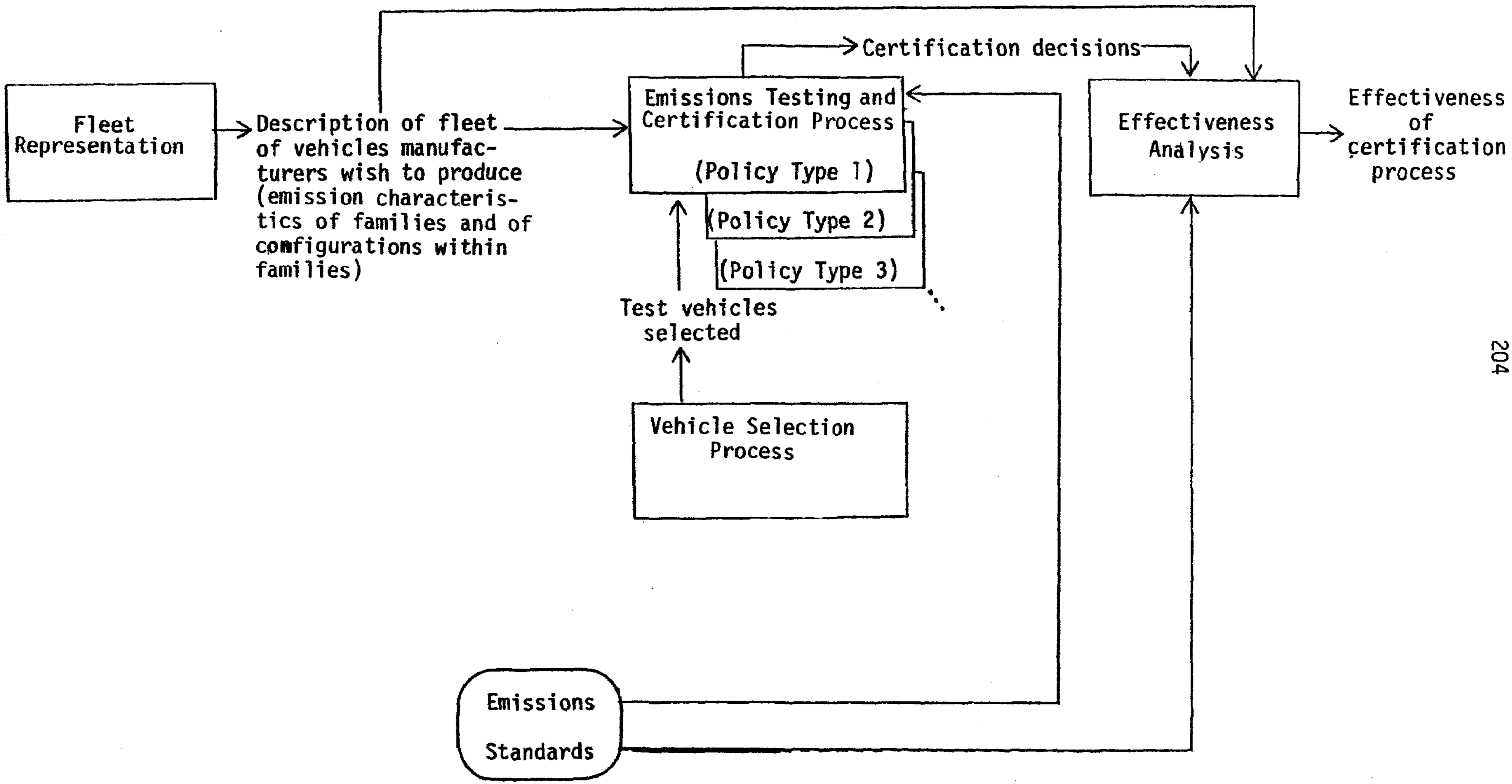

EXHIBIT F-2: EXPRESSION FOR THE PROBABILITY A VEHICLE DOES NOT FAIL CERTIFICATION UNDER A POLICY OF AVERAGING ON FAILURE OF THE FIRST TEST

TERMS	CONDITIONS
$P(u_1)P(u_2)P(u_3)$	(1) Pass first test
$+L(u_1,-v_1,-\rho)L(-u_2,-v_2,\rho)L(-u_3,-v_3,\rho)$	(2) Fails only pollutant 1 on first test
$+L(-u_1,-v_1,\rho)L(u_2,-v_2,-\rho)L(-u_3,-v_3,\rho)$	(3) Fails only pollutant 2 on first test
$+L(-u_1,-v_1,\rho)L(-u_2,-v_2,\rho)L(u_3,-v_3,-\rho)$	(4) Fails only pollutant 3 on first test
$+L(u_1,-v_1,-\rho)L(u_2,-v_2,-\rho)L(-u_3,-v_3,\rho)$	(5) Fails pollutants 1 and 2 on first test
$+L(u_1,-v_1,-\rho)L(-u_2,-v_2,\rho)L(u_3,-v_3,-\rho)$	(6) Fails pollutants 1 and 3 on first test
$+L(-u_1,-v_1,\rho)L(u_2,-v_2,-\rho)L(u_3,-v_3,-\rho)$	(7) Fails pollutants 2 and 3 on first test
$+L(u_1,-v_1,-\rho)L(u_2,-v_2,-\rho)L(u_3,-v_3,-\rho)$	(8) Fails all 3 pollutants on first test

Note: The above terms use the facts that

$$L(-h,-k,\rho) = \int_{-\infty}^{h}\int_{-\infty}^{k} g(b,c,\rho)\,db\,dc$$

and

$$L(h,-h,-\rho) = \int_{h}^{\infty}\int_{-\infty}^{k} g(b,c,\rho)\,db\,dc.$$

Note: In term (1), no second test is conducted; in terms (2)-(8), vehicle passes standard for every pollutant when the first and second tests are averaged.

APPENDIX G

DESCRIPTION OF EPA FUEL ECONOMY TESTING PROGRAM

One task of the present study was to develop an understanding of the relationships between the fuel economy and emissions certification programs. This task was necessary to insure that Emission Data Vehicle test strategies developed during the course of the present study would take into account the constraints imposed by fuel economy testing. The descriptions developed in this task are therefore intended to show the study team's understanding of the fuel economy process and its implications for emission vehicle testing. For this reason, the descriptions were submitted to the EPA Fuel Economy Unit for review to ascertain that this understanding is adequate.

The results of VRI's review of EPA's comments on the preliminary versions of this document are incorporated in this appendix. It contains a flowchart overview of the entire fuel economy process and detailed explanations of the steps involved in carrying it out. The appendix describes such items as vehicle classification and selection methods, interactions with the emissions certification program, calculation and use of the manufacturer's average fuel economy, the labeling program, etc.

In developing this understanding of the process, the study team interviewed members of the Fuel Economy Unit of the Light Duty Certification Branch. Since many of the policies for 1978 and subsequent years are still in a development stage, and not fully documented, their contribution was an essential component of the study team's review. In addition, a number of documents were collected and reviewed, including ones on the Energy Act [US General Accounting Office, 1974], [US Congress, Senate, Committee of Conference, 1975], and [US Congress, Senate, and House, 1975]; procedures published in the *Federal Register* [US Environmental Protection Agency, 1976b and 1976c]; EPA position papers [US Environmental Protection Agency, 1976f and 1976g]; *MASPC Advisory Circulars* [US Environmental Protection Agency, 1976d, 1976e, and 1976h]; and miscellaneous papers on lab policy and fuel economy factors [US Department of Transportation, and US Environmental Protection Agency, 1975]; and [US Environmental Protection Agency, 1975 and 1976a]. Pertinent factors in the present fuel economy process were derived from these documents and incorporated in the description in this appendix.

As a result of these activities the study group concluded that the fuel economy process does not place a severe constraint on Emission Data Vehicle test strategies, i.e., the primary focus of this study. Further, because of the large degree of freedom left to the Administrator in the statute and the primacy accorded the emissions testing process, it is clear that most changes to emissions certification procedures suggested here would have limited effect on the fuel economy program. For example, most changes in selection schemes for Emission Data Vehicles will have only a minor effect in numbers of separate vehicles necessary to be tested for fuel economy purposes.[1] In fact, the number of extra vehicles required for fuel economy purposes was approximately 12 for the 1977 model year. Any change in policies which mandated a large increase in fuel economy testing would alter

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[1]Changes in the selection scheme may influence EPA fuel economy testing when they eliminate EDVs which are the sole representatives of base levels (defined later) for calculation of the average fuel economy. Unrepresented base levels must have data for fuel economy data vehicles (FEDV) submitted by manufacturers to fill that void. Present policy is that a minimum of 25 percent of all FEDVs must be tested for confirmation of the test data by EPA. A selection scheme which dramatically reduces the number of EDVs will, however, have a significant effect on the number of FEPVs produced.

the degree to which the suggested changes to emission testing procedure would influence this program. This situation does not however seem imminent at present. In general, presently foreseen policies appear not to cause any major increase in workload for the fuel economy unit. In fact, a recently created EPA policy of requiring manufacturers to perform the initial checks to determine that all the specified classifications (base levels) are represented by test vehicles will have an effect of decreasing the EPA workload.

G.1 Background

The Energy Policy and Conservation Act sets standards for the average fuel economy of passenger vehicles produced for sale in the US. These standards begin with a minimum average of 18.0 miles per gallon for the 1978 model year and increase to a minimum of 27.5 in 1985. The Act also sets out a civil penalty to be assessed against any manufacturer failing to meet these standards. This penalty is five dollars per passenger automobile produced per .1 mile per gallon that the manufacturer's average fuel economy (AFE) is below the standard for that model year. Since this penalty could easily be several million dollars for a manufacturer, there is good reason for attempting to meet the standards prescribed. It is also a good reason to have a defensible way of determining AFE.

The Act authorizes EPA to develop in conjunction with each manufacturer an average fuel economy to be sent to the Secretary of Transportation for compliance action.[1] In addition, it imposes constraints as to the

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[1]An additional requirement is that EPA must separate a manufacturer's output into groupings of domestically produced and imported vehicles for calculation of the average (i.e., there are both domestic and imported averages for some manufacturers).

procedures to be employed to derive these averages. Specifically, the fuel economy testing must be done in conjunction with the emissions tests for certification under the Clean Air Act using the procedures for the 1975 model year (or procedures yielding comparable results). Because of the large degree of freedom left to the Administrator, it is clear that any changes made in the emissions certification testing process could be adapted to the fuel economy program, as long as it remains comparable to the 1975 process.

The present procedure for selecting vehicles for testing by EPA has been termed the "secure base level approach". In essence, this method starts with data from the emissions certification testing program and data supplements from the manufacturers for use in the fuel economy labeling program (described later). These data are for calculation of an initial average fuel economy (AFE) prior to the beginning of the model year. If a manufacturer's average is sufficiently above the following year's standard or sufficiently above the applicable model year's standard and he waives any credit for the following year, then no additional test data is required, since there is little chance that a penalty will be assessed or a credit allowed (described later). A manufacturer has the option to submit additional data to increase the accuracy of the average, since the number of data points is extremely small compared to a statistical sampling scheme. Additional tests may also be necessary if a manufacturer makes mid-year changes or additions to his product line. (Of course, this allows the manufacturer to make design improvements to enhance his average if he initially does not comply with the standards.)

The following section presents VRI's understanding of the procedures for selecting and testing vehicles and the method of calculating the average fuel economy values. The procedures described are those in effect for the 1978 model year, with appropriate comments as to proposed changes for 1979 and succeeding years. It should be noted that the procedures for the labeling process and the AFE process have been combined in the description, even though they constitute separate requirements, since they rely on the same sets of test data which are produced during the course of the year.

G.2 The Fuel Economy Testing Process

In order to comply with the intent of the energy act, EPA designed the fuel economy process to be employed in conjunction with the emissions certification process. That is, most data for fuel economy calculations are derived directly from vehicles tested for emissions, and the program itself is conducted at the Motor Vehicle Emissions Laboratory at Ann Arbor.

The following subsections describe the activities conducted by EPA in carrying out this process, and correspond for the most part to the items in exhibit G-1, the fuel economy process flowchart. This flowchart shows the sequence of steps of the process and its reliance on sharing test facilities and data sources with the emissions certification process (these points of interaction are the items on the left of the vertical dotted line).

It is anticipated that the volume of vehicles required for testing by EPA will not increase dramatically as the full fuel economy process is effected as of the 1978 model year. A possible exception to this could result if a change proposed for 1979 and later years is instituted. This change would reduce by 1/2 the range of each vehicle weight class constituting a base-level (defined later) from 500 pounds to 250 pounds, and from 250 pounds to 125 pounds for the two class sizes, which could create up to twice as many base level vehicles. This option is only at proposal stage, however, even if implemented, EPA does not expect it to significantly affect the fuel economy testing workload. To maintain current workload levels using this option one test vehicle would be used to reoresent multiple base level classes by testing the vehicle at its true weight.

G.2.1 Manufacturer Determines Base Levels, Notifies EPA

For purposes of testing and calculation of fuel economy averages, EPA established a system of classification called base levels,[1] which are almost the same as model types,[2] except that weight is substituted for car line.[3] The base level classes are delineated by those factors which have the greatest

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[1]A base level is a unique combination of inertia weight class, basic engine, and transmission class. Note: The significance of base levels is that they are the means of subdividing a manufacturer's product line into smaller groups for determining test requirements. Example: A 3,500 pound vehicle, with a 231 cubic inch, 6 cylinder engine with 2 barrel carburetor, catalyst, and manual transmission.

[2]A model type is a unique combination of car line, basic engine, and transmissions class. (A basic engine is an engine of particular displacement, number of cylinders, fuel system, and catalyst usage; a transmission class is the type of transmission such as manual, semi-automatic, or automatic.) Since this definition includes key items which affect fuel economy and are used and understood by the average consumer, it is used for publishing fuel economy information as well as for calculating a manufacturer's average fuel economy.

[3]A car line is a group of vehicles within a make or car division which has a degree of commonality in construction. Car line does not consider any level of decor or opulence and is generally not distinguished by characteristics such as roof line, number of doors, seats, or windows, although station wagons are distinct car lines from sedans. Example: Buick, a division of General Motors, lists nine car lines--Electra, Skylark, Skyhawk, Opel, Century Wagon, LeSabre, Estate Wagon, and Riviera.

influence on fuel economy. At least one vehicle from each base level, and from vehicle configurations representing 90 percent of the sales within each significant[1] base level must be tested in order to calculate the fuel economy average for a manufacturer. It is the responsibility of the manufacturer to determine these base levels and to compare the base levels to the vehicles which are being submitted for emissions certification pruposes (the emissions data vehicles). For each base level not represented by an emissions data vehicle (where only one vehicle test is required to represent that base level), the manufacturer must test a representative vehicle configuration,[2] and prepare and submit a Fuel Economy Data Vehicle[3] (FEDV) "package" for that vehicle. This package includes vehicle specifications, mileage accumulation data, maintenance records, and fuel economy test results.

G.2.2 Manufacturer Submits Voluntary and Required FEDVs

The FEDVs required of a manufacturer to fill a base level "slot" are not expected to produce a great number of test cases. Overall, for all manufacturers for the 1977 model year, only about 12 FEDV packages were submitted to fulfill the base level rules. However, the manufacturers have an option to and are encouraged to submit voluntary FEDVs to augment the

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[1]A significant base level is one which represents one percent of total production.

[2]Vehicle configuration--a unique combination of inertia weight class, basic engine, and transmission class (which define a base level) plus engine code, transmission configuration, and axle ratio. (Engine code denotes a basic engine further specified for variations in carburetor, distributor, and other key engine and emission control system components; transmission configuration is a transmission class further specified by number of forward gears.) Note: Base levels are subdivided into vehicle configurations in order to identify individual test vehicles. Example: A 3,500 pound vehicle with 231 cubic inch, 6 cylinder, 2 barrel carburetor engine of engine code 4, with catalyst, 4-speed manual transmission, and 2.56 axle ratio.

[3]A Fuel Economy Data Vehicle (FEDV) is a vehicle used for fuel economy purposes which is not an original certification vehicle.

minimum representation of only one test vehicle per base level. It should be expected that these voluntary packages will be selected by the manufacturer to enhance his calculated average fuel economy, rather than simply to improve the accuracy of the calculation of the average.

G.2.3 EPA Reviews FEDV Package, Decides on Confirmatory Test

For each FEDV package submitted by a manufacturer, voluntary or required, EPA performs a review to determine the acceptability of the vehicle and the data. This review is directed to assuring the completeness of vehicle information, mileage accumulation, and maintenance records, as well as judging the relation of the weight, engine specifications, etc., to expected ranges of fuel economy values. If after this analysis there is some doubt as to the validity or accuracy of the data, a confirmatory test is required by EPA.

In addition to the results of this review, the availability of test facilities influences the decision as to whether to accept manufacturer data without EPA testing. A total of approximately 200 FEDVs were submitted for the 1977 model year, and of these, 84 were selected for confirmatory testing. Of these 84, 20 vehicles required the retest sequence. This testing includes checks on emission levels, and if standards are not met, the fuel economy data will not be used, but the emission data cannot be used against a manufacturer for purposes of certification compliance. However, consistent failures by a vehicle configuration to demonstrate compliance with emission standards are referred to the mobile source enforcement division. In other words, the emission test results are not furnished to certification for direct use in the certification process.

G.2.4 EPA Performs Confirmatory FE Test, Retests if Necessary

If it is decided that a confirmatory test is needed, EPA requires the manufacturer to submit the vehicle on which the FEDV package was based for testing. This testing, while not directly involved with certification, nonetheless causes a certain interaction by creating an additional load on the available test facilities.

The confirmatory test procedure involves making an initial fuel economy test, then comparing the results to those submitted by the manufacturer. If the initial value is within approved limits of the manufacturer's data,[1] then these initial test results (not the manufacturer's) are taken as the final values for that FEDV. However, if the initial results are not close to the manufacturer's, then a series of retests are performed, and the average of these test results may be used as the value for that FEDV.

The retest criteria are the same as those used in performing tests on EDVs, which are the main source of data for the AFE. (EDV testing is described below.) These criteria involve: (1) comparing the two city fuel economy test bags to determine whether they are within the same range, (2) comparing the new city and highway fuel economy results to previous EPA and/or manufacturer results (must be within 10 percent, and (3) comparing the ratio of the latest EPA highway fuel economy test result to the latest city result to determine whether they are within acceptable ranges.[1] If the new results fail any one of those tests, the corresponding city or highway test is rescheduled.

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[1]Based on a memorandum from L. I. Ranka to EPA Light Duty Vehicle teams and Fuel Economy groups dated July 27, 1976.

The responsibility for making these checks and scheduling retests, if necessary, lies with the certification team for required FEDVs and with the Fuel Economy Group for Voluntary FEDVs.[1] If more than one retest is necessary for either required or voluntary FEDVs, the Fuel Economy Group may decide to terminate testing.[2] The finally-accepted FE value (which is selected by the FE Group) can be:

(1) the data from a single EPA test;

(2) the average of the manufacturer's tests; or

(3) the average of all the EPA tests.

The decision as to which value to accept is determined by engineering judgment, using fuel economy trend data based on such items as axle ratio, horsepower, etc., and the history of correlation between the particular manufacturer's and EPA's test results. The value determined to be more reasonable in light of the trends and correlations is then established as final for that vehicle.

G.2.5 EPA Develops FE Values on All Emissions-Approved EDVs

In order to meet the guideline established by the Energy Conservation Act to rely as much as possible on the certification program for data for fuel economy, a policy of use of Emission Data Vehicles (EDVs)[3] for generation of fuel economy data was established. That is, vehicles representing

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[1]Conversations with the Fuel Economy Group indicate that of all vehicles tested for the 1976 model year, approximately 7.5 percent required at least one rerun for the city test, and 10 percent for the highway test. In the period 5/1/76 - 11/27/76, the city test was rerun for 5.4 percent of all EDVs and 23.8 percent of all FEDVs. In the same period, 6.9 percent of all highway tests were rerun.

[2]It is VRI's understanding that EPA may request another vehicle to be supplied by the manufacturer if test data from the initial vehicle are erratic.

[3]An Emission Data Vehicle (EDV) is a 4,000-mile vehicle selected and tested by EPA as part of the emissions certification process.

determined base levels are chosen from the EDVs selected by the certification process to the greatest extent possible.

Thus, all EDVs are run through the highway fuel economy test after they complete the emissions test, which is the same as the urban fuel economy test. If it is determined, after applying the deterioration factor, that a vehicle passes the emissions test when the fuel economy results are used from both the urban and highway cycles. This reliance on certification testing and selection processes forms the greatest interface of the fuel economy program with the certification program. Any changes in the selection procedure for EDVs can therefore potentially impact the degree to which the additional vehicles must be tested to cover all fuel economy base levels. That is, any unrepresented base levels must have a fuel economy data vehicle whose test results are submitted by the manufacturers and, depending on the percentage of confirmatory tests required, may affect the total number of FEDVs by EPA.

G.2.6 EPA Stores Manufacturer Data and EPA Data, Checks Reasonableness

As data from manufacturer's FEDV packages and EPA-generated test data are assembled, a complete file is created representing all base levels. These data are added to, corrected, deleted, etc., throughout the year, and form the base for all initial and final calculations of the AFEs. As each piece of data is added to a base level's file, it is checked for "reasonableness." This check is basically a comparison of the submitted values with what could be expected given the specifications of the vehicle, and in this sense is similar to the judgment used to decide on confirmatory testing. If the data is determined unreasonable, further justification or confirmation is required.

G.2.7 Manufacturer May Request Specific Label Values, EPA Must Approve Before Use

The labeling process, which involves developing the fuel economy values that must be posted on all vehicles sold in the US, is carried on as an adjunct to the preparation of the average fuel economy for the manufacturers. The sales-weighted values prepared in the fuel economy process for the model types and vehicle configurations are those values which must be posted on new vehicle windows. A general label is related to an entire model type average (consisting of several vehicle configurations), whereas a specific label shows the average for only one vehicle configuration.

If, for whatever reason, a manufacturer decides to sell vehicles before determination of general label values, it must request approval of specific labels for each configuration to be sold. EPA reviews each request and makes a determination as to whether to approve such use. It should be noted that, regardless of when specific labels are used, all vehicle configurations within a model type must use specific labels if any one configuration uses them.

G.2.8 Manufacturer Requests General Label Determination, Provides Initial Sales Projections, Submits Car Line Classification Information

Manufacturers must formally request a general label value determination for the labeling process to be initiated. At this time, approximately July-August prior to the introduction of the new models, the initial sales projections are provided for all vehicles to be manufactured throughout the year.

In addition, each automobile manufacturer submits to EPA information necessary for determining the appropriate car line class for each proposed vehicle. The major determinants of these classes for passenger vehicles are interior volume and the number of passengers which the vehicle can transport. Pickup truck classes are separated from each other on the basis of gross vehicle weight rating (GVWR), and other non-passenger automobiles which are not pickup trucks are classified as vans/special purpose trucks.

In addition to the car line information, the manufacturers submit information on vehicle weights, engines, transmissions, use of catalytic converters, and axle ratios which will be available in each car line. Some of this information is used by EPA in determining model types, and the balance for determining base levels and vehicle configurations, discussed later.

G.2.9 If Any Base Levels Are Not Represented, Manufacturer Must Submit FEDV Package

At this point, EPA checks to see that all base levels are represented by either an EDV or an FEDV. If any levels are not included, the manufacturers are notified of this lack and required to submit an FEDV for each such base level. The FEDV packages submitted as a result of this check are reviewed for confirmatory testing in the same manner as previously discussed.

G.2.10 EPA Determines Test Results To Be Used in Fuel Economy Calculations

EPA performs a final reasonableness check in determining which test results in the data file for each base level are to be used in the calculations to produce general and specific label values and initial average fuel economy (AFE) levels for the manufacturers.

G.2.11 Manufacturer Submits Revised Sales Projections

The sales projections may be revised in September-October to the final values to be used for calculating label values and initial AFEs.[1]

G.2.12 EPA Calculates FE Values and Ranges

With all test results from EDVs, required and voluntary FEDVs, and running changes made early in the year available, and any revised sales projections made, EPA calculates fuel economy values for each vehicle configuration, base level, and model type. If enough of these values are available at this time, ranges for the values (overall similar classes for all manufacturers) are established also. Calculations of the fuel economy range values are always made according to the sales-weighted, harmonic average of the urban and highway test results.

G.2.13 Manufacturer Reviews Data, EPA Corrects

EPA allows the manufacturers a review of the calculated FE values and of the data used to produce the values. If corrections are deemed necessary by EPA after careful review of manufacturer's objections, these are made and the affected FE values recalculated.

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[1] For compliance the actual production values are used.

G.2.14 General Label Values Are Established, Booklet Is Published

The final general label values are calculated after the review-correction cycle and are used for consumer information during the model year. The values for all vehicles of all manufacturers certified by the fall cut-off date are published in the *Gas Mileage Guide* which must be made available to consumers in every dealer's showroom throughout the country. A second guide is compiled in January to cover any late submittals.

G.2.15 Manufacturer May Elect to Use Specific Labels

If all vehicle configurations within a given model type have specific label values available, then EPA will approve the use of these labels provided that all vehicle configurations within the model type are labeled concurrently. This has been a source of some controversy, since some manufacturers asked to be allowed to use specific labels for certain configurations and general labels for others (all within the same model type). This policy was established to assure equity and eliminate the possibility of misrepresentation (by using the general labels on those configurations which had fuel economy values below the average and specific labels on those above).

G.2.16 EPA Compares Preliminary Calculation of Average Fuel Economy to Assurance Level

The decision rule as to whether fuel economy data must be collected from running change vehicles is based on a comparison of the preliminary calculated average fuel economy with an *assurance level* yet to be established by EPA. At the least, this level will be the minimum acceptable value for AFE for the year following the model year being studied (i.e., the 1978 model year value must exceed the 1979 standard of 19 MPG), or will follow the provisions of G.2.18 which follows. It is expected that some safety or assurance margin will be added to that following year's value to produce the minimum acceptable AFE for this exemption to be granted.

If the calculated AFE is above the *assurance level*, then the manufacturer may apply for an exemption of further testing. If it is not, then a vehicle must be tested for fuel economy for each approved running change. Current policy[1] is that fuel economy results from *all* EPA tests for emission levels of running change vehicles (even though the fuel economy testing requirement exemption has been granted) will be used in calculation of the final AFE. This is possible since the standard practice is to run the highway cycle test for every vehicle tested on which an urban cycle test is performed.

G.2.17 EPA Tests Vehicles for Approved Running Changes

If a manufacturer's preliminary AFE is below the assurance level, and a running change is made which does not result in the addition of a base level, then EPA must test the highest-selling vehicle configuration in each affected base level. Regardless of whether the preliminary AFE is above or below the assurance level, if the manufacturer adds a significant base level,[2] then vehicle configurations representing 90 percent of the projected sales of that

[1]EPA personnel anticipate the creation of another policy which would allow exemption for testing running changes for the fuel economy (as well as emissions) if.the proposed change is a simple modification within certain calibration limits.

[2]Recall that a significant base level is one which represents one percent or more of total production volume.

significant base level must be tested, the preliminary AFE is recalculated and a new determination is made as to whether running change testing is required. If this recalculation results in the AFE moving from above to below the assurance level, then the manufacturer must submit for testing any running change vehicles which were previously exempted.

If the manufacturer adds a non-significant base level (less than one percent of production), regardless of the preliminary AFE, then only one vehicle representing only the highest selling configuration is tested. However, if during the course of the year, non-significant base levels are added that accumulate to 3 percent or more of production, then the preliminary AFE is recalculated and the running change retroactive test rule applies if the AFE is lowered from above to below the assurance level.

This possibility is most prevalent for the large domestic manufacturers, since their present averages are closest to the accept/reject AFE level. If it should occur, then a heavy additional burden will be placed on the test facilities for these required tests.

The fuel economy testing of running changes is often in conflict with the emissions certification of running changes since the EDVs normally selected for these tests are the "highest emitter" cases, which often are not high-volume vehicles. Thus, if a running change is emissions-approved and the EDV was not a properly representative vehicle, additional fuel economy data must be collected to satisfy the above requirements. When the data from any of this testing have been approved, they are added to the FE data base.

G.2.18 Manufacturer May Waive Credit Based on Preliminary Calculations

The statute includes credit carryover provisions such that if a manufacturer's final AFE (including running change data) is above the year's AFE minimum level, then the amount by which it is above that level may be used as a credit in the following year, if in that following year his AFE is below standard. If the manufacturer's AFE is above the applicable year's standard by the margin, but below the next year's standard plus assurance margin, then the manufacturer has the option of waiving any credit for future years' AFEs in order to be relieved of the necessity for running change testing. Waiver of this carryover credit is the final requirement for exemption from running change testing in those cases. Thus, a manufacturer may waive the next year's credit if he feels that he will have no trouble in meeting the next year's AFE requirement and wishes to avoid the cost and inconvenience of additional testing.

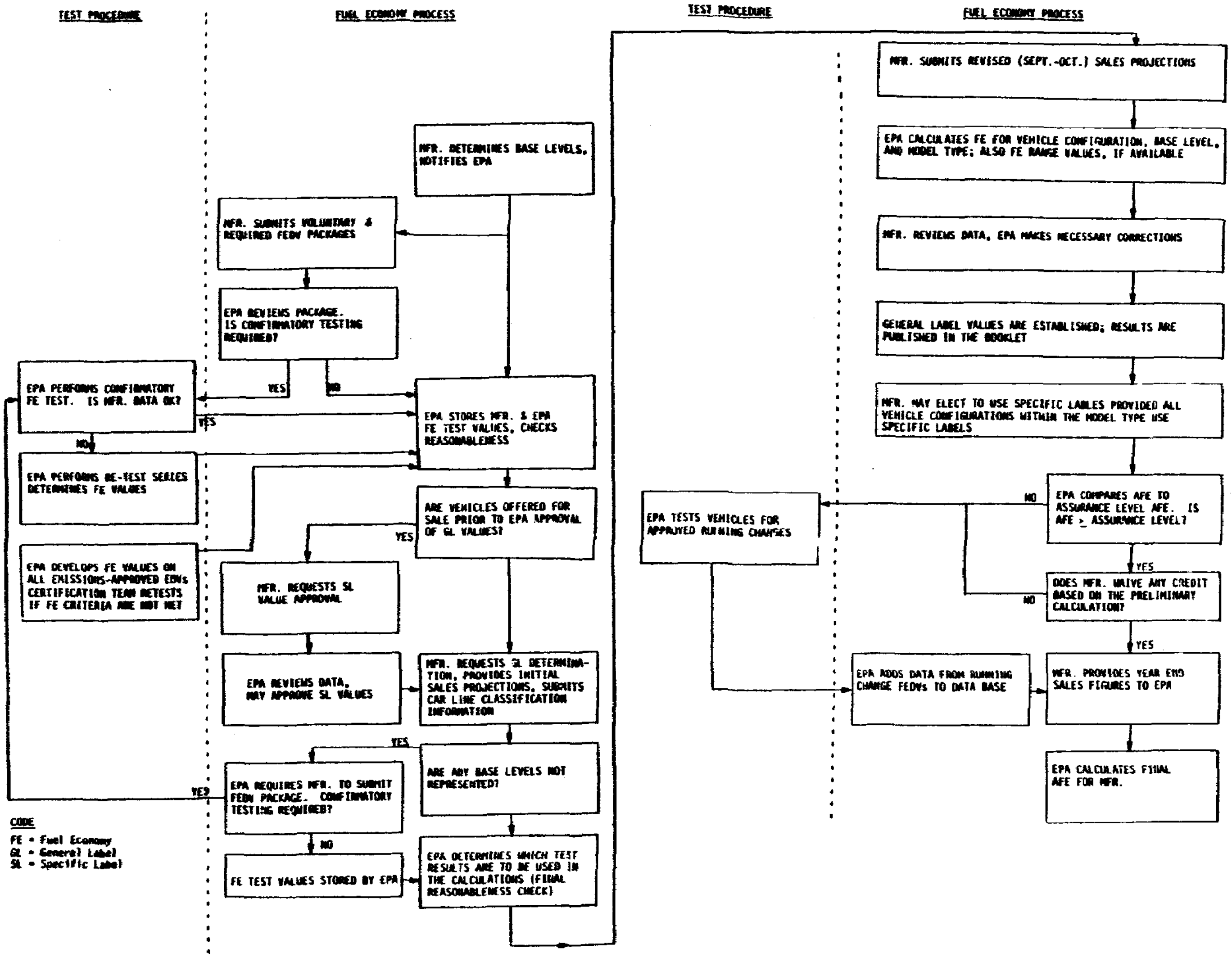
G.2.19 Manufacturer Provides Year-End Production Figures, EPA Calculates Final AFE for Manufacturer

At the end of production of the model year, each manufacturer is required to submit final production figures for all vehicles he produces and/or imports. These figures are used as the final update for the sales-weighted harmonic averaging, along with updates on any fuel economy data from voluntary and required FEDVs added since the initial calculation. The production figures are subject to audit checks for veracity.

This final AFE is the value which must exceed the applicable standard (the standard in the Act or a standard set by the Department of Transportation as a result of a manufacturer's request) for that model year (taking into account any credits from the previous year) in order to avoid being assessed a penalty. However, the statute provides that a "carryback" credit may also be allowed in certain cases, so that passage by a margin in a particular year may produce a credit for a previous year's failing.

It should be noted that each domestic manufacturer which offers imported vehicles (or vehicles which contain a high percentage of imported parts) have separate AFE's calculated for both the domestic and imported vehicles (i.e., a domestic AFE and an imported AFE) both of which must pass the standards.

EXHIBIT G-1: FUEL ECONOMY PROCESS AND TEST PROCEDURES



APPENDIX H

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