Calspan

# Technical Report

ANALYSES OF ASSEMBLY LINE TESTING

Final Report

R. J. Mogavero and W. R. Fairchild

Calspan No. NA-5194-D-II

EMISSIONS & EXHAUST GASES

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Office of Mobile Source Air Pollution Control
Environmental Protection Agency
Ann Arbor, Michigan 48105

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# 1. OVERVIEW AND SUMMARY OF RESULTS

## 1.1 Summary of Project Objectives

Stated very briefly, the focus of this project has been to organize and summarize the results on automobile exhaust emissions levels as estimated from the data base gathered because of the California Air Resources Board Assembly Line Test Program; to assess the nationwide reduction in emissions which might be realized with currently existing emission control systems if alternate assembly line test procedures were employed on a nationwide basis; to extrapolate these results to proposed catalyst type emission control systems; and to assess the nationwide costs of such programs.

The California Assembly Line Test Program for 1972-73 consists of the following:

| | | |
|---|---|---|
| 1972 | Seven mode test | 25% of production |
| | CVS audit test | 2% of production |
| 1973 | Seven mode test | 25% of production |
| | Idle test | 75% of production |
| | CVS audit test | 2% of production |

The 75% idle test requirement for 1973 was implemented in stages over the model year so that, at some stages, fractions of less than 75% were idle tested.

## 1.2 Summary of Results

The results of the many analyses undertaken will be briefly summarized here. More detailed data underlying these results, as well as a description of the methodology employed in approaching the numerous subtasks is contained in subsequent chapters of this report. To the extent feasible, the results will be presented and discussed in the order mentioned in Section 1.1.

Frequency and Patterns of Seven Mode Test Failures

The failure rates experienced on seven mode tests applied during the 1972 model year varied considerably among manufacturers and at different times of the production year within a manufacturer. The variation among manufacturers is illustrated below.

| Manufacturer | Overall Failure Rate Seven Mode Tests |
|---|---|
| Chrysler | 25.5 % |
| Ford | 24.8 % |
| General Motors | 5.3 % |

Table 1.2-1
Overall Seven Mode Failure Rates

Throughout the production quarters of the 1972 model year, there appeared to be a decrease and then increase in the seven mode test failure rate, and this pattern seemed to hold for all three manufacturers. This is illustrated below.

| Manufacturer | Production Quarter | | | | | Overall |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | |
| General Motors | N.A. | 6.19 | 4.95 | 3.83 | 15.82 | 5.3 |
| Ford | N.A. | 21.0 | 19.5 | 30.2 | 41.1 | 24.8 |
| Chrysler | 34.0 | 16.3 | 27.4 | 24.1 | 36.6 | 25.5 |

Table 1.2-2
Quarterly Seven Mode Failure Rates

It is apparent that a gradual improvement in test results occurred as the model year proceeded, "bottoming out" generally in one of the middle quarters and then increasing dramatically in the fifth or buildout quarter. While very noticeable increases in failure rates were observed throughout this data base for the buildout quarter it should be noted that this quarter normally accounts for about 8% of yearly production.

While these failure rates, within a manufacturer, were analyzed and compiled on engine category, division, etc. bases, such detail will not be presented here. These breakdowns can be reviewed in Chapter 3. For our purposes, at present, it will suffice to say that large variations exist in failure rates from one engine family to another, from one division to another, etc. The time pattern in failure rates cited earlier appears, however, to prevail in spite of these "category" differences.

## Frequency, Patterns and Reasons For Audit Test Failures

The overall failure rates on audit tests are shown below for the 1972 and 1973 model year data available.

| Manufacturer | Failure Rate (%) | |
|---|---|---|
| | 1972 Model Year | 1973 Model Year |
| General Motors | 7.0 | 15.7 |
| Ford | 15.7 | 11.5 |
| Chrysler | N.A. | 17.37 |

Table 1.2-3
Overall Audit Failure Rates

These failure rates reflect the number of original test failures as a percentage of the number of original audit tests performed by a manufacturer. Within a given manufacturer there were large variations in audit failure rates between divisions, engine families, engine sizes, etc. This high degree of variability was true for all three manufacturers and is elaborated on in Chapter 3. An interesting characteristic which prevailed among all manufacturers represented in the data base was that on audit test failures, the HC , CO and $NO_x$ attributed failures tended to be disjoint; that is, if a car failed on the HC standard it usually did not fail CO and/or $NO_x$. Consequently, the overall audit failure rates appear to be, by and large, accounted for by the accumulated failure rates of cars which failed HC only, CO only and $NO_x$ only.

One of the manufacturers (i.e. - General Motors) provided descriptors for the reasons of an audit failure in their data base. Upon analysis of these "reasons for failure", two major patterns presented themselves: First, while there were many described reasons for failing an audit test a comparatively small number of these "reasons for failure" accounted for 90% of the number of audit failures recorded. From the 1972 data base 19 of the 52 listed reasons for failure accounted for 90.26% of the failures. From the 1973 data base 8 of the 41 listed reasons for failure accounted for 90.4% of the failures. The second point observed is that the reason for failure most frequently listed in both years covered was "rerun no repair" accounting for 40.8% and 68.3% of the failures in 1972 and 1973 respectively. This descriptor is applied when a car fails the audit test but no attributable reason for failure could be isolated. This frequently occurring situation suggests a high degree of variability among repeated tests on the same car. Whether this variability is attributable to the so called "green engine effect", to inherent variability of the test procedure, or possibly some combination of both of these factors was not determinable from the data base available for this study.

Nationwide Emissions Level Changes From Assembly Line Tests

Upon an analysis of the experiences with seven mode, idle and audit testing during the brief history of the California Assembly Line Testing Program it appears that an extension of a similar program to a nationwide basis would increase emissions levels.

This analysis:

(1) determined changes in average CVS emissions from the second to fifth quarters of 1972

(2) compared CVS emissions for cars that were seven mode tested and those not seven mode tested

(3) compared CVS emissions for cars that were idle tested and those not idle tested

(4) compared initial and final CVS emissions for cars that were audit tested.

Tables 1.2-4 through 1.2-7 present, in summary fashion, the results of estimating the changes in emissions levels, on a nationwide basis, if these programs (i.e. - 25% seven mode testing, 75% idle testing and 2% audit testing) were implemented. The estimated emission levels contained in these tables are based on extrapolations which employed one years production volume and assumed an average yearly mileage of 12000 miles per year for this automobile population.

Some brief interpretive comments are in order here. Regarding the 1972 data base (i.e. - Table 1.2-4) the only emissions changes estimated are for hydrocarbon and carbon monoxide, since oxides of nitrogen were not measured by C.V.S. techniques during that model year. The emission level changes associated with a trend in the average emissions during the year show a decrease in hydrocarbons and an increase in carbon monoxide. For reasons discussed at some length in Chapter 4 it is felt that such changes cannot, on the basis of the data in this study, be attributed to nor disassociated from the Assembly Line Testing Program, and consequently shall not be dwelt upon here. Seven mode test results, which were only estimable from General Motors data, showed a decrease in both hydrocarbon and carbon monoxide ; however, these estimates were based on a relatively small sample of automobiles seven mode tested and these were concentrated in a small number of assembly plants and engine categories. Consequently, these are not to be interpreted as typical of what results might be expected across all engine types, manufacturers, etc. The audit changes are seen to be very small. In summary then, while general patterns and magnitudes of emissions changes were estimable from the 1972 data base, their overall utility is quite limited.

The 1973 data base yielded more useable results as related to assembly line testing. Sample sizes of automobiles seven mode tested and/or idle tested were large and comprehensive enough to lend more confidence in the estimates of emission level changes associated with the tests applied on a nationwide basis. The most interesting result from this analysis is that

| Source of Emissions Level Changes | Manufacturer | Emissions Type | | |
|---|---|---|---|---|
| | | HC | CO | NOX |
| Trend | GM | -1555 | +35750 | NA |
| | Ford | -1272 | +82576 | NA |
| | Chrysler | -66 | -108 | NA |
| | Total | -2893 | +118218 | NA |
| Seven Mode | GM | -2310 | -29040 | NA |
| | Ford | NA | NA | NA |
| | Chrysler | NA | NA | NA |
| | Total | -2310 | -29040 | NA |
| Audit | GM | -122 | -39 | NA |
| | Ford | NA | NA | NA |
| | Chrysler | NA | NA | NA |
| | Total | -122, | -39 | NA |
| | Total | -5324 | +89139 | NA |

Table 1.2-4

Summarized Emissions Level Changes - 1972
(tons per year)

- decrease in tons per year (nationwide)

+ increase in tons per year (nationwide)

| Source of Emissions Level Change | Manufacturer | Emissions Type | | |
|---|---|---|---|---|
| | | HC | CO | NOX |
| Trend | GM | -0.0236 | +0.5417 | NA |
| | Ford | -0.0292 | +1.8957 | NA |
| | Chrysler | -0.0338 | -0.0558 | NA |
| 7-mode | GM | -0.0350 | -0.4400 | NA |
| | Ford | NA | NA | NA |
| | Chrysler | NA | NA | NA |
| Audit | GM | -0.00185 | -0.02253 | NA |
| | Ford | NA | NA | NA |
| | Chrysler | NA | NA | NA |

Table 1.2-5

Summarized Emissions Level Changes - 197[illegible]

(grams per mile)

| Source of Emissions Level Changes | Manufacturer | Emissions Type | | |
|---|---|---|---|---|
| | | HC | CO | NOX |
| Trend | GM | NA | NA | NA |
| | Ford | NA | NA | NA |
| | Chrysler | NA | NA | NA |
| | Total | NA | NA | NA |
| Seven Mode | GM | 0 | -60500 | +825 |
| | Ford | +872 | 0 | +3815 |
| | Chrysler | -64 | 0 | 0 |
| | Total | +808 | -60500 | +4640 |
| Idle | GM | +14355 | +103950 | +2970 |
| | Ford | -4185 | 0 | -2943 |
| | Chrysler | 0 | +851 | +45 |
| | Total | +10170 | +104801 | +72 |
| Audit | GM | -121 | -2317 | -62 |
| | Ford | NA | NA | NA |
| | Chrysler | -30 | -589 | -34 |
| | Total | -151 | -2906 | -96 |
| | Total | +10827 | +41395 | +4616 |

Table 1.2-6
Summarized Emissions Level Changes - 1973
(tons per year)

| Source of Emissions Level Changes | Manufacturer | Emissions Type | | |
|---|---|---|---|---|
| | | HC | CO | NOX |
| Trend | GM | NA | NA | NA |
| | Ford | NA | NA | NA |
| | Chrysler | NA | NA | NA |
| 7-mode | GM | 0 | -0.9167 | +0.0125 |
| | Ford | +0.02001 | 0 | +0.0876 |
| | Chrysler | -0.0032 | 0 | 0 |
| Idle | GM | +0.2175 | +1.5750 | +0.045 |
| | Ford | -0.0961 | 0 | -0.0676 |
| | Chrysler | 0 | +0.0429 | + 0.0023 |
| Audit | GM | -0.00183 | -0.0351 | -0.0009 |
| | Ford | NA | NA | NA |
| | Chrysler | -0.00153 | -0.0297 | -0.0017 |

Table 1.2-7

Summarized Emissions Level Changes - 1973

(grams per mile)

there appears to be an overall increase in emissions resulting from the combined effects of seven mode, idle and audit tests. The idle tests, in particular, dominate the overall impact and if one omits the idle test effect it would appear that the nationwide emission change would be:

| | | | |
|---|---|---|---|
| I) | Hydrocarbon | 657 ton per year | <u>increase</u> |
| II) | Carbon Monoxide | 63406 ton per year | <u>decrease</u> |
| III) | Oxides of Nitrogen | 4544 ton per year | <u>increase</u> |

This is a grossly different pattern than with any idle testing. The development of these results and an extensive discussion of the data and methodology on which they are based is contained in Chapter 4 of this report.

Nationwide Emissions Changes From Alternate Assembly Line Tests

Tables 1.2-8 a,b and c summarize the estimated nationwide emission level changes which would result from combinations of representative levels of seven mode and audit test rates employed as alternates to the current structure of the California assembly line test program. Note that idle tests are not considered here, this being a result of the apparent increase in emissions levels attributable to idle testing. It is further re-iterated at this point that the changes in nationwide emissions levels estimated here result from the "rectifying aspects" of the alternate tests considered; that is to say, from the adjustments performed on failing cars and their resultant impact on the overall distribution of emissions. Any changes in emissions levels which may be attributable to trends (as discussed previously) are not included here. The two most striking patterns apparent from these data are that: (1) only carbon monoxide shows a decrease in emissions and, (II) increases in audit test rates reflect nominal changes in emission levels by comparison to the seven mode test effect.

| Seven Mode Test Rate (%) | Audit Test Rate (%) | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 5 | 10 |
| 25 | + 716 | + 624 | + 533 | + 349 | -109 |
| 50 | +1524 | +1432 | +1341 | +1157 | + 698.45 |
| 75 | +2332 | +2240 | +2149 | +1965 | +1506.45 |
| 100 | +3139 | +3047 | +2956 | +2772 | +2313.45 |

Table 1.2-8a

Hydrocarbon Emission Level Changes

For Various Seven Mode/Audit Test Rates

(tons per year)

| Seven Mode Test Rate (%) | Audit Test Rate (%) | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 5 | 10 |
| 25 | -62701 | -64902 | -67103 | -71505 | -82510 |
| 50 | -123201 | -125402 | -127603 | -132005 | -143010 |
| 75 | -183701 | -185902 | -188103 | -192505 | -203510 |
| 100 | -244201 | -246402 | -248603 | -253005 | -264010 |

Table 1.2-8b

Carbon Monoxide Emission Level Changes

For Various Seven Mode/Audit Test Rates

(tons per year)

| Seven Mode Test Rate (%) | Audit Test Rate (%) | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 5 | 10 |
| 25% | + 4567 | + 4495 | + 4422 | + 4276 | + 3913 |
| 50% | + 9207 | + 9135 | + 9062 | + 8916 | + 8553 |
| 75% | +13847 | +13775 | +13702 | +13556 | + 13193 |
| 100% | +18487 | +18415 | +18342 | +18196 | + 17833 |

Table 1.2-8c
Oxides of Nitrogen Emission Level Changes
For Various Seven Mode/Audit Test Rates
(tons per year)

## Nationwide Emissions Changes From Proposed Catalyst Type Systems

Viewing the catalytic converter systems to be employed on 1976 automobiles as essentially 1973 automobile engines feeding into a catalytic converter, the nationwide emissions estimated from alternate assembly line test programs are essentially fractional multiples of the levels estimated under conventional designs and discussed earlier. Therefore, the emissions levels and changes in emissions levels from 1973 assembly line testing are reduced by a fixed percentage in order to assess emissions levels and changes in emissions levels from assembly line testing of catalyst equipped vehicles. One should be cautioned to note, however, that this extrapolation technique assumes fully functioning catalysts in all cars and does not account for intermittent failures of catalyst units which may occur. Alternately, this technique does not include any beneficial effects which the presence of assembly line testing may contribute to the quality control of catalyst systems. With hot start tests considered ineffective in estimating emission reductions attributable to catalytic systems, the only alternate tests considered were audit tests and the emissions changes anticipated are summarized below:

| Audit Rate in % | Emission Level Change (tons per year) | | |
|---|---|---|---|
| | HC | CO | NOX |
| 1 % | - 16.79 | -319.16 | - 9.67 |
| 2 % | - 33.58 | -638.31 | - 19.34 |
| 3 % | - 50.37 | -957.47 | - 29.02 |
| 5 % | - 83.95 | -1595.78 | - 48.37 |
| 10 % | -167.91 | -3191.55 | - 96.75 |

Table 1.2-9
Audit Rate Related Emissions Changes
with Catalytic Converter System

It is apparent from these estimates that the anticipated magnitudes of emission reductions with catalytic systems are quite small; however it should be kept in mind that with the catalytic converters the magnitudes of both total emission levels and incremental changes in emissions will be a small fraction of the corresponding emissions components from a 1973 system. The ratio of "change in emissions" to "total emissions level" will be the same for both the 1973 and 1976 (i.e. - catalytic systems) considered in this report.

Costs of Alternate Assembly Line Test Programs

Cost analyses performed on alternate assembly line test programs are discussed at length in Chapter 7. Summarized very briefly here, alternate configurations of assembly line test programs considered for use with current engine/control system combinations covered average test costs over a range of $5.20 to $28.00 per automobile and when extrapolated to nationwide production yielded anticipated nationwide costs in the range from 51 million to 274 million dollars per year. These cost estimates stem *from two basic types of source data: First, estimates of the unit costs of* the component tests included in alternate test programs considered (i.e. - seven mode test, idle test, and audit test) and secondly the sampling rates associated with each type of test in a particular test program configuration (e.g. - 25% seven mode, 75% idle and 2% audit testing). Cost effectiveness of these test programs, in terms of Nationwide Testing Costs per Ton Emission Change is discussed in Chapter 7.

Shown below are the estimated ranges of unit costs associated with the three types of tests employed (at varying sampling rates) in the alternate test programs considered.

| Test Type | Unit Cost Range (Dollars per Test) |
|---|---|
| Seven-mode | $8.00 - $20.00 |
| Idle | $.32 - $1.20 |
| Audit | $68.00 - $350.00 |

## 1.3 Comments on Data Base

The analyses and extrapolations performed in the course of this study were based on data supplied by three automobile manufacturers, this data being derived from assembly line testing programs required by the California Air Resources Board for automobiles sold in the State of California. The data base employed did not include test information about exhaust emissions from automobiles not assembly line tested. As in most studies of this sort limitations on time and resources precluded the development and/or acquisition of as comprehensive a data base as would ideally be desired.

# 2 GENERAL METHODOLOGICAL APPROACH

## 2.1 Introduction and Overview of Emission Level Changes

In presenting the methodological approach to assessing the magnitudes of emissions reductions which would result if assembly line testing procedures similar to those currently employed in California were employed on a nationwide basis, it will be helpful to construct a framework within which the plausible factors which operate combine to determine general emission levels. Consider, for example, a situation in which a single manufacturer produces a single automobile on which there is only one engine/emission control system combination available.

If we were to measure the HC emission levels from a large number of these automobiles (say by C.V.S. sampling) at a fixed point in time, t, during the production year and plot a histogram of these emission levels,we would obtain a "picture" or "histogram" of emissions which would tend to be distributed in a manner similar to the schematic of Figure 2.1-1.

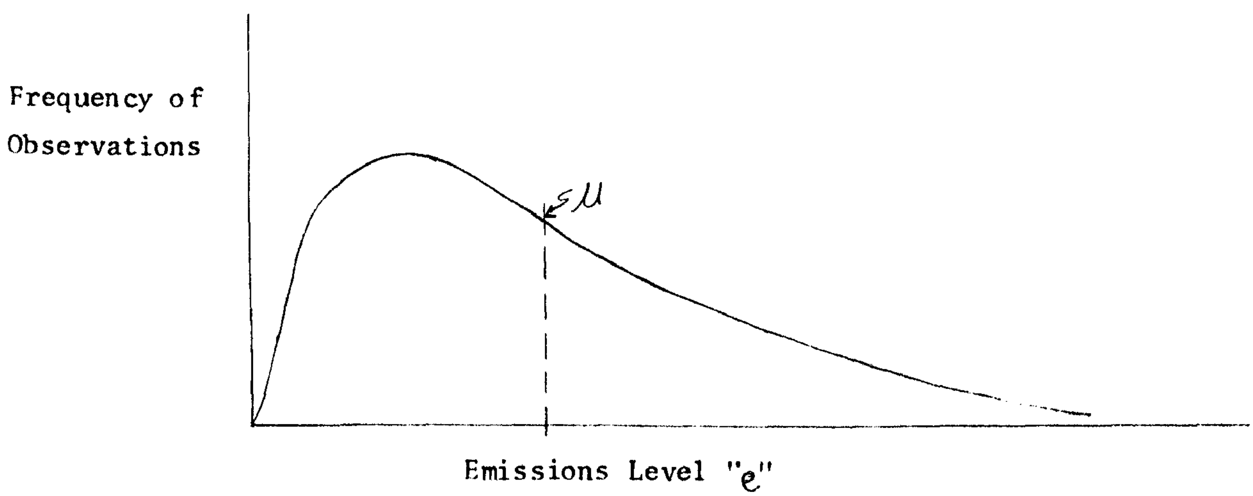



Figure 2.1-1
Schematic of Typical Emissions Distribution

Typically, such plots of emissions measurements will tend to be skewed to the right. Let us refer to these emissions as being distributed with some population average, $\mu_t$, and population variance, $\sigma_t^2$, (i.e. $e = D(\mu_t, \sigma_t^2)$). Of fundamental importance in assessing changes in emissions levels of new automobiles, over time during a production year, is the ability to describe how the average emissions level (i.e. $\mu_t$) varies, with time, during that production year. Conceptually, one would hope to be able to specify how the average emission level varies as a function of the "time of production year" as depicted in Figure 2.1-2.

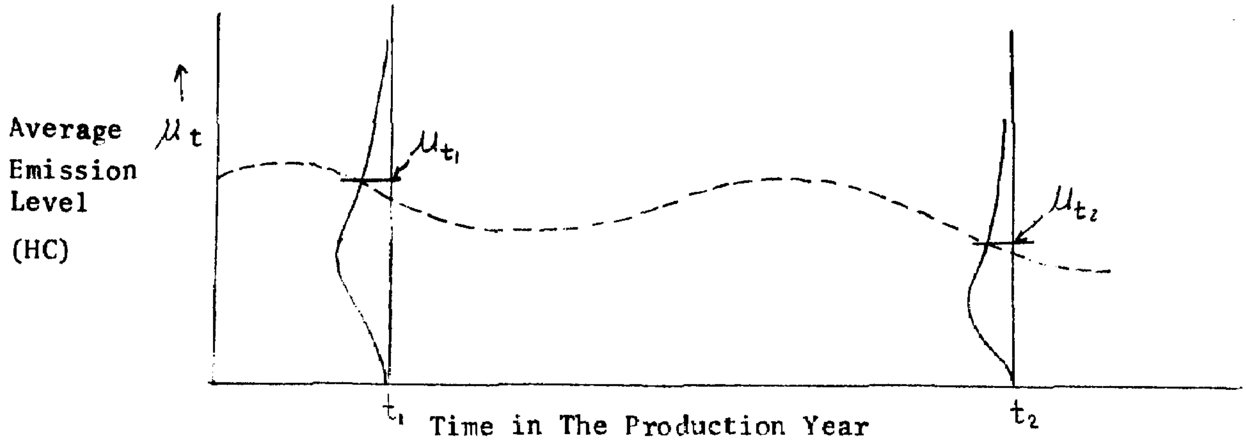



Figure 2.1-2
Temporal Patterns of Average Emissions Level

If one were able to obtain sufficient data to describe the manner in which $\mu_t$ varies with time, a logical next question is to consider what factors contribute to, and combine, to determine the dependence of $\mu_t$ on time. This project will, for the purpose of providing some structure within which to approach this task, segment those factors into two major categories:

I.) Specific Actions Taken in the Production/Inspection Process which are clearly identifiable and whose impact on emissions lend themselves to measurement and isolation of effects. Included here would be factors such as the presence or absence of seven mode testing, different levels of audit testing, etc.

II.) Long-Term Trends and Less Identifiable Factors: - included here would be that nebulous "other" category of the elusive and ill-characterized factors which, individually are virtually impossible to isolate, but collectively account for changes in the emission levels patterns and distributions which are otherwise unexplainable.

Reference to Figure 2.1-3 will, perhaps, facilitate a clearer understanding of this "segmenting" of factors accounting for emissions level changes. At a fixed point in time, say t, the emissions levels prevailing among all automobiles produced are thought of as being distributed according to some distributional pattern with an average $\mu_{ot}$ and variance $\sigma^2_{ot}$, i.e. - D( $\mu_{ot}$, $\sigma^2_{ot}$). Let us think of this distribution as the one which would prevail if we were able to measure the emissions levels of each automobile as it came off the production line.

Now, over a "short period of time" some changes may occur to these automobiles as a result of certain identifiable actions. Specifically, a fraction of them ( $\alpha_1$) may be hot seven mode tested, a fraction of them ( $\alpha_2$) may be idle tested, another fraction of them ( $\alpha_3$) may receive both a hot seven mode and idle test, and finally a fraction ( $\alpha_o$) may receive no tests at all. Conceptually, we will describe any changes which may result in the emissions distribution as a result of the particular action (i.e. - testing type) taken by means of indicating a modified set of parameters a-posteriori to the testing. For example, at time t, the emissions were distributed D( $\mu_{ot}$, $\sigma^2_{ot}$) whereas that fraction, $\alpha_1$, of automobiles which were 7- mode tested only, at time t will, after testing, be distributed D( $\mu_{1,t}$, $\sigma^2_{1t}$) - possibly different from prior to this testing type. In a manner similar to this the impact of the other actions (i.e. - modes of inspection testing) are reflected in their changed distributions. After the respective tests are performed on the portions of the incoming population of automobiles and these tested subpopulations are pooled together again, we can conceive of the resulting emissions distribution as being $D(\mu_{4t}, \sigma^2_{4t})$ and this constitutes the statistical nature of the emissions population which becomes the input population to the C.V.S. testing (i.e. - audit testing) phase.

Again, any change in emissions patterns which may be introduced as a result of audit testing is indicated by a modified set of parameters after such testing (i.e. - $D(\mu_{5t}, \sigma^2_{5t})$) as compared to the situation before this testing (i.e. - $D(\mu_{4t}, \sigma^2_{4t})$).

In summary then, at a "fixed" point in time, t, the total impact on the emissions patterns which results from these specific actions (i.e. - combinations of 7-mode, idle and C.V.S. tests) is described by a comparison of the emissions patterns <u>before</u> these steps (i.e. - $D(\mu_{ot}, \sigma^2_{ot})$) and the emissions patterns <u>after</u> these steps - (i.e. - $D(\mu_{5t}, \sigma^2_{5t})$). It is these types of changes which are included in the first category described earlier, that is, "Specific Actions Taken in the Production/Inspection Process".

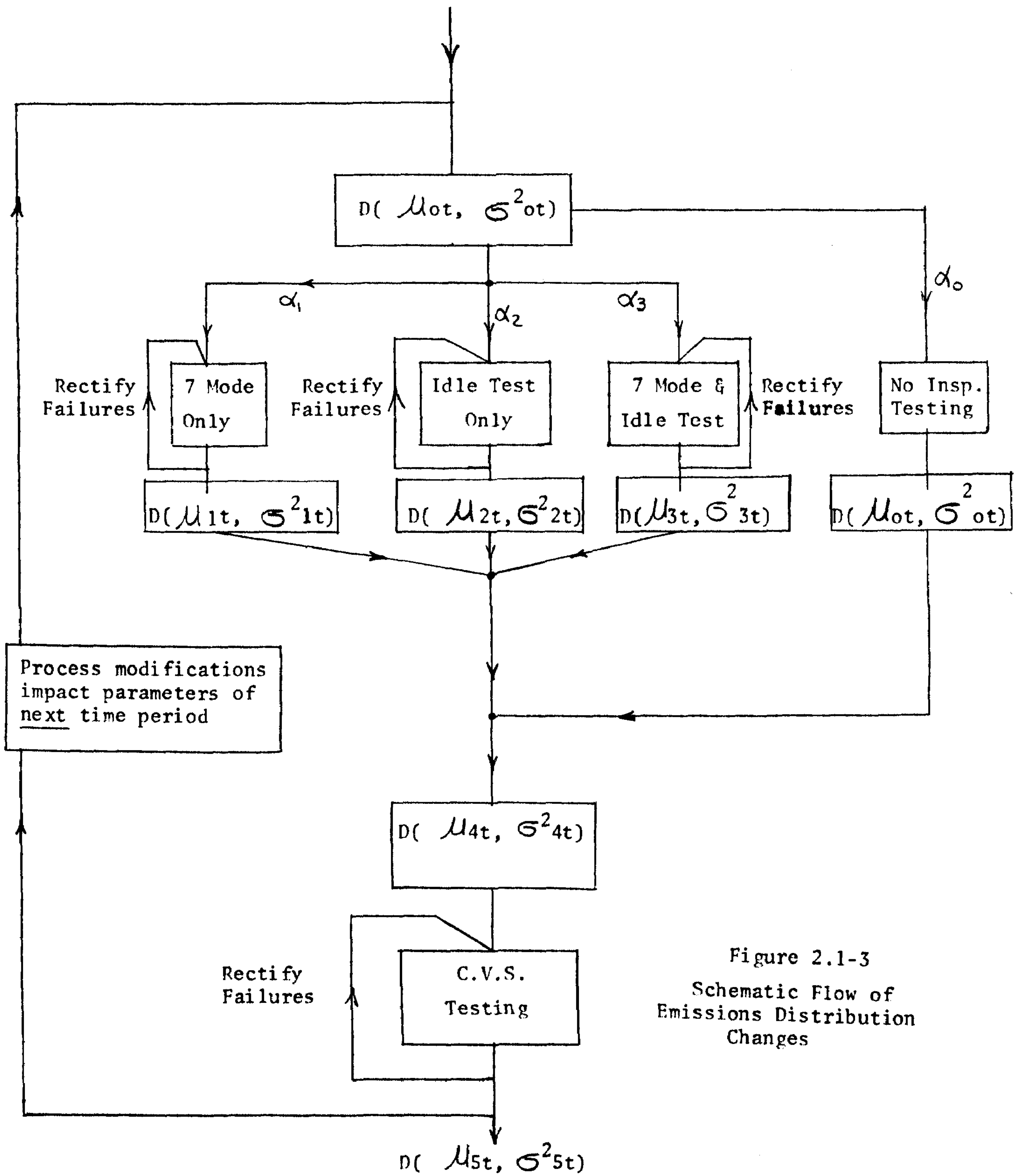



Figure 2.1-3
Schematic Flow of Emissions Distribution Changes

## 2.2 Trends in Average Emissions Levels During a Production Year

Suppose that at the time t within a production year one can specify:

$n(t) \equiv$ the number of automobiles produced at time t of that production year.

$\mu(t) \equiv$ average emissions level of the new automobile produced at time t (in grams per mile).

$\Gamma \equiv$ conversion factor which will convert grams per mile to tons per year (assuming a fixed number of miles per year driven by an "average" car).

Then

$$\mathcal{E} = \Gamma \int_0^T n(t)\mu(t)\,dt \qquad (2.2.1)$$

represents the total average emissions (in tons per year) which will be generated as a result of the production pattern and time pattern of average emissions. This assumes that automobiles produced at time t will continue to generate emissions at an average level $\mu(t)$ throughout their driving life cycle.

Alternately, consider that instead of automobiles produced at time t emitting at the average level $\mu(t)$, one were to assume that the average emission level were constant, say $\mu^{(0)}$. Then,

$$\mathcal{E}^{(0)} \equiv \Gamma \int_0^T \mu^{(0)} n(t)\,dt$$

$$= \Gamma \mu^{(0)} \int_0^T n(t)\,dt \qquad (2.2.2)$$

would represent the total average emissions (in tons per year) if all new automobiles produced had the same average emissions level, i.e., $\mu^{(0)}$.

Further, $E^{(0)} - E$, would represent the change in average emissions which would result during the production year if average emissions follow the pattern $\{\mu(t): 0 \leq t \leq T\}$ rather than stay at the average level $\mu^{(0)}$ for all production during the year.

This admittedly simplistic approach to measuring change in average emission levels stimulates a number of questions:

(1) Is sufficient data available to support an adequate characterization of the functions $\mu(t)$, $\Omega(t)$, etc.? If not, what modifications in this approach would be necessary to enable a similar measurement to be developed which is in harmony with available data?

(2) Even if the computations, or a reasonable approximation thereof, can be attained, can one attribute the estimated emission level changes to any causal factors?

Regarding (1) above, the data available for analysis in the report were summary results covering various production quarters during 1972 and 1973 model years. This aggregated (in time) data precludes an analysis of emissions level change in continuous time, however, modifications of the conceptual approach to estimating changes in levels of emissions so as to employ aggregated data will be presented in Chapter 4 of this report. The second point (2) above is perhaps a more crucial one. The absence of any data on emissions levels which were gathered on automobiles produced prior to the introduction of assembly line testing procedures in California would appear to raise serious questions about whether or not any trends (i.e., changes) in emissions levels occurring over time during the production year can validly be attributed to the presence of assembly line testing as the causal factor. Stated alternately, the data base available for analysis only reflects the "after assembly line testing" situation and there was not available any "before assembly line testing" data against which to compare. Because of this, there has been no attempt in this report to either assess the statistical significance of changes in emissions levels over time during a production year or to identify the presence of assembly line testing as the cause of any such changes as may appear significant. Rather, such changes in emissions levels as may be estimated by the techniques briefly described earlier, are presented in the hopes that such preliminary information on the magnitudes and patterns of such changes during a production year may provide useful insight into a more fundamental understanding of the nature of this type of testing.

## 2.3 Short Inspection Tests and Their Impact Assessment

This section will focus on a discussion of the methodology employed to assess the impact of those combinations of hot seven mode tests and dle ests which are applied to end of production line automobiles. In Figure 2.1-3 we can view this as that segment of the "flow" of automobiles through the portion of the Assembly Line Test Procedure which terminates just prior to the C.V.S. Testing Phase. The primary interest of this section, then, is an analysis of the manner in which 7- mode testing, for example, at some level will affect the average level of the emissions distributions.

Consider some end of line inspection test, T, say, the effect of which one seeks to investigate. Specifically, we desire to estimate any difference in average emissions levels which may exist due to the presence of testing some fraction $\alpha$ of automobiles produced by this test procedure.

Let $\mu_{Tj}$ be defined as the average (i.e. - 1st moment) of the distribution of emissions of type j for the population of automobiles which have been tested by procedure $T$ prior to audit testing. Conversely, let $\mu_{\bar{T}j}$ be the mean of the distribution of emissions of type j for the population of automobiles which have not been tested by procedure $T$ prior to audit testing. If it is true that the fraction $\alpha$ of the total population of automobiles have received test $T$, and the fraction $(1-\alpha)$ have not received test $T$, then the expected value of the emissions resulting from audit testing from the total (and mixed) population of automobiles is:

$$\begin{aligned} \mu_j &\equiv \mu_{Tj} \cdot \alpha + (1-\alpha)\mu_{\bar{T}j} \\ &= \mu_{\bar{T}j} + \alpha\left(\mu_{Tj} - \mu_{\bar{T}j}\right) \qquad (2.3.1) \end{aligned}$$

If, in fact, the average level of emissions (as measured by audit testing) in the presence of test procedure $T$ (i.e. - $\mu_{Tj}$) is significantly different from the average level in the absence of procedure $T$ (i.e. - $\mu_{\bar{T}j}$), then the fraction, $\alpha$ , of the population receiving test $T$ represents the rate at which the overall process mean will deviate from $\mu_{\bar{T}j}$ in "units" of ( $\mu_{Tj} - \mu_{\bar{T}j}$) grams per mile. Consequently the term

$$\alpha(\mu_{Tj} - \mu_{\bar{T}j}) \qquad (2.3.2)$$

represents the deviation in grams per mile of the mean level of emissions when applying test $T$ to $100\alpha$ % of the automobiles produced from the mean level when none of the automobiles receive procedure $T$

In order to express this average emissions level in terms of tons per year, one can convert as follows:

$$\mathcal{E}_j = \mu_j \cdot \Gamma \cdot M \cdot N \qquad (2.3.3)$$

where

$\mu_j$ = overall mean emission level, as defined previously, of emission type j

$\Gamma$ = conversion factor ($1.1 \times 10^{-6}$ tons/gram)

$M$ = average yearly mileage per automobile

$N$ = number of automobiles produced per year

## 2.4 Audit Tests and Their Impact Assessment

This section focuses on an analysis of the impact on emissions reduction occurring as a result of the screening or rectifying aspect of the audit test procedures. Aside from the long term effect which may occur simply due to the fact that some kind of emissions level monitoring exists, an interesting question, in and of itself, is, to what extent are overall emission levels changed if a 2% audit test is applied to all cars produced in the nation. This section focuses on an analysis of just that question.

Consider the following situation. Emissions measurements, via C.V.S techniques as employed currently in California, are taken for a single emittent (say, hydrocarbon) and the density function of the random variable, $e$, is determined. We shall think of this distribution of $e$ as characterizing the distribution of original measurements of C.V.S. tests on this population of automobiles of a single engine category. Assume the distribution to be of the form as shown in Figure 2.4-1.

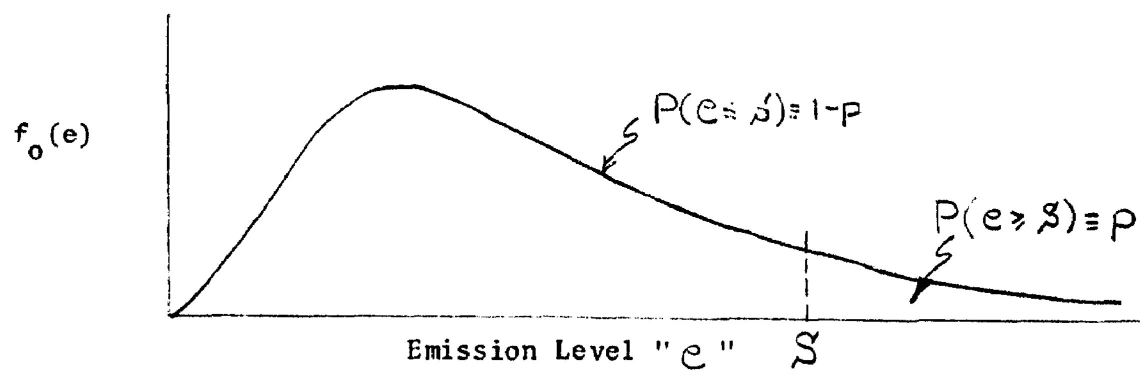



Figure 2.4-1
Skewed Emission Patterns

The shape of this density is similar to that so commonly observed in emissions measurements, i.e. - non-negative, skewed to the right and approximately log-normally distributed. Shown in Figure 2.4-1 is a value of the standard, "$S$", which is to be interpreted as the current standards in the California procedures. We shall denote:

$$p = \int_{\mathcal{S}}^{\infty} f_o(e)\,de$$
$$= P\{e > \mathcal{S}\} \qquad (2.4.1)$$

that is, p equals the probability that one observation on this population (i.e. - emissions measurement on an automobile) exceeds the standard $\mathcal{S}$ . In a similar manner, we denote

$$1-p = \int_{0}^{\mathcal{S}} f_o(e)\,de$$
$$= P\{e \leq \mathcal{S}\} \qquad (2.4.2)$$

that is, the probability that one observation on this population does not exceed the standard.

Of basic concern is, what happens to average emissions levels as a result of the audit sampling and any modifications which occur in the emissions distribution because of it. We shall focus on three subsets of the total population:

I. The set of automobiles not audit tested
II. The set of automobiles audit tested and passing the test
III. The set of automobiles audit tested and failing the test.

The intent is to determine the distributional form of emissions, after the audit sampling, so as to relate this in some way to the audit sampling rate, $\beta$ , say. Let us consider how the distributional characteristics of the three subsets described above will contribute to this - "post audit sampling" emissions distribution.

Case I - Automobiles Not Audit Tested

Given this population of automobiles not audit tested, one one would anticipate that if they were C.V.S. tested their distribution of emissions would be reasonably approximated by $f_o(e)$, the density in Figure 2.4-1 which described the distribution of original measurements of emissions. We thus assume:

$$f(e|\text{not audit tested}) = f_o(e)$$

It is further noted that $(1-\beta)$ is the fraction of the total population of automobiles to which this density applies.

Case II - Automobiles Audit Tested and Passing the Test

This subset of automobiles is restricted to those which, upon C.V.S. testing, yielded emission values no greater than $\mathcal{S}$. In Figure 2.4-1 this is the set of emission values, e, less than or equal to $\mathcal{S}$. Now, if sufficient retesting were performed on automobiles in this subset one could characterize the distribution of emissions of such cars, after the impact (if any) of initially being C.V.S tested and having passed that test has been accounted for. Let us denote $f_2(e)$ as the density function of the distribution of emissions from such automobiles. It is important to note that this distribution is not, necessarily, identical with that of cars not audit tested at all since this category does not include failing vehicles. Further, this distribution is characteristic of a fraction $\beta(1-p)$ of the total population of original automobiles.

Case III - Automobiles Audit Tested and Failing the Test

This subset of automobiles is a fraction of the upper tail of the density function of Figure 2.4-1. Let us denote the density function characterizing this distribution of emissions as $f_3(e)$. As in the previous case it is important to note here that $f_3(e)$ is not, in general, identical with $f(e)$ for after automobiles are audit tested, have initially failed, and are subsequently adjusted, repaired, etc. to a point where they can pass a retest, the distribution of their emissions may be substantially modified. The sum total of this modification is encompassed in $f_3(e)$. Again, as earlier, observe that this density will be characteristic of a fraction $\beta p$ of the total population of original automobiles.

We reiterate, at this point, the central question of this section. How does the average emission level change as a result of the audit sampling procedure employed? Consider first the average emissions which would prevail if no audit testing were employed. This is

$$\bar{e}^{(0)} \equiv \bar{e}_0 = \int_0^\infty e\, f_0(e)\,de \qquad (2.4.3)$$

Alternately, what average emissions level will prevail if audit testing is executed at the rate $\beta$? It is readily seen that

$$\bar{e}^{(f)} = (1-\beta)\int_0^\infty e\, f_0(e)\,de + \beta(1-p)\int_0^\infty e\, f_1(e)\,de + \beta p \int_0^\infty e\, f_2(e)\,de$$

$$= (1-\beta)\bar{e}_0 + \beta(1-p)\bar{e}_1 + \beta p\, \bar{e}_2 \qquad (2.4.4)$$

That is, the resulting average emissions level is a weighted average of the average emissions levels of the three subsets of automobiles discussed earlier, the scaling weights being those fractions of the total population falling into the respective subsets.

The change in average emissions levels attributable to the audit sampling rate, $\beta$, is the difference in these two averages, namely:

$$\Delta \equiv \bar{e}^{(o)} - \bar{e}^{(f)}$$

$$\Delta = \bar{e}^{(o)} - \left\{(1-\beta)\bar{e}_o + \beta(1-p)\bar{e}_1 + \beta p \bar{e}_2\right\}$$

$$\Delta = \beta\bar{e}_o - \beta(1-p)\bar{e}_1 - \beta p\bar{e}_2 \quad (2.4.5)$$

We thus have the change in average emissions (in grams per mile) resulting from this sampling and rectifying procedure. The discussion thus far has assumed a single automobile or engine category and also a single emittant type. If these additional factors, as well as different manufacturers, are incorporated a straightforward modification of expression (2.4.5) above applies. Let us denote:

$\ell$ = manufacturer's index; $\ell$ = 1,2,3 for General Motors, Ford and Chrysler, respectively

j = emission type index; j = 1,2,3 for hydrocarbon, carbon monoxide and oxides of nitrogen, respectively

$p_\ell$ = overall failure rate for manufacturer $\ell$ in the audit tests

$\bar{e}_{\ell j}^{(o)}$ = average emissions level for emission type j, manufacturer $\ell$ on original measurements of automobiles not audit tested

$\bar{e}_{\ell j}^{(1)}$ = average emissions level for emission type j, manufacturer $\ell$ on measurements of automobiles which were audit tested and passed the test originally

$\bar{e}_{\ell j}^{(2)}$ = average final emissions levels for emission type j, manufacturer $\ell$ on measurements of automobiles which were audit tested, failed the test and were adjusted so as to pass a subsequent C.V.S. test

It is now possible to denote the change in emissions attributable to a sampling rate, $\beta$, for a specific emission type and manufacturer. This is a modification of expression (2.4.5) employing the above notation:

$$\Delta_{\ell j} = \beta \bar{e}^{(0)}_{\ell j} - \beta(1-p_\ell)\bar{e}^{(1)}_{\ell j} - \beta p_\ell \bar{e}^{(2)}_{\ell j} \qquad \begin{matrix} j = 1,2,3 \\ \ell = 1,2,3 \end{matrix} \qquad (2.4.6)$$

These emissions changes are in grams per mile. To relate this change to tons per year, it is necessary to account for the average mileage (per year) an automobile is driven, and the number of automobiles being manufactured. Defining

$M_\ell$ = average miles per year driven by a typical automobile from manufacturer $\ell$

$N_\ell$ = number of automobiles produced, per year, by manufacturer $\ell$

$\Gamma$ = conversion factor to relate grams per mile to tons per mile (i.e. - $\Gamma = 1.1 \times 10^{-6}$ tons/grams)

One obtains

$$\mathcal{E}_{\ell j} = \Gamma \cdot \Delta_{\ell j} \cdot M_\ell \cdot N_\ell \qquad \begin{matrix} \ell = 1,2.3 \\ j = 1,2.3 \end{matrix}$$

as the average change in emissions (in tons per year) for emissions type j associated with manufacturer $\ell$ as a result of the audit testing program as currently conducted in California.

As outlined above, this methodology is employed for the assessment of emissions levels changes which would be attained if audit testing, as currently employed in California, were extended to a nationwide basis. Specific results emanating from this type of analysis applied to the currently available data base are contained in Chapter 4 of this report. Extension of this methodology in order to consider alternate modes of audit sampling is contained in Chapter 5.

# 3. FAILURE RATES AND REASONS FOR FAILURE OBSERVED FROM ASSEMBLY LINE TEST PROGRAM DATA

## 3.0 Introduction

An overview of the failure rates and descriptions of reasons for failure is presented in this chapter. It will be helpful to have this "baseline" understanding of current inspection and audit testing failure rates being experienced by the various manufacturers whose data is employed in this study, prior to moving on to an analysis of emissions reductions which may be attainable on a nationwide basis from these and related testing programs.

## 3.1 Seven Mode Inspection Tests

### 3.1.1 Overview of Failure Rates

For the 1972 model year, the failure rates for the seven mode inspection tests which were run are summarized in Table 3.1-1. This data represents the overall results by manufacturer.

| Manufacturer | Number of Tests | Overall Failure Rates (Seven Mode Inspection Tests) |
|---|---|---|
| Chrysler | 31669 | 25.5% |
| Ford | 81953 | 24.8% |
| General Motors | 96519 | 5.29% |

Table 3.1-1

1972 Model Year Seven Mode Inspection Test Failure Rates (by Manufacturer)

Within a manufacturer there are a variety of ways in which these overall failure rates can be segmented for analyses. Further, variations in the reporting format from one manufacturer to another can result in differing interpretations of "failure rates". Because of these differences, further discussion of the seven mode inspection test results will be presented for each manufacturer.

3.1.2 Failure Rates: General Motors Corporation

a.) Data Base

Summary test data was available on seven mode tests performed for the 2nd, 3rd, 4th and 4th plus buildout quarters of the 1972 model year only. Reporting requirements for the 1973 model year tests are such that the 1973 seven mode test results are not available. For the 1972 data available the total number of units initially tested, the number of units failing initial tests and the number of units passing initial tests were reported (classified, in each case, by Manufacturing Division/Engine Displacement/Carburetor barrels categories).

An analysis of the failure rates on inspection tests was complicated somewhat by variations in the reporting format of data from the different production quarters for the 1972 model year. Specifically, for the second and fourth plus buildout quarters, the results for units failing initial tests tables contained (by category) data on the number tested and the number of gross fails. The similar tables from the third and fourth quarters included (by category) data on the number tested, number of gross fails and number of good reruns.

Ambiguity in the definition of "gross fails" leads to some confusion on how to handle a summary of failure rates. To illustrate, consider third production quarter data for the Pontiac 400 C.I.D. (4 barrel) engines as reported by GM:

| | |
|---|---|
| Number of Initial Tests | 884 |
| Number of Failing initial Tests | 33 |
| Gross Fails among initial Tests | 13 |
| Good Reruns | 10 |

The gross fails may have resulted from a mixture of two sources. On the one hand they could all be attributable to test equipment (and/or procedure) malfunctions, and as such, the corresponding test results would represent invalid data points. Alternately, they could all be attributable to unaccountably extreme variations in an engine's results even though there was no test equipment (and/or procedure) malfunction. Here such data, while undesirable, represents valid data and test results. If the former case prevails we might adjust our interpretation of the source data as follows:

Number of valid initial tests = Number of Initial Tests - Number of Gross Fails
= 884 - 13
= 871

Number of valid failing initial tests = Number of failing initial tests - Number of gross fails
= 33 - 13
= 20

and

$$\% \text{ Failure Rate} = \frac{\text{Number of valid failing initial tests}}{\text{Number of valid initial tests}} \times 100$$
$$= \frac{20}{871} \times 100$$
$$= 2.3\%$$

In the second situation cited above, we might consider the failure rate as:

$$\text{Failure Rate } (\%) = (\text{Number of Failing Initial Tests}) \div (\text{Number of Initial Tests}) \times 100$$
$$= \frac{33}{884} \times 100$$
$$= 3.74\%$$

These two alternatives represent the bounding cases, and if the indicated gross fails consisted of a mixture of test equipment/procedure related gross fails and engine related gross fails the failure rate for that category would always be between these two extreme values. Consequently it is illuminating to consider the discrepency in failure rates (for a given category) which may occur.

b.) Seven Mode Test Failure Rates

Assuming that all gross failures are attributable to engine variability and not test malfunctions, the failure rates for the 1972 model year tests are summarized in Tables 3.1-2 thru 3.1-4.

| Division | Production Quarter (1972 Model Year) | | | | Total Year |
|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | |
| Chevrolet | 6.9 | 2.4 | 3.4 | 15.4 | 4.4 |
| Pontiac | 4.7 | 3.4 | 3.8 | 21.6 | 4.1 |
| Oldsmobile | 11.5 | 10.4 | 7.0 | 12.2 | 10.1 |
| Buick | 1.4 | 6.6 | 5.7 | 41.6 | 4.9 |
| Cadillac | 4.0 | 1.6 | 1.8 | - | 2.5 |
| Overall | 6.19 | 4.95 | 3.83 | 15.82 | 5.29 |

Table 3.1-2

7 Mode Test Failure Rates (in %)

General Motors: 1972 Model Year

(By Division and Production Quarter)

From Table 3.1-2 one observes a number of patterns:

I Some noticeable differences in the failure rates from one division to another (e.g., Oldsmobile and Cadillac show strikingly different failure rates).

II Within an operating division, there is the general trend of a decreasing inspection test failure rate as the production year proceeds, except for the buildout quarter in which there is a consistent increase in the failure rate. This appears to indicate that there is a gradual improvement in the ability of the production process to satisfy the testing procedures as "experience" in production of that model grows, with the exception of the buildout quarter.

Aggregating the data according to engine size (i.e., C.I.D.) rather than operating division similar tone patterns appear, as seen from Table 3.1-3.

| Engine Size | Production Quarter (1972 Model Year) | | | | Total Year |
|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | |
| 140 | 15.7 | 9.7 | 9.2 | 15.9 | 12.1 |
| 250 | 5.2 | 2.7 | 3.4 | 6.1 | 3.5 |
| 350 | 5.4 | 4.0 | 3.3 | 14.0 | 4.3 |
| 400 | 6.1 | 2.5 | 2.6 | 35.9 | 4.1 |
| 455 | 5.2 | 4.2 | 2.9 | 11.8 | 4.5 |
| 472 | 3.8 | 1.5 | 1.5 | 0.0 | 2.2 |
| 500 | 4.5 | 2.4 | 4.0 | - | 3.6 |
| Overall | 6.19 | 4.95 | 3.83 | 15.82 | 5.29 |

Table 3.1-3

7 Mode Test Failure Rates (in %)

General Motors: 1972 Model Year

(By Engine Size and Production Quarter)

In Table 3.1-4, the seven mode test failure rates are presented when segmented into categories indexed by Division/Displacement/Carburetor barrels combinations for the production quarters available from the 1972 model year.

| Engine Category | | Production Quarter | | | | Total |
|---|---|---|---|---|---|---|
| | | 2 | 3 | 4 | 5 | |
| Chev. | 140-1 | 20.6 | 19.2 | 13.2 | 19.8 | 17.8 |
| | 140-2 | 14.8 | 8.7 | 8.6 | 15.0 | 11.2 |
| | 250-1 | 5.2 | 2.7 | 3.4 | 6.1 | 3.5 |
| | 350-2 | 3.1 | 1.2 | 1.4 | 6.1 | 1.7 |
| | 350-4 | 4.2 | 1.9 | 2.1 | 8.5 | 2.7 |
| | 400-2 | 7.5 | 2.1 | 2.6 | 38.2 | 4.4 |
| Pont. | 350-2 | 5.4 | 3.6 | 5.5 | 10.7 | 4.7 |
| | 400-2 | 5.0 | 2.6 | 2.8 | 23.5 | 3.5 |
| | 400-4 | 2.9 | 3.7 | 2.5 | 20.0 | 3.2 |
| | 455-2 | 4.9 | 6.5 | 4.9 | 40.0 | 5.8 |
| | 455-4 | 5.4 | 2.6 | 3.2 | 43.5 | 4.2 |
| Olds. | 350-2 | 2.3 | 4.9 | 5.0 | 18.2 | 4.5 |
| | 350-4 | 20.7 | 16.2 | 11.2 | 29.3 | 16.6 |
| | 455-4 | 7.7 | 6.1 | 2.3 | 7.4 | 6.2 |
| Buick | 350-2 | 3.5 | 10.9 | 8.7 | 3.3 | 8.0 |
| | 350-4 | 5.6 | 9.0 | 6.7 | 48.7 | 7.7 |
| | 455-4 | 2.9 | 2.7 | 3.0 | 37.9 | 3.0 |
| Cad. | 472-4 | 3.8 | 1.5 | 1.5 | 0.0 | 2.2 |
| | 500-4 | 4.5 | 2.4 | 4.0 | - | 3.6 |

Table 3.1-4

7 Mode Test Failure Rates (in %)

General Motors: 1972 Model Year

(By Engine/Division Category and Production Quarter)

c. Seven Mode Test Failure Rates: Adjusted For Test Malfunctions

Considering the situation where the indicated gross failures are assumed to be attributable to test and/or equipment malfunctions the failure rates are only slightly modified in contrast to the earlier situation. These failure rates, after adjustment for test malfunctions, are summarized in Tables 3.1-5 through 3.1-7.

| Division | Production Quarter (1972 Model Year) | | | | Total Year |
|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | |
| Chevrolet | 6.7 | 2.4 | 3.4 | 15.3 | 4.3 |
| Pontiac | 4.1 | 3.0 | 3.5 | 20.9 | 3.7 |
| Oldsmobile | 10.8 | 10.0 | 7.0 | 11.5 | 9.7 |
| Buick | 1.3 | 6.5 | 5.7 | 4.16 | 4.9 |
| Cadialac | 3.6 | 1.3 | 1.5 | 0.0 | 2.2 |
| Overall | 5.89 | 4.78 | 3.77 | 15.61 | 5.15 |

Table 3.1-5
7 Mode Test Failure Rates (in %)

| Engine Size | Production Quarter (1972 Model Year) | | | | Total Year |
|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | |
| 140 | 15.72 | 8.95 | 8.28 | 15.85 | 11.68 |
| 250 | 5.1 | 2.7 | 3.3 | 5.3 | 3.4 |
| 350 | 5.02 | 3.86 | 3.29 | 13.33 | 4.12 |
| 400 | 5.74 | 2.17 | 2.42 | 35.87 | 3.80 |
| 455 | 4.98 | 3.99 | 2.92 | 11.57 | 4.34 |
| 472 | 3.5 | 1.20 | 1.10 | 0.00 | 1.90 |
| 500 | 4.0 | 2.20 | 4.00 | 0.00 | 3.40 |
| Overall | 5.89 | 4.78 | 3.77 | 15.61 | 5.15 |

Table 3.1-6
7 Mode Test Failure Rates (in %)
Adjusted for Test Malfunctions

General Motors: 1972 Model Year
(By Engine Size and Production Quarter)

| Engine Category | | Production Quarter (1972 Model Year) | | | | Total Year |
|---|---|---|---|---|---|---|
| | | 2 | 3 | 4 | 5 | |
| Chevrolet | 140-1 | 20.6 | 19.2 | 13.2 | 19.8 | 17.8 |
| | 140-2 | 14.8 | 8.7 | 8.6 | 15.0 | 11.2 |
| | 250-1 | 5.1 | 2.7 | 3.3 | 5.3 | 3.4 |
| | 350-2 | 3.1 | 1.2 | 1.4 | 5.3 | 1.7 |
| | 350-4 | 3.6 | 1.8 | 2.0 | 8.0 | 2.5 |
| | 400-2 | 7.5 | 2.1 | 2.6 | 38.2 | 4.4 |
| Pontiac | 350-2 | 5.2 | 3.5 | 5.5 | 9.1 | 4.6 |
| | 400-2 | 4.6 | 2.4 | 2.8 | 23.5 | 3.4 |
| | 400-4 | 1.5 | 2.3 | 1.0 | 20.0 | 1.8 |
| | 455-2 | 4.9 | 6.5 | 4.9 | 40.0 | 5.8 |
| | 455-4 | 4.8 | 2.3 | 3.2 | 43.5 | 3.9 |
| Oldsmobile | 350-2 | 0.30 | 4.2 | 5.0 | 15.6 | 3.5 |
| | 350-4 | 20.0 | 15.8 | 11.2 | 28.4 | 16.2 |
| | 455-4 | 7.5 | 6.0 | 2.3 | 7.2 | 6.0 |
| Buick | 350-2 | 3.2 | 10.8 | 8.7 | 3.3 | 7.9 |
| | 350-4 | 5.6 | 8.9 | 6.7 | 48.7 | 7.6 |
| | 455-4 | 2.9 | 1.5 | 3.0 | 37.9 | 2.6 |
| Cadillac | 472-4 | 3.5 | 1.2 | 1.1 | 0.0 | 1.9 |
| | 500-4 | 4.0 | 2.2 | 4.0 | 0.0 | 3.4 |

Table 3.1-7

7 Mode Test Failure Rates (in %)

Adjusted For Test Malfunctions

General Motors: 1972 Model Year

(By engine/division category and production quarter)

### 3.1.3 Failure Rates: Ford Motor Company

a.) Data Base

Summary test data for 7-mode tests was available for the 2nd, 3rd, 4th and 4th plus buildout quarters of the 1972 model year. The Ford data is broken down by engine size, across all divisions (Ford, Mercury and Trucks), and does not include vehicles that failed because of test equipment malfunctions.

b.) Seven Mode Test Failure Rates

In Table 3.1-8 the seven mode test failure rates are presented. Here they are classified by engine category and production quarter.

| Engine | Production Quarter | | | | Total |
|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | |
| 98-1V | 40.6 | 39.2 | 34.8 | 50.0 | 38.8 |
| 122-1V | 34.9 | 36.2 | 38.3 | 62.6 | 39.8 |
| 159-2V | - | 34.9 | 61.4 | - | 58.8 |
| 170-1V | 0.0 | 26.7 | 24.5 | 0.0 | 22.9 |
| 200-1V | 38.4 | 19.1 | 31.9 | 51.1 | 29.3 |
| 240-1V | 18.0 | 12.1 | 14.3 | 5.6 | 12.8 |
| 250-1V | 38.0 | 36.5 | 37.5 | 55.8 | 37.5 |
| 302-2V | 31.6 | 26.7 | 31.0 | 33.6 | 29.4 |
| 351-2V | 15.7 | 6.2 | 18.7 | 28.9 | 12.8 |
| 351-4V | 5.9 | 16.0 | 18.4 | 25.7 | 18.4 |
| 360-2V | 31.6 | 32.3 | 40.5 | 49.4 | 37.6 |
| 390-2V | 56.3 | 33.3 | 41.8 | 20.0 | 37.8 |
| 400-2V | 9.5 | 3.6 | 8.7 | 14.1 | 7.7 |
| 429-2V | 13.1 | 8.8 | 8.2 | 9.6 | 10.4 |
| 460-2V | 20.8 | 14.0 | 14.0 | 19.8 | 16.3 |
| Overall | 21.0 | 19.5 | 30.2 | 41.1 | 24.8 |

Table 3.1-8
7 Mode Test Failure Rates (in %)
Ford: 1972 Model Year
(By Engine Size)

3.1.4 Failure Rates: Chrysler Corporation

a.) Data Base

Summary test data for seven mode tests from the Chrysler Corporation was available for the 1st through 5th (i.e. - buildout) quarter of the 1972 model year. This data was categorized by engine size and production quarter, and reflected the number of initial tests and the number of initial failures.

b.) Seven Mode Test Failure Rates

In Table 3.1-9, the seven mode test failure rates are presented for the 1972 model year Chrysler data. These failure rates are classified by engine category and production quarter.

| Engine Size | Production Quarter (1972 Model Year) | | | | | Total |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | |
| 198 | 0.0 | 16.3 | 39.6 | 49.0 | 33.3 | 34.3 |
| 225 | 88.9 | 53.3 | 74.5 | 77.1 | 85.4 | 75.8 |
| 318 | 38.1 | 11.9 | 4.7 | 13.4 | 22.7 | 15.8 |
| 340 | 6.0 | 3.2 | 3.5 | 0.6 | 2.5 | 3.2 |
| 360 | 44.3 | 32.8 | 23.6 | 9.4 | 10.7 | 20.7 |
| 400 | 14.1 | 12.3 | 4.8 | 4.1 | 6.8 | 8.7 |
| 440 | 10.9 | 8.3 | 3.5 | 3.8 | 8.9 | 7.1 |
| Overall | 34.0 | 16.3 | 27.4 | 24.1 | 36.6 | 25.5 |

Table 3.1-9

7 Mode Test Failure Rates (in %)

Chrysler Corporation: 1972 Model Year

(By Engine Size)

## 3.2 Audit Tests

### 3.2.1 Overall Audit Test Failure Rates

Tables 3.2-1(a) and (b) present the overall audit test failure rates for the three manufacturers included in this study.

| Manufacturers | Number of Original Tests | Overall Failure Rate Audit Test |
|---|---|---|
| General Motors | 9296 | 7.0 % |
| Ford | 6514 | 15.7 % |
| Chrysler * | N.A. | N.A. |

Table 3.2-1(a)
Overall Audit Test Failure Rates
1972 Model Year

* Audit test failure rates not computed for 1972 model year Chrysler data.

| Manufacturers | Number of Original Tests | Overall Failure Rate Audit Test |
|---|---|---|
| General Motors | 4090 | 15.7 % |
| Ford | 2901 | 11.5 % |
| Chrysler | 1462 | 17.37 % |

Table 3.2-1(b)
Overall Audit Test Failure Rates
1973 Model Year

It should be noted that Table 3.2-1(a) is based on test data covering production quarters 2 through buildout, within the 1972 model year, and Table 3.2-1(b) is based on test data covering production quarters 1 and 2 of the 1973 model year.

### 3.2.2 Audit Test Failure Rates: General Motors

Tables 3.2-2 through 3.2-5 summarize the audit failure rates as determined from the 1972 and 1973 model year data available from General Motors. In all cases here, the failure rate is the ratio of failures on original tests divided by number of original tests. The columns in Tables 3.2-3 and 3.2-5 refer to distinct failure type categories, that is, entries in the column labelled HC refers to the failure rate for tests which failed the HC standard only, the column HC and CO refers to the failure rate for tests which failed both the HC and CO standards only, etc.

| Division | Engine Category | Number Tests | Number Failures | Failure Rate % |
|---|---|---|---|---|
| Chevrolet | 140-1,2 | 1041 | 96 | 9.2 |
| | 250-1 | 289 | 19 | 6.4 |
| | 350-2 | 1661 | 116 | 7.0 |
| | 350-4 | 827 | 53 | 6.4 |
| | 400-2 | 862 | 44 | 5.1 |
| Pontiac | 350-2 | 419 | 33 | 7.8 |
| | 400-2 | 133 | 5 | 3.8 |
| | 400-4 | 154 | 31 | 20.1 |
| | 455-2 | 52 | 4 | 7.7 |
| | 455-4 | 152 | 7 | 4.6 |
| Oldsmobile | 350-2 | 174 | 6 | 3.4 |
| | 350-4 | 413 | 21 | 5.1 |
| | 455-4 | 359 | 14 | 3.9 |
| Buick | 350-2 | 273 | 15 | 5.5 |
| | 350-4 | 336 | 15 | 4.5 |
| | 455-4 | 422 | 30 | 7 1 |
| Cadillac | 472-4 | 476 | 52 | 10.9 |
| | 500-4 | 116 | 7 | 6.0 |

Table 3.2-2
Audit Failure Rates (in %)
1972 General Motors
(by Division/Engine Category)

| Division | Failure Type or Combination | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | HC | CO | HC and CO | NOX | HC and NOX | CO and NOX | HC, CO and NOX | |
| Chevrolet | 2.1 | 3.6 | 0.3 | 0.9 | 0.1 | 0 | 0 | 7.0 |
| Pontiac | 3.1 | 3.3 | 1.5 | 0.4 | 0 | 0 | 0 | 8.3 |
| Oldsmobile | 1.7 | 1.0 | 0.0 | 1.7 | 0 | 0 | 0 | 4.4 |
| Buick | 1.3 | 1.3 | 0.4 | 2.7 | 0.1 | 0.1 | 0 | 5.9 |
| Cadillac | 0.2 | 8.1 | 0.0 | 1.7 | 0 | 0 | 0 | 10.0 |
| Trucks | 6.4 | 1.1 | 0.7 | 0.1 | 0 | 0 | 0 | 8.3 |

Table 3.2-3
Audit Failure Rates (in %)
1972 General Motors
(by Failure Type and Division)

| Division | Engine Category | Number Tests | Number Fails | Failure Rate % |
|---|---|---|---|---|
| Chevrolet | 140-1,2 | 338 | 53 | 16.0 |
| | 250-1 | 69 | 7 | 10.0 |
| | 350-2 | 723 | 65 | 10.0 |
| | 350-4 | 268 | 27 | 10.0 |
| | 400-2 | 206 | 37 | 18.0 |
| Pontiac | 250-1 | 8 | 1 | 13.0 |
| | 350-2 | 186 | 43 | 23.0 |
| | 400-2 | 96 | 21 | 22.0 |
| | 400-4 | 97 | 25 | 26.0 |
| | 455-4 | 74 | 6 | 8.0 |
| Oldsmobile | 350-2 | 44 | 27 | 61.0 |
| | 350-4 | 161 | 4 | 2.0 |
| | 455-4 | 196 | 9 | 5.0 |
| Buick | 350-2 | 185 | 50 | 27.0 |
| | 350-4 | 124 | 15 | 12.0 |
| | 455-4 | 266 | 90 | 34.0 |
| Cadillac | 472-4 | 254 | 16 | 5.0 |
| | 500-4 | 64 | 4 | 6.0 |

Table 3.2-4

Audit Failure Rates (in %)

1973 General Motors

(by Division/Engine Category)

| Division | Failure Type or Combination | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | HC | CO | HC and CO | NOX | HC and NOX | CO and NOX | HC, CO and NOX | |
| Chevrolet | 2 | 8 | 1 | 3 | 0 | 1 | 0 | 13 |
| Pontiac | 2 | 2 | 0 | 18 | 0 | 0 | 0 | 22 |
| Oldsmobile | 2 | 4 | 2 | 2 | 0 | 0 | 0 | 10 |
| Buick | 10 | 9 | 5 | 1 | 1 | 1 | 0 | 26 |
| Cadillac | 1 | 3 | 0 | 1 | 0 | 0 | 0 | 6 |
| Trucks | 3 | 13 | 3 | 5 | 0 | 0 | 0 | 24 |

Table 3.2-5
Audit Failure Rates (in%)
1973 General Motors
(by Failure Type and Division)

### 3.2.3 Audit Test Failure Rates: Ford Motor Company

Tables 3.2-6 through 3.2-9 summarize the audit failure rates as determined from the 1972 and 1973 model year data available from Ford. As in the previous section, the failure rate referred to here is the ratio of original failures to number of original tests.

| Division | Engine Category | Number Tests | Number Fails | % Fail |
|---|---|---|---|---|
| Ford | 98-1 | 210 | 9 | 4.0 |
| | 122-2 | 1611 | 157 | 10.0 |
| | 200-1 | 166 | 4 | 2.0 |
| | 302-2 | 579 | 36 | 6 |
| | 351-2 | 783 | 157 | 20 |
| | 400-2 | 743 | 97 | 13 |
| | 429-4 | 532 | 42 | 8 |
| | 170-1 | 34 | 17 | 50 |
| | 250-1 | 85 | 1 | 1 |
| | 351-4 | 38 | 2 | 5 |
| Mercury | 122-2 | 154 | 5 | 3 |
| | 200-1 | 19 | 0 | 0 |
| | 302-2 | 133 | 4 | 3 |
| | 351-2 | 284 | 54 | 19 |
| | 351-4 | 11 | 2 | 18 |
| | 400-2 | 197 | 35 | 18 |
| | 429-4 | 1 | 0 | 1 |
| | 460-4 | 271 | 35 | 13 |
| | 250-1 | 20 | 1 | 5 |
| | 170-1 | 2 | 0 | 0 |
| | 159-2 | 87 | 9 | 10 |
| Trucks | 240-1 | 77 | 9 | 12 |
| | 302-2 | 184 | 68 | 37 |
| | 351-2 | 44 | 5 | 11 |
| | 360-2 | 197 | 71 | 36 |
| | 351-4 | 18 | 2 | 11 |
| | 390-2 | 34 | 1 | 3 |

Table 3.2-6
Audit Failure Rates (in %)
1972 Ford
(by Division/Engine Category)

| Division | Engine Category | Number Tests | Number Fails | % Fails |
|---|---|---|---|---|
| Ford | 98-1 | 103 | 3 | 3 |
| | 122-2 | 666 | 95 | 14 |
| | 250-1 | 47 | 5 | 11 |
| | 302-2 | 380 | 32 | 8 |
| | 351-2 | 568 | 47 | 8 |
| | 400-2 | 426 | 80 | 19 |
| | 429-2 | 179 | 18 | 10 |
| Mercury | 302-2 | 108 | 11 | 10 |
| | 351-2 | 9 | 1 | 11 |
| | 460-4 | 271 | 15 | 5 |
| Trucks | 240-1 | 10 | 0 | 0 |
| | 302-2 | 114 | 16 | 14 |
| | 360-2 | 14 | 10 | 71 |
| | 400-2 | 6 | 0 | 0 |

Table 3.2-7
Audit Failure Rates (in %)
1973 Ford
(by Division/Engine Category)

| Division | Failure Type or Combination | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | HC | CO | HC, CO | NO | HC,NO | CO,NO | HC, CO, NO | TOTAL |
| Ford | 1 | 7 | 2 | 0 | 0 | 0 | 0 | 11 |
| Mercury | 2 | 7 | 1 | 2 | 0 | 0 | 0 | 12 |
| Trucks | 11 | 5 | 12 | 0 | 0 | 0 | 0 | 28 |

Table 3.2-8
Audit Failure Rates (in %)
1972 Ford
(by Failure Type and Division)

| Division | Failure Type or Combination | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | HC | CO | HC, CO | NO | HC,NO | CO,NO | HC, CO, NO | TOTAL |
| Ford | 3 | 3 | 1 | 4 | 0 | 0 | 0 | 12 |
| Mercury | 2 | 4 | 1 | 1 | 0 | 0 | 0 | 7 |
| Trucks | 10 | 2 | 3 | 2 | 0 | 0 | 0 | 18 |

Table 3.2-9
Audit Failure Rates (in %)
1973 Ford
(by Failure Type and Division)

### 3.2.4 Audit Test Failure Rates: Chrysler Corporation

Table 3.2-10 summarizes the audit failure rate as determined from the 1973 Chrysler data base .

| Engine Category | Number Tests | Number Fails | % Fail |
|---|---|---|---|
| 225 | 401 | 84 | 20.94 |
| 318 | 459 | 66 | 14.37 |
| 340 | 19 | 14 | 73.68 |
| 360 | 156 | 15 | 9.61 |
| 400 | 295 | 55 | 18.64 |
| 440 | 103 | 12 | 11.65 |
| Spl. 8 | 29 | 6 | 20.68 |
| Overall | 1462 | 252 | 17.37 |

Table 3.2-10
Audit Failure Rates (in %)
1973 Chrysler
(by Engine Category)

## 3.3 Audit Test Failure Reasons

The audit tests performed on the 1972 and 1973 model year production for General Motors provided some diagnostic descriptions of reasons for audit test failures. From the 1972 data base there were a total of 716 audit test runs which failed the test; in 1973 there were 974 such failures. These numbers include more than the number of original failures, for a single car which failed originally and on one or more subsequent retests will have generated more than one "failure" data point.

Tables 3.3-1 and 3.3-2 summarize the patterns of "reasons for audit failures" as observed from the 1972 and 1973 General Motors data, respectively. Each table presents the failure reasons, ranked, from most frequent to least frequently occurring in their respective data sets.

| Descriptor of Failure Reason | Number of Failures | % of Total | Cumulative % of Total |
|---|---|---|---|
| Rerun no Repair | 292 | 40.78 | 40.78 |
| Carb. Change | 97 | 13.54 | 54.32 |
| Electrical Conn Shy | 37 | 5.16 | 59.48 |
| Idle Low 75 RPM Slow | 29 | 4.05 | 63.53 |
| Rich Choke Action | 26 | 3.63 | 67.16 |
| Idle Stop Solenoid Bad | 18 | 2.51 | 69.67 |
| Miscellaneous Repair | 18 | 2.51 | 72.18 |
| Vacuum Conn Shy/Leaking | 17 | 2.37 | 74.55 |
| Improper Precondition | 13 | 1.81 | 76.36 |
| Loose/Shy/Damaged Ign. | 13 | 1.81 | 78.17 |
| Damaged/Stick Choke St. | 12 | 1.67 | 79.84 |
| Timing Was Advanced | 11 | 1.53 | 81.37 |
| Vacuum Hose Leak | 10 | 1.39 | 82.76 |
| Vacuum Hose Leak/Diset | 10 | 1.39 | 84.15 |
| Wrong/Broken Spark Plg. | 10 | 1.39 | 85.54 |
| Equipment Malfunction | 9 | 1.25 | 86.79 |
| Idle High 75 RPM fast | 9 | 1.25 | 88.04 |
| Brakes Dragging/Defe | 8 | 1.11 | 89.15 |
| Loose Mounting | 8 | 1.11 | 90.26 |
| Wrong Plug Gap | 8 | 1.11 | 91.37 |
| Engine Change | 5 | .69 | 92.06 |
| Test Bench Malfunction | 4 | .55 | 92.61 |
| Choke Rod Disconnected | 3 | .41 | 93.02 |
| Incorrect Dwell | 3 | .41 | 93.43 |
| Sgs. Switch | 3 | .41 | 93.84 |
| Valves | 3 | .41 | 94.25 |
| Diverter Value Defect | 3 | .41 | 94.66 |
| Driver Error | 3 | .41 | 95.07 |
| Timing was Retarded | 3 | .41 | 95.48 |
| Valve Lifter | 3 | .41 | 95.89 |
| Accelerator Linkage | 2 | .27 | 96.16 |
| Distributor Defect | 2 | .27 | 96.43 |
| Idle Stop Solenoid Deft | 2 | .27 | 96.70 |
| Incorrect/No Upshift | 2 | .27 | 96.97 |
| Stove Pipe Disct/Shy | 2 | .27 | 97.24 |
| Ran out of Gas | 2 | .27 | 97.51 |
| Air Hose Disct/Shy | 1 | .13 | 97.64 |
| Fluid Leak | 1 | .13 | 97.77 |
| Probe Fell out | 1 | .13 | 97.90 |

( Table 3.3-1 continued on next page)

(Cont'd)

| Descriptor of Failure Reason | Number of Failures | % of Total | Cumulative % of Total |
|---|---|---|---|
| Air Cleaner Sw Sensor | 1 | .13 | 98.03 |
| Air Pump Defect | 1 | .13 | 98.16 |
| Data Instrument Failure | 1 | .13 | 98.29 |
| Driver off Schedule | 1 | .13 | 98.42 |
| Foreign Obj. in Carb. | 1 | .13 | 98.55 |
| Fuel Pump Defect | 1 | .13 | 98.68 |
| Inop. Pre-Conditioning | 1 | .13 | 98.81 |
| Ignition Wires Crossed | 1 | .13 | 98.94 |
| Throttle Blade Binds | 1 | .13 | 99.07 |
| Computer Malfunction | 1 | .13 | 99.20 |
| Overheater | 1 | .13 | 99.33 |
| TCS Fuse | 1 | .13 | 99.46 |
| TCS Temp. Override Swt | 1 | .13 | 99.59 |

Table 3.3-1

Audit Test Failure Reasons

(ranked by frequency of occurrence)

1972 General Motors

| Descriptor of Failure Reason | Number of Failures | % of Total | Cumulative % of Total |
|---|---|---|---|
| Rerun No Repair | 665 | .683 | .683 |
| Carb. Change | 121 | .124 | .807 |
| Idle Stop Solenoid Bad | 25 | .026 | .833 |
| Timing was Advanced | 19 | .020 | .853 |
| Miscellaneous Repair | 18 | .018 | .871 |
| Vacuum Hose Leak | 13 | .013 | .884 |
| Brakes Dragging/Defective | 11 | .011 | .895 |
| Equipment Malfunction | 9 | .009 | .904 |
| Idle Low 75 RPM Slow | 7 | .007 | .911 |
| Incorrect Fast Idle | 7 | .007 | .918 |
| EGR Valve Defective | 6 | .006 | .924 |
| Engine Change | 5 | .005 | .929 |
| Loose Mounting | 5 | .005 | .934 |
| Distributor Defect | 5 | .005 | .939 |
| TCS/TVS Defect Disconn. | 4 | .004 | .943 |
| Vacuum Break Defect | 4 | .004 | .947 |
| Incorrect/No Up Shift | 4 | .004 | .951 |
| Overheater | 3 | .003 | .954 |
| Wrong Plug Cap | 3 | .003 | .957 |
| Wrong/Broken Spark Plg. | 3 | .003 | .960 |
| Vacuum Hose Leak | 3 | .003 | .963 |
| Electrical Conn. Shy | 3 | .003 | .966 |
| Idle High 75 RPM Fast | 3 | .003 | .969 |
| Incorrect Dwell | 2 | .002 | .971 |
| Loose/Shy/Damaged Ign. | 2 | .002 | .973 |
| TCS Temp Override Sect. | 2 | .002 | .975 |
| Veh. Not Driveable | 2 | .002 | .977 |
| Air Hose Disct/Shy | 2 | .002 | 970 |
| Rich Choke Action | 2 | .002 | 981 |
| Timing was Retarded | 2 | .002 | .983 |
| Vacuum Conn. Shy/Leaking | 2 | .002 | .985 |
| Driver Error | 2 | .002 | .987 |
| Delay Relay Defective | 2 | .002 | .989 |
| Incorrect Choke Index | 1 | .001 | .990 |
| Wrong/Damaged Ign. Wire | 1 | .001 | .991 |
| Idle Stop Solenoid Deft | 1 | .001 | .992 |
| Improper Calibration | 1 | .001 | .993 |
| Incorrect Choke Rod Set | 1 | .001 | .994 |
| Stove Pipe Disct/Shy | 1 | .001 | .995 |
| Egr. Valve Leaks | 1 | .001 | .996 |
| Fluid Leak | 1 | .001 | .997 |

Table 3.3-2
Audit Test Failure Reasons
(ranked by frequency of occurrence)
1973 General Motors

# 4. AN ASSESSMENT OF EMISSIONS REDUCTIONS ATTAINABLE FROM A NATIONWIDE APPLICATION OF CURRENT ASSEMBLY LINE TEST PROCEDURES

## 4.0 Introduction

As discussed in Chapter 2, the analysis and assessment of emissions reduction which may appear to be associated with the Assembly Line Testing activities will focus on three contributing segments: (1) Trends, (2) Short Tests, and (3) Audit Tests. This chapter presents the specific results of analyses of the available data base and an attempt to assess the magnitude of emissions level changes as well as identify the plausible contributors to these changes.

## 4.1 Emission Level Changes Association with Trends During a Production Year

### 4.1.1 Introduction

The discussion in Section 2.2 of Chapter 2 presented a conceptual approach to estimating the magnitude of changes in emissions associated with trends in average emission levels during a production year. In this section, that approach is developed with respect to the data base available for this project and the consequent constraints placed on the computational procedure. Specifically, due to the availability of emission data and production data on a quarterly basis, rather than continually throughout the year, some distinct modifications in the estimation technique are necessary. These are developed in the next section.

### 4.1.2 Methodology

Assume that in production quarters j there are $n_j$ autos produced. Consider a baseline quarter in which emissions are distributed $D(\mu_o, \sigma_o^2)$. Suppose in production quarter j the autos manufactured have emissions distributed $D(\mu_j, \sigma_j^2)$. One can then pose the question, "What difference in emittants (i.e., in tons per year) results from producing the $n_j$ autos from quarter j at the average emissions level $\mu_j$ rather than $\mu_o$?"

(1) If produced at average emissions level $\mu_o$, the emissions in tons per year are:

$$E_o = \mu_o \cdot \Gamma \cdot M \times n_j \tag{4.1.1}$$

where $\mu_o \equiv$ average emissions (gm/mile) level at <u>baseline</u>

$\Gamma \equiv$ conversion factor tons/gm

$M \equiv$ average yearly mileage

$n_j \equiv$ number of autos produced in "quarter" j:j=1,2,...,5

(2) If produced at average emissions level $\mu_j$, the emissions in tons per year are:

$$E_j = \mu_j \cdot \Gamma \cdot M \cdot N_j \tag{4.1.2}$$

where $\mu_j$ = average emissions level (gm/mile) for $j^{th}$ production quarter

and $\Gamma$, M, and $n_j$ are as before.

The difference in emissions levels (in tons per year) as a result of producing the j cars at level $\mu_j$ rather than level $\mu_o$ is seen to be:

$$\mathcal{E}_{oj} = E_o - E_j = (\mu_o - \mu_j)\Gamma M n_j \tag{4.1.3}$$

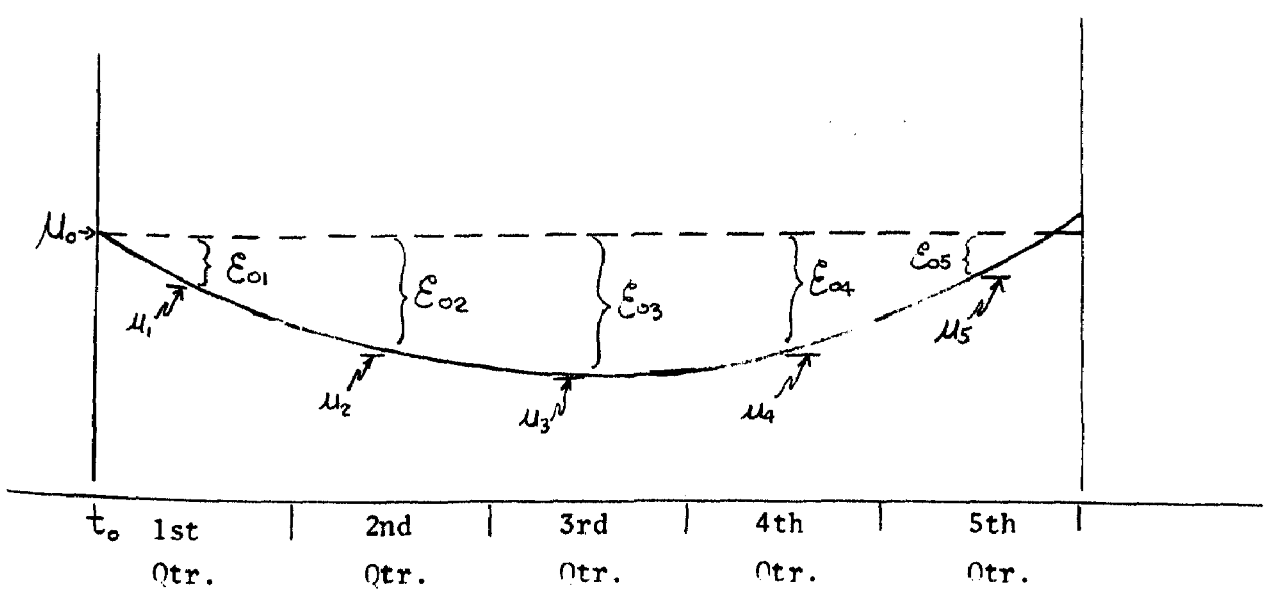
Since this difference in emissions levels involves only one production quarter, one can add these over all production quarters of a model year subsequent to that quarter in which the baseline level $\mu_o$ prevailed, obtaining

$$\mathcal{E}_o = \sum_j \Gamma M (\mu_o - \mu_j) n_j \tag{4.1.4}$$

as the change in emissions, relative to operating through the entire production year at average emission level $\mu_o$. In particular, if the baseline emission level, $\mu_o$, were viewed at the level prevailing at the beginning of a model year, then one would accumulate the changes over the 5 production quarters of a typical model year (i.e., the four calendar quarters plus the buildout quarter); thus:

$$\mathcal{E}_o = \sum_{j=1}^{5} \Gamma M(\mu_o - \mu_j) n_j \qquad (4.1.5)$$

Schematically, it may be helpful to interpret expression 4.1.5 in the context of the figure below. The horizontal dotted line represents the average emissions level which is presumed to prevail at the beginning of a production year (i.e. - at time to). The curved solid line represents a particular pattern of how average emissions levels may vary, with time throughout the production year. At times $t_1, \ldots, t_5$ the average emissions levels prevailing are $\mu_1, \ldots, \mu_5$ and let us assume that these can be viewed (as defined previously) as an average level typical of all production in quarters 1,2,...,5. Application of expressions 4.1.1 and 4.1.2, for each quarter, will yield the total emissions resulting from that quarters production at the respective levels $\mu_o$ and $\mu_j$. The "change" in emissions then (i.e. - expression 4.1.3) is then seen to be attributable to the difference in emissions levels prevailing in the respective quarters and as portrayed below.



Three comments are appropriate at this point. First of all, the discussion thus far has not distinguished between types of emittants. Since HC, CO and $NO_x$ are all of concern in this study, changes in emissions will ultimately be estimated for all three types of emissions; however, for purposes of discussion and methodological development, the text will generally refer to a "single emittant type." The second comment regards the "$j^{th}$ quarter production level, $\eta_j$," employed in expression (4.1.5). Upon analysis of nationwide production data for the three manufacturers considered in this study (i.e., General Motors, Ford and Chrysler), it occurred that the fraction of yearly total production which occurs in the various production quarters maintains a relatively constant split among the 5 production quarters of a model year, as follows:

| Production Quarter of Model Year | Fraction of National Production in Quarter |
|---|---|
| 1 | 0.17 |
| 2 | 0.25 |
| 3 | 0.25 |
| 4 | 0.25 |
| 5 | 0.08 |

Hereafter we shall define:

(1) $\alpha_j \equiv$ fraction of national yearly production taking place in production quarters $j (j=1,2,\ldots,5)$

(2) $N \equiv$ nationwide yearly production of the manufacturer under consideration.

and then

$$n_j = N\alpha_j \qquad (j=1,2,\ldots,5)$$

that is, the $j^{th}$ quarters production will be specified as a fractional multiple of the applicable nationwide production level.

The third comment concerns the average emission levels (i.e., $\mu_o$, $\mu_j$'s) employed in expression (4.1.5). Analysis of manufacturer's data reveals that there is generally no single average emission level representative of all engine categories, consequently, it is appropriate to make expression (4.1.5) "engine category specific" by relating the average emissions levels to a manufacturer's engine category as follows:

Define: (1) $\mu_{io}$ = baseline average emission level for engine category $i$ ($i = 1,2,\ldots,C$)

(2) $\mu_{ij}$ = average emission level for quarter j and engine category i

(3) $\beta_i$ = fraction of a manufacturer's yearly nationwide production which is in engine category i (note $\sum_{i=1}^{C} \beta_i = 1$ )

Then, employing this additional notation, the previous computational procedure is readily modified to account for "engine category specific" computations, as follows:

$$\mathcal{E}_o = \sum_{i=1}^{c} \sum_{j=1}^{5} (E_{io} - E_{ij})$$

$$= \sum_{i=1}^{c} \sum_{j=1}^{5} (\mu_{io} - \mu_{ij}) \Gamma M \beta_i \alpha_j N$$

$$\mathcal{E}_o = \Gamma M N \left\{ \left( \sum_{i=1}^{c} \mu_{io} \beta_i \right) - \left( \sum_{i=1}^{c} \sum_{j=1}^{5} \mu_{ij} \beta_i \alpha_j \right) \right\} \qquad (4.1.6)$$

Note:

$\sum_{i=1}^{c} \mu_{io} \beta_i$ = weighted initial average emissions level (weighted by engine category production)

and $\sum_{i=1}^{c} \left( \sum_{j=1}^{5} \mu_{ij} \alpha_j \right) \beta_i$ = weighted average emissions level through the years' production quarters as well as engine categories.

The basic computational procedure in estimating emission level differences, as a result of differences in average emission levels, was expanded, in the preceding material, to handle different engine categories. This procedure assumed that data was available to establish the mean emission levels $\{\mu_{ij}: 1 \leq j \leq 5;\ 1 \leq i \leq c\}$ for all five quarters of a model year under consideration as well as the baseline mean emission level, i.e., $\mu_{io}$.

For much of the data of this study, the entire model year's data was not available. For example, 1972 General Motors data covered only production quarters 2, 3, 4 and 5. This situation necessitated a modification in the computational procedure employed as well as in the interpretation of the results. Consider the 1972 General Motors situation.

Suppose data is available only for production quarters $\ell$ through 5 ($\ell > 1$). During these quarters the total production is $N(\sum_{j=\ell}^{5} \alpha_j)$ rather than N, the entire year's production. Consequently, the total average emissions generated if the entire remaining year's production were at a level $\mu_{io}$, is:

$$E_o^{(\ell)} \equiv \sum_{i=1}^{c} \sum_{j=\ell}^{5} \mu_{io} \Gamma M \beta_i N \alpha_j$$

$$= \Gamma M (N \sum_{j=\ell}^{5} \alpha_j) \sum_{i=1}^{c} \mu_{io} \beta_i \qquad (4.1.7)$$

Alternately, if in production quarter j the average emission level were $\mu_{ij}$, for engine category $i$, the corresponding emissions for that quarter would be:

$$\sum_{i=1}^{c} \mu_{ij} \Gamma M N \alpha_j \beta_i$$

and, for all quarters,

$$E^{(\ell)} \equiv \sum_{j=\ell}^{5} \sum_{i=1}^{c} \mu_{ij} \Gamma M N \alpha_j \beta_i$$

$$= \Gamma M N (\sum_{j=\ell}^{5} \sum_{i=1}^{c} \mu_{ij} \beta_i \alpha_j) \qquad (4.1.8)$$

As previously, the change in emissions during the remainder of the year, in lieu of staying at levels $\{\mu_{io}\}$, is:

$$\mathcal{E}_o^{(\ell)} = E_o^{(\ell)} - E^{(\ell)}$$

$$= \Gamma M N \sum_{j=\ell}^{5} \alpha_j \sum_{i=1}^{c} \mu_{io} \beta_i - \Gamma M N \sum_{j=\ell}^{5} \sum_{i=1}^{c} \mu_{ij} \beta_i \alpha_j$$

$$= \Gamma M N \sum_{j=\ell}^{5} \alpha_j \left\{ \sum_{i=1}^{c} (\mu_{io} - \mu_{ij}) \beta_i \right\} \qquad (4.1.9)$$

In summary then, the estimate $\mathcal{E}_o^{(\ell)}$ of change in emissions, is a "scaled" emissions change, conditional on measuring changes for the remainder of the model year, starting from quarter $\ell$ .

### 4.1.3 Summary of Results

Based on the data and computations discussed at length in Section 4.1.4 of this chapter, the estimated changes in emissions which would appear to occur during the 1972 model year analyzed in this study, if the changes observed in the California data base are extrapolated to nationwide production, are as indicated in Table 4.1-0.

| | Emission Type | | |
|---|---|---|---|
| Manufacturer | HC | CO | $NO_x$ |
| General Motors | -1555* | +35750** | NA |
| Ford | -1272 | +82576 | NA |
| Chrysler | -66 | -108 | NA |

Table 4.1-0

Trend Associated Emissions Changes (Tons per Year)

* A minus sign (-) indicates a decrease in tons per year, nationwide

** A plus sign (+) indicates an increase in tons per year, nationwide.

As discussed at length in Chapter 2, these data must be interpreted with extreme caution since they are from data sources operating only under the existence of an operational California assembly line test program. Further, while the General Motors and Ford values result from analysis of 4 production quarters' data, the Chrysler data estimates a change over a 3-quarter period.

| Division | Engine Category CID/bbls | Average Emissions Level (by quarter) 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Chevrolet | 140-1, 2 | 1.64 | 1.25 | 1.44 | 2.40 |
| | 250-1 | 1.31 | 1.66 | 1.35 | 1.43 |
| | 350-2 | 1.92 | 1.79 | 1.83 | 1.88 |
| | 350-4 | 2.06 | 1.76 | 1.87 | 2.52 |
| | 400-2 | 1.93 | 1.73 | 1.88 | 1.95 |
| Pontiac | 350-2 | 2.72 | 2.53 | 2.39 | 3.32 |
| | 400-2 | 2.26 | 2.00 | 2.05 | 2.30 |
| | 455-2 | 2.07 | 2.13 | 2.21 | 2.21 |
| | 400-4 | 2.33 | 2.37 | 2.29 | 2.50 |
| | 455-4 | 1.96 | 1.93 | 1.92 | 2.22 |
| Oldsmobile | 350-2 | 2.30 | 2.28 | 2.58 | 2.50 |
| | 350-4 | 2.40 | 2.23 | 2.35 | 2.42 |
| | 455-4 | 1.40 | 1.24 | 1.42 | 1.59 |
| Buick | 350-2 | 2.00 | 2.08 | 2.02 | 2.00 |
| | 350-4 | 1.81 | 1.73 | 1.74 | 1.76 |
| | 455-4 | 2.32 | 2.10 | 2.45 | 3.02 |
| Cadillac | 472-4 | 1.00 | 1.13 | 1.21 | 1.60 |
| | 500-4 | 0.87 | 0.89 | 0.87 | 0.87 |

Table 4.1-1

Average Hydrocarbon Emissions from Audit Tests
(By Engine Category and Production Quarter)
1972 General Motors
(grams per mile)

| Division | Engine Category CID/bbls | Average Emissions Level (by quarter) | | | |
|---|---|---|---|---|---|
| | | 2 | 3 | 4 | 5 |
| Chevrolet | 140-1, 2 | 21.75 | 19.87 | 18.66 | 19.36 |
| | 250-1 | 21.17 | 26.75 | 22.04 | 22.39 |
| | 350-2 | 27.95 | 28.18 | 31.71 | 32.13 |
| | 350-4 | 18.02 | 18.52 | 23.35 | 24.38 |
| | 400-2 | 24.91 | 22.42 | 27.37 | 27.35 |
| Pontiac | 350-2 | 28.76 | 24.26 | 22.34 | 26.60 |
| | 400-2 | 27.81 | 18.08 | 19.45 | 22.00 |
| | 455-2 | 28.00 | 25.46 | 26.57 | 26.57 |
| | 400-4 | 26.84 | 25.55 | 26.11 | 32.56 |
| | 455-4 | 17.50 | 18.50 | 17.50 | 22.50 |
| Oldsmobile | 350-2 | 24.86 | 24.18 | 26.00 | 40.20 |
| | 350-4 | 19.23 | 16.84 | 18.75 | 17.00 |
| | 455-4 | 15.36 | 16.80 | 24.88 | 19.37 |
| Buick | 350-2 | 26.27 | 26.25 | 29.31 | 32.00 |
| | 350-4 | 17.94 | 18.70 | 20.87 | 22.00 |
| | 455-4 | 21.31 | 21.29 | 26.61 | 29.44 |
| Cadillac | 472-4 | 24.41 | 26.90 | 31.09 | 46.00 |
| | 500-4 | 23.20 | 23.97 | 22.76 | 22.76 |

Table 4.1-2

Average Carbon Monoxide Emissions from Audit Tests
(By Engine Category and Production Quarter)
1972 General Motors
(grams per mile)

4.1.4 Data and Computations: Trend Analyses

Tables 4.1-1 and 4.1-2 present the average hydrocarbon and carbon monoxide levels of audit tests indexed by engine category (within division) and production quarter for the 1972 General Motors data set. The similar data for $NO_x$ was not used since 7-mode tests were employed in 1972.for NOX Measurements. Using these average emission levels, and the computational procedures discussed in Section average emission levels, and the computational procedures discussed in Section 2.2, the changes in emissions levels for the remainder of the 1972 model year were determined. Specifically, the equation (4.1.9) was used; that is:

$$\mathcal{E}^{(2)} - \Gamma M N_\ell \left\{ \left(\sum_{j=3}^{5} \alpha_j\right) \sum_{i=1}^{18} \mu_{i2}\beta_i - \sum_{j=3}^{5} \alpha_j \sum_{i=1}^{18} \mu_{ij}\beta_i \right\} \tag{4.1.10}$$

Observe that for the General Motors analysis the baseline emission level used is the average emission level in the second production quarter and consequently the emission level changes estimated here are in terms of changes from quarter 2 of the 1972 model year.

It is further pointed out that, at the request of the manufacturers supplying this data, the production figures regarding engine category production as a fraction of total year production is being treated in a confidential manner. Consequently, the actual values of $\{\beta_i : i = 1,2,\ldots,18\}$ will not be recorded in this report but rather, the summary result from expression (4.1.10) will be presented. Ford and Chrysler data will be treated in a similar manner.

For the GM data, one obtains:

(1) Hydrocarbons:

$$\mathcal{E}^{(2)} = \Gamma M N_1 \left\{ \left(\sum_{j=2}^{5} \alpha_j\right) \sum_{i=1}^{18} \mu_{i2}\beta_i - \sum_{j=2}^{5} \sum_{i=1}^{18} \mu_{ij}\beta_i \right\}$$

$$= (1.1 \times 10^{-6} \text{ tons/gm})(12000 \frac{\text{miles}}{\text{car/yr}})(5 \times 10^{6} \frac{\text{cars}}{\text{yr}}) \quad 0.02356 \frac{\text{gm}}{\text{mile}}$$

= 1555 tons per year decrease in HC.

(2) Carbon Monoxide

$$\mathcal{E}^{(2)} = \Gamma M N_1 \left\{ - 0.54167 \text{ gm/mile} \right\}$$

= 35750 tons per year increase in CO.

(3) Oxides of Nitrogen

Indeterminate since 1972 tests were by 7-mode methods.

Tables 4.1-3 and 4.1-4 present the average hydrocarbon and carbon monoxide emission levels of audit tests, indexed by engine category and production quarter, for the 1972 Ford data set. As with all manufacturers, $NO_x$ results were not analyzed. Proceeding as with General Motors, emissions changes for that portion of the 1972 model year beyond quarter 2 were determined employing equation (4.1.9) and using baseline average emission levels equal to second production quarter results.

| Engine Category CID | Average Emissions Level (by quarter) | | | |
|---|---|---|---|---|
| | 2 | 3 | 4 | 5 |
| 98 | 2.45 | 2.35 | 2.41 | 2.41 |
| 122 | 2.54 | 2.51 | 2.49 | 2.19 |
| 170 | 2.49 | 2.47 | 2.47 | 2.47 |
| 200 | 2.57 | 2.39 | 2.32 | 2.32 |
| 240 | 2.67 | 2.72 | 2.85 | 2.73 |
| 250 | 2.13 | 2.03 | 2.03 | 2.28 |
| 302 | 2.64 | 2.52 | 2.23 | 3.05 |
| 351 | 2.48 | 2.49 | 2.61 | 2.49 |
| 360 | 3.10 | 3.09 | 3.19 | 3.25 |
| 390 | 3.11 | 2.59 | 2.69 | 2.69 |
| 400 | 2.07 | 2.08 | 1.90 | 1.87 |
| 429 | 2.07 | 2.18 | 2.11 | 2.29 |
| 460 | 2.44 | 2.35 | 2.58 | 2.38 |

Table 4.1-3

Average Hydrocarbon Emissions from Audit Tests
(By Engine Category and Production Quarter)
1972 Ford

(grams per mile)

| Engine Category CID | Average Emissions Level (by quarter) | | | |
|---|---|---|---|---|
| | 2 | 3 | 4 | 5 |
| 98 | | | | |
| 122 | 22.93 | 28.59 | 29.18 | 26.56 |
| 170 | 16.88 | 17.58 | 17.68 | 17.68 |
| 200 | 23.10 | 23.46 | 24.21 | 24.21 |
| 240 | 24.84 | 30.67 | 33.06 | 32.17 |
| 250 | 23.14 | 21.12 | 21.12 | 23.88 |
| 302 | 19.35 | 23.40 | 18.98 | 35.34 |
| 351 | 22.46 | 28.65 | 34.58 | 30.88 |
| 360 | 25.61 | 29.36 | 30.44 | 33.04 |
| 390 | 22.40 | 25.77 | 20.10 | 20.10 |
| 400 | 34.28 | 32.77 | 25.91 | 21.13 |
| 429 | 24.28 | 26.18 | 25.64 | 30.08 |
| 460 | 28.19 | 28.30 | 42.58 | 33.02 |

Table 4.1-4

Average Carbon Monoxide Emissions from Audit Tests
(By Engine Category and Production Quarter)
1972 Ford

(grams per mile)

From the Ford data, one obtains:

(1) Hydrocarbons

$$\mathcal{E} = \Gamma M N_2 \left\{ \left( \sum_{j=2}^{5} \alpha_j \sum_{i=1}^{13} \mu_{i2} \beta_i \right) - \sum_{j=2}^{5} \alpha_j \sum_{i=1}^{13} \mu_{ij} \beta_i \right\}$$

$$= (1.1 \times 10^6 \ \frac{\text{tons}}{\text{gm}})(12000 \ \frac{\text{miles}}{\text{car/yr}})(3.3 \times 10^6 \ \text{cars}) \quad .0292 \ \frac{\text{gms}}{\text{mile}}$$

$$= (43.56 \times 10^3)(.0292) \ \text{tons/yr}$$

$\mathcal{E}$ = 1272 tons per year <u>decrease</u> in HC.

(2) Carbon Monoxide

$$\mathcal{E} = \Gamma M N_2 \left\{ \left( \sum_{j=2}^{5} \alpha_j \sum_{i=1}^{3} \mu_{i2} \beta_i \right) - \sum_{j=2}^{5} \alpha_j \sum_{i=1}^{13} \mu_{ij} \beta_i \right\}$$

$\mathcal{E}$ = $(43.56 \times 10^3)(-1.8957)$ tons per year

$\mathcal{E}$ = 82576 tons per year <u>increase</u> in CO.

(3) Oxides of Nitrogen

Indeterminate since 1972 tests were by 7-mode methods.

Tables 4.1-5 and 4.1-6 present the average hydrocarbon and carbon monoxide emission levels of audit tests, indexed by engine category and production quarter, for the 1972 Chrysler data set. In contrast to General Motors and Ford, the Chrysler data began with production quarter 3, hence, this was used as a baseline.

| Engine Family CID | Average Emissions Level (by quarter) | | |
| --- | --- | --- | --- |
| | 3 | 4 | 5 |
| 198 | 1.9 | 1.6 | 1.6 |
| 225 | 1.6 | 1.5 | 1.6 |
| 318 | 2.0 | 2.0 | 2.0 |
| 340 | 2.1 | 1.5 | 1.5 |
| 360 | 2.2 | 2.1 | 2.0 |
| 400 | 1.5 | 1.3 | 1.2 |
| 440 | 1.4 | 1.2 | 1.2 |

Table 4.1-5

Average Hydrocarbon Emissions from Audit Tests
(By Engine Category and Production Quarter)
1972 Chrysler
(grams per mile)

| Engine Family CID | Average Emissions Level (by quarter) | | |
| --- | --- | --- | --- |
| | 3 | 4 | 5 |
| 198 | 27.5 | 34.1 | 28.8 |
| 225 | 27.2 | 26.4 | 26.5 |
| 318 | 24.6 | 26.2 | 25.4 |
| 340 | 21.5 | 18.5 | 20.8 |
| 360 | 36.0 | 31.8 | 32.6 |
| 400 | 26.3 | 26.4 | 25.5 |
| 440 | 23.9 | 25.0 | 24.6 |

Table 4.1-6

Average Carbon Monoxide Emissions from Audit Tests
(By Engine Category and Production Quarter)
1972 Chrysler
(grams per mile)

Using the procedures, as earlier, with the Chrysler data one obtains:

(1) Hydrocarbons

$$\mathcal{E} = \Gamma M N_3 \left\{ \left(\sum_{j=3}^{5} \alpha_j\right)\left(\sum_{i=1}^{7} u_{i3}\beta_i\right) - \sum_{j=3}^{5} \alpha_j \sum_{i=1}^{7} u_{ij}\beta_i \right\}$$

$$= \left(1.1 \times 10^{-6} \frac{\text{tons}}{\text{gm}}\right)\left(12000 \frac{\text{miles}}{\text{car/yr}}\right)\left(1.5 \times 10^{6} \frac{\text{cars}}{\text{yr}}\right) \quad 0.0338 \frac{\text{gm}}{\text{mile}}$$

= 65.8 tons per year <u>decrease</u> in HC.

(2) Carbon Monoxide

$$\mathcal{E} = (1.98 \times 10^{3}) \left\{ 0.05578 \text{ gm/mile} \right\}$$

$\mathcal{C}$ = 108 tons per year <u>decrease</u> in CO.

(3) Oxides of Nitrogen

Indeterminate since 1972 tests were by 7 Mode methods.

Trend estimates for the 1973 model year were not computed since, during this project, data from only two production quarters of the 1973 model year was available and this was judged insufficient to calculate 1973 trends.

## 4.2 Emission Level Changes Associated with Short Inspection Tests

### 4.2.0 Introduction

The methodology for assessing changes in emission levels associated with the presence or absence of hot 7-mode tests, idle tests, or combinations thereof was described in Chapter 2, Section 2.3. Application of this methodology to the particular data base available is presented in this section.

### 4.2.1 Methodology

As employed in the 1973 California test procedures, two short inspection test types are employed, namely, (i) the hot cycle 7-mode test and, (ii) the idle test. Of interest here is an assessment of what (if any) change in emissions levels (as measured by C.V.S. "audit" test procedures) results from the presence of this short test procedure.

Considering the "hot cycle 7-mode test" as a "procedure $T$" discussed in Section 2.3 of this report, we can investigate the manner in which the average level of emissions of type j depends on the fraction ( $\alpha$ ) of automobiles receiving this test. Applying expressions 2.3.1 and 2.3.2 where $T \equiv 7M$ (i.e. - $7M \Leftrightarrow$ "presence of hot seven mode cycle test") one obtains

$$\begin{aligned} \mathcal{E}_j &= \mu_j \Gamma \cdot M \cdot N \\ &= \{\alpha \mu_{7M,j} + (1-\alpha)\mu_{\overline{7M},j}\} \Gamma \cdot M \cdot N \\ \mathcal{E}_j &= \{\mu_{\overline{7M},j} + \alpha(\mu_{7M,j} - \mu_{\overline{7M},j})\} \Gamma \cdot M \cdot N \end{aligned} \qquad (4.2.1)$$

In a similar fashion we can consider the "idle test" as a "procedure $T$" as discussed in Section 2.3. Again applying expressions 2.3.1 and 2.3.2 as above, but in this case with $T \equiv I$ (i.e. $I \Leftrightarrow$ "presence of idle test"), one obtains:

$$\tilde{\mathcal{E}}_j = \mu_j \Gamma M N$$
$$= \left\{ \tilde{\alpha}\, \mu_{I_j} + (1-\tilde{\alpha})\, \mu_{\bar{I},j} \right\} \Gamma M N$$
$$\tilde{\mathcal{E}}_j = \left\{ \mu_{\bar{I},j} + \tilde{\alpha}\left( \mu_{I_j} - \mu_{\bar{I}_j} \right) \right\} \Gamma M \cdot N \qquad (4.2.2)$$

where $\tilde{\alpha}$ is the fraction of total production receiving dle ests.

### 4.2.2 Data Base Available

For the analyses performed in this section, data from the 1972 production year of General Motors, and 1973 production year of General Motors, Ford and Chrysler were employed. While a detailed description of the data base available and/or employed on this project is contained in Appendix A , the specific subsets of data employed, and the analysis executed is described here.

Selected data was analyzed to assess the changes in emissions levels which appear to have occurred due to combinations of the presence or absence of hot seven mode testing and/or idle testing. The emissions measurements analyzed were the hydrocarbon (H.C.), carbon monoxide (C.O.) and oxides of nitrogens (NOX) levels, in grams per mile, as determined from constant volume sampling test procedures currently employed in the California Assembly Line Test procedures. On 1972 model year data the NOX measurements were not analyzed since they were developed by 7-mode rather than C.V.S. testing. The data available, and the sample sizes of the various categories analyzed, are presented in Figures 4.2-1, 4.2-2, 4.2-3 and 4.2-4, and are grouped according to the manufacturer.

I. General Motors Corporation

There were test results from 9284 original C.V.S. measurements on 1972 production year automobiles. Source data available did not indicate whether or not these were idle tested, however, for each it was stated whether or not a 7-mode test had been performed on the car.

Further, data from the third, fourth and fifth (i.e. - buildout) quarter indicated, for those cars 7-mode tested, whether or not the car had passed that test. Figure 4.2-1 illustrates the breakdown of the test/no test samples and their corresponding sizes.

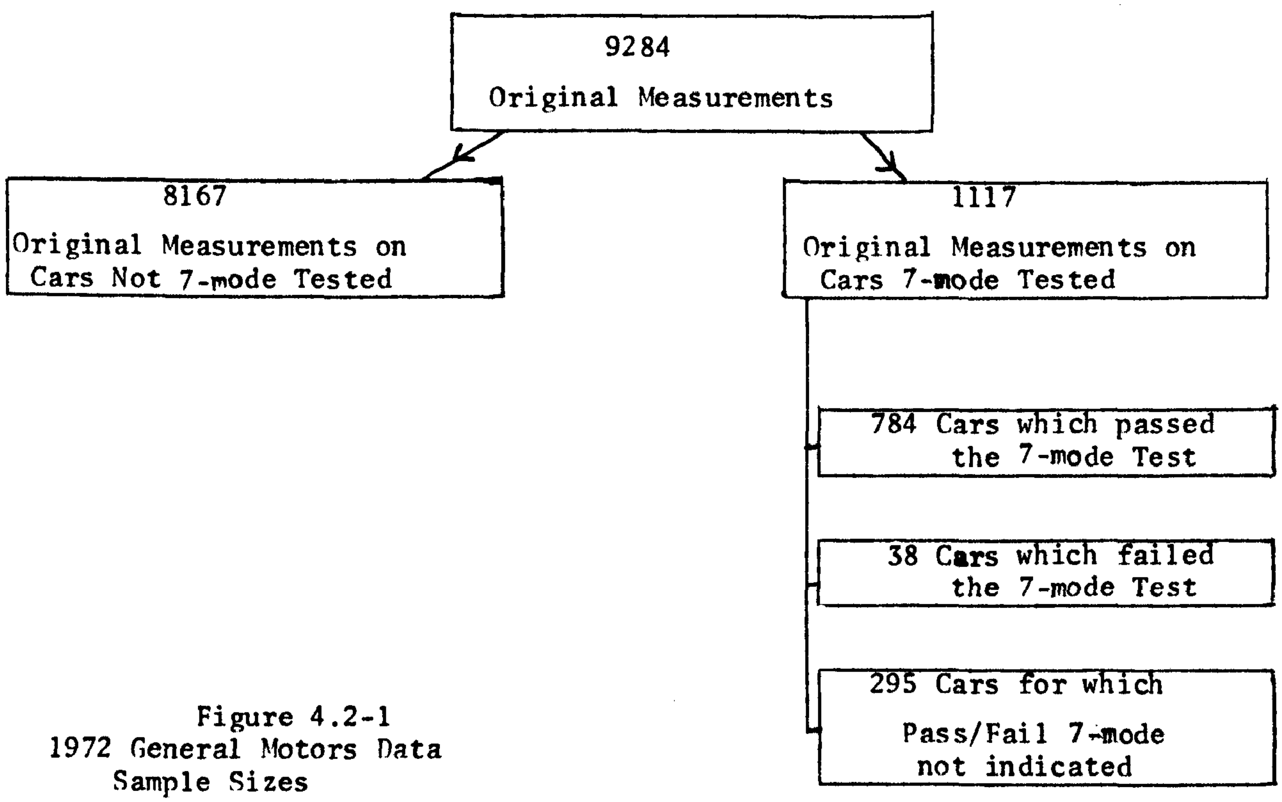



Figure 4.2-1
1972 General Motors Data
Sample Sizes
7-mode Tested Automobiles

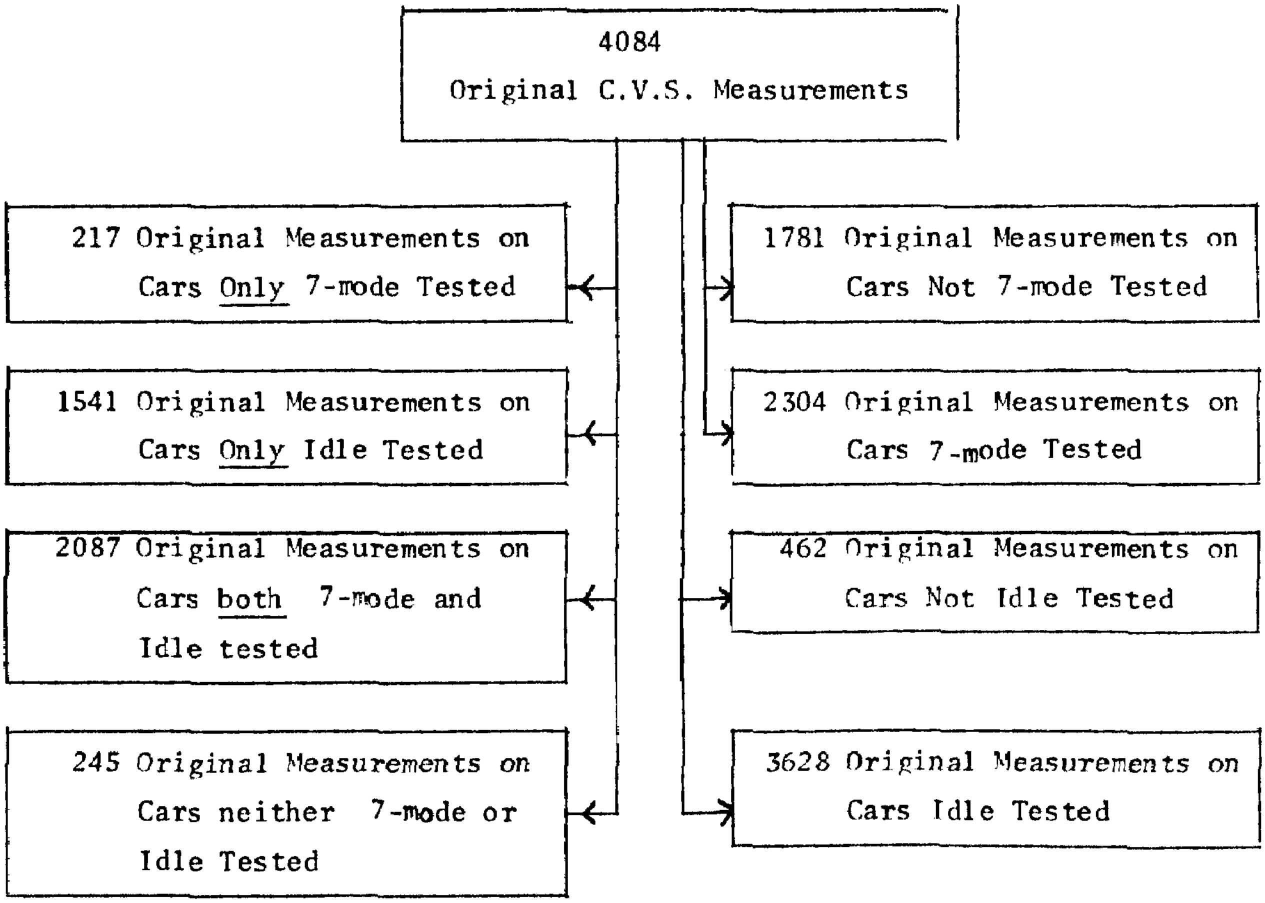



Figure 4.2-2

1973 General Motors Data

Sample Sizes

7-mode and/or Idle Tested Automobiles

The 1973 General Motors data base available included C.V.S. test results from the first and second production quarters of the model year. Since Idle Testing was statutorily required on this model year, this data base was capable of being segmented into a larger number of subcategories than in the 1972 data. Figure 4.2-2 presents this breakdown.

II. Ford Motor Company

The 1973 Ford data base employed in this section contained 2903 original C.V.S. measurements, each of these containing an indication of whether or not 7-mode and/or idle tests had been performed on the automobiles. This is presented in Figure 4.2-3.

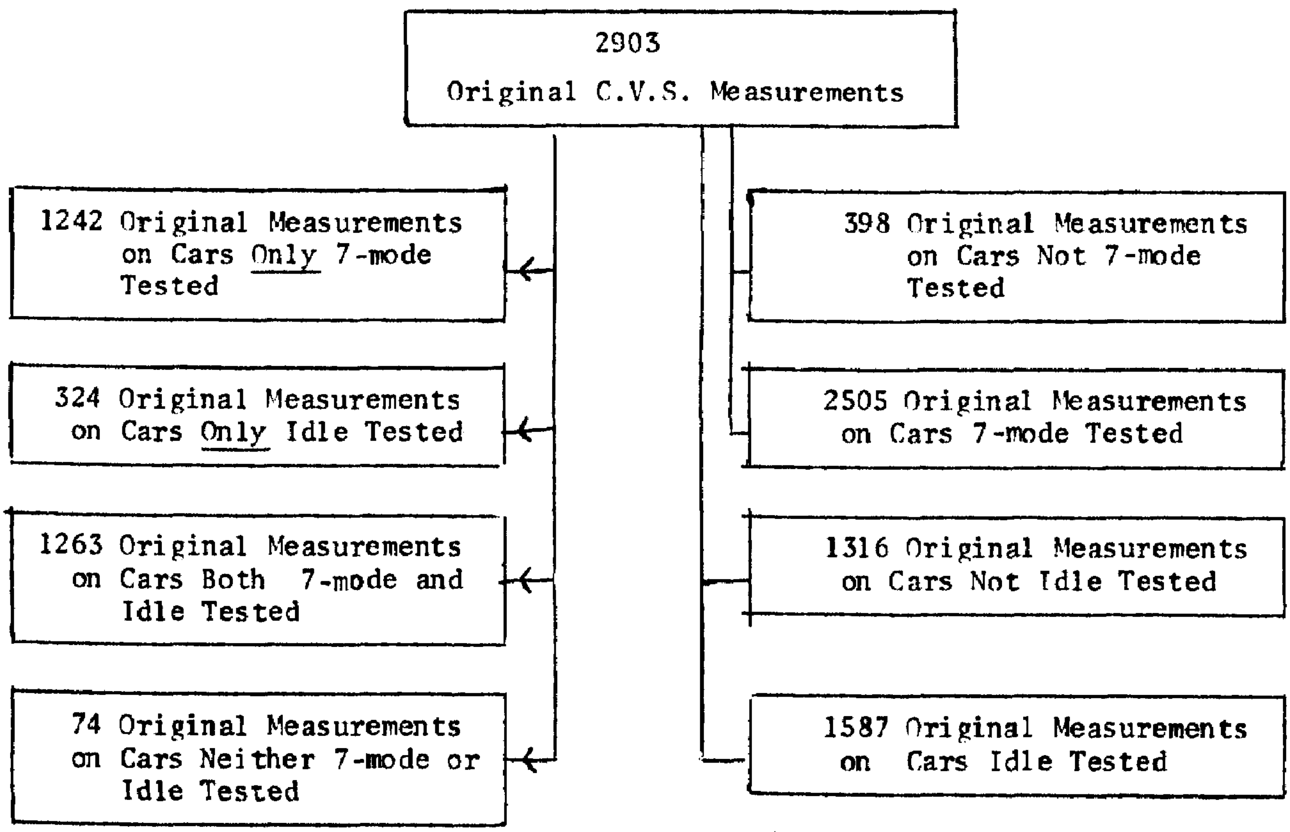



Figure 4.2-3
1973 Ford Data
Sample Sizes
7-mode and/or Idle Tested Automobiles

III. Chrysler Corporation

The 1973 Chrysler data base employed in this section contained 1462 original C.V.S. measurements, each of these containing an indication of whether or not 7-mode and/or idle tests had been performed on the automobiles. This is presented in Figure 4.2-4.

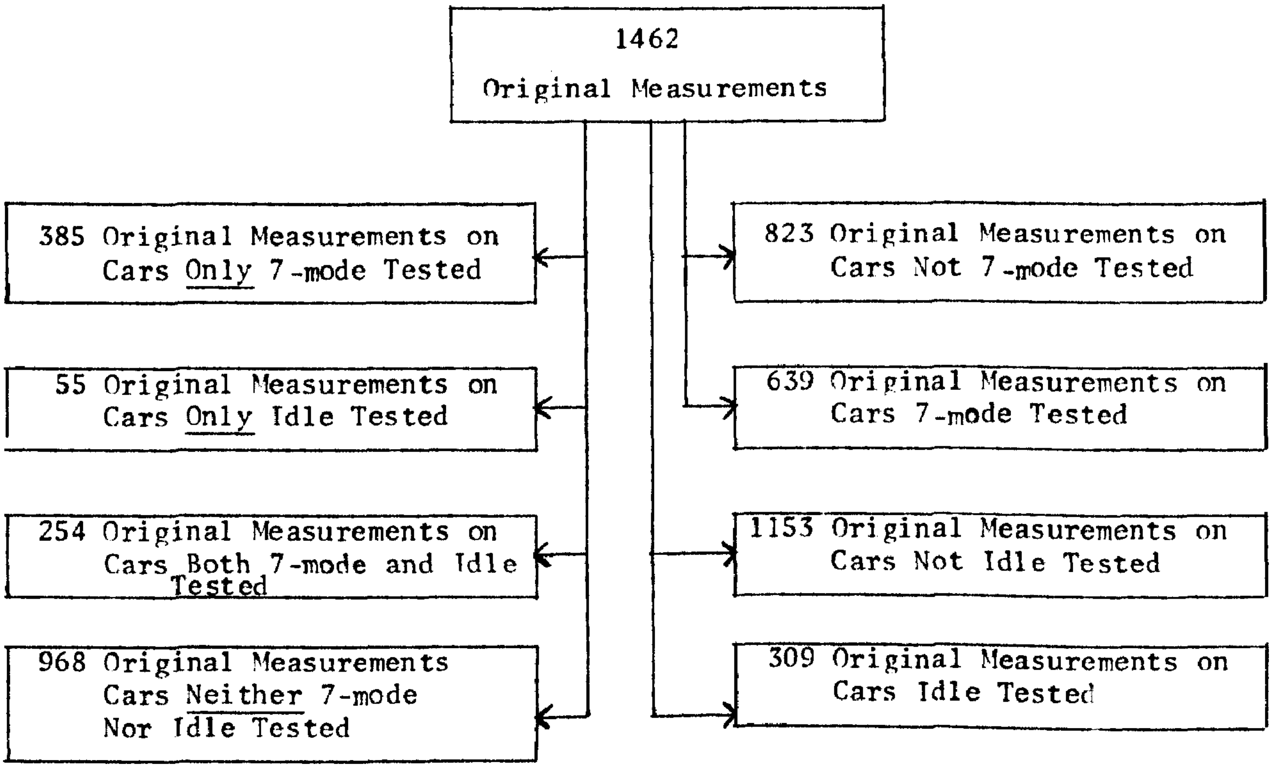



Figure 4.2-4
1973 Chrysler Data
Sample Sizes
7-mode and/or Idle Tested Automobiles

4.2.3 Summary of Results

Table 4.2-1 summarizes the estimated emissions level changes which would result from a nationwide application of hot 7-mode and idle testing as is currently being performed for California production. To reiterate, this would incorporate hot 7-mode testing of a 25% (randomly selected) sample of production and idle testing of the remainder of production

| Source of Emissions Level Changes | Mfr. | Emissions Type | | |
|---|---|---|---|---|
| | | HC | CO | NOx |
| 7 Mode Test (1972 Model Year) | GM | - 2310 | - 29040 | NA |
| | F | NA | NA | NA |
| | C | NA | NA | NA |
| | Total | - 2310 | - 29040 | NA |
| 7 Mode Test (1973 Model Year) | GM | 0 | - 60500 | + 825 |
| | F | + 872 | 0 | +3815 |
| | C | - 64 | 0 | 0 |
| | Total | + 808 | - 60500 | +4640 |
| Idle Test (1973 Model Year) | GM | +14355 | +103950 | +2970 |
| | F | - 4185 | 0 | -2943 |
| | C | 0 | + 851 | + 45 |
| | Total | +10170 | +104801 | + 82 |

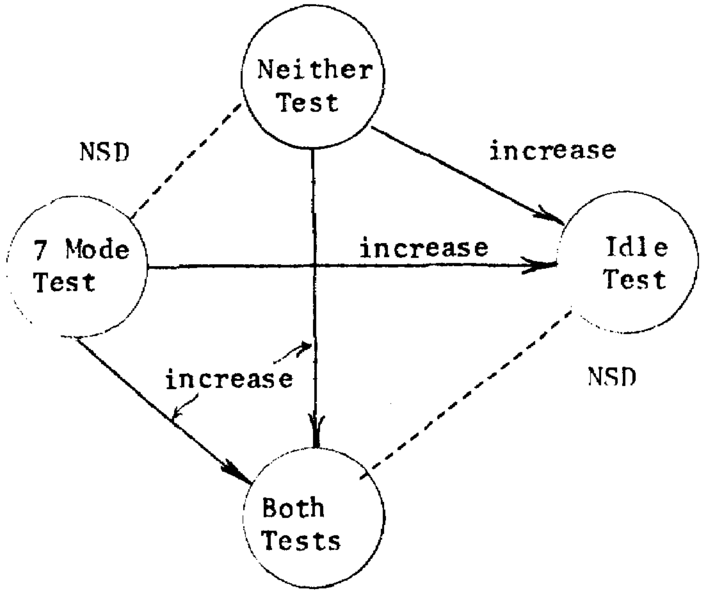
Table 4.2-1

Emissions Level Changes From Short Inspection Tests (tons per year)

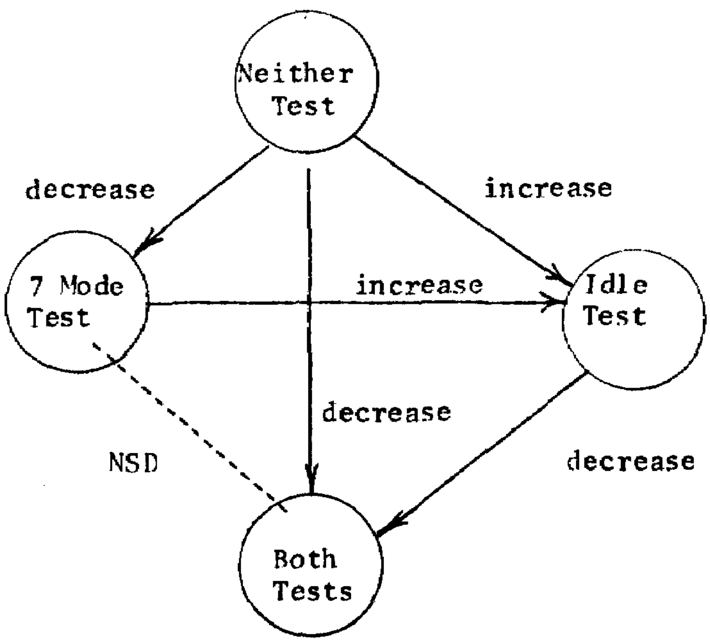
The specific data and computations on which these results are based are presented in Section 4.2.4 of this chapter.

In addition to the emissions changes attributed to 7-mode tests or idle tests as presented in the previous table, it is informative to consider the patterns of emissions level changes associated with automobiles receiving only 7-mode testing, only idle testing, neither 7-mode nor idle testing or, finally, both 7-mode and idle testing. Such considerations are summarized, schematically, in Figures 4.2-5 thru 4.2-7. Each of these charts portrays the type of change in the audit test emission level as a result of a particular combination of short tests. All changes portrayed start from the "reference point" of the average audit test emission level when no short test has been executed. For example, consider Figure 4.2-5a, hydrocarbon emissions on 1973 General Motors data. Relative to audit test levels on cars which received no previous short tests, this chart reveals that cars which were only 7 Mode tested do not differ in average HC emission levels, (i.e., No Significant Difference indicated on the broken line between the "Neither Test" and "7-mode Test" cell). The average HC emission on cars idle tested only reflected an increase relative to cars receiving Neither Test.

In general then, a broken line between two connected cells indicates no difference in the average emissions level under the two associated test conditions; a solid line indicates that the cell toward which the arrow points reflects an increased (decreased) emission level as compared to the connected cell according as an increase (decrease) note is along the connecting link.

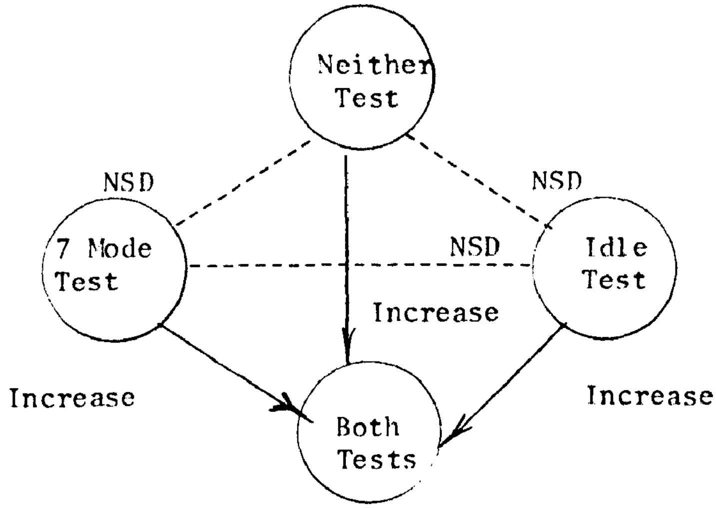



a.) Hydrocarbon Emission Changes



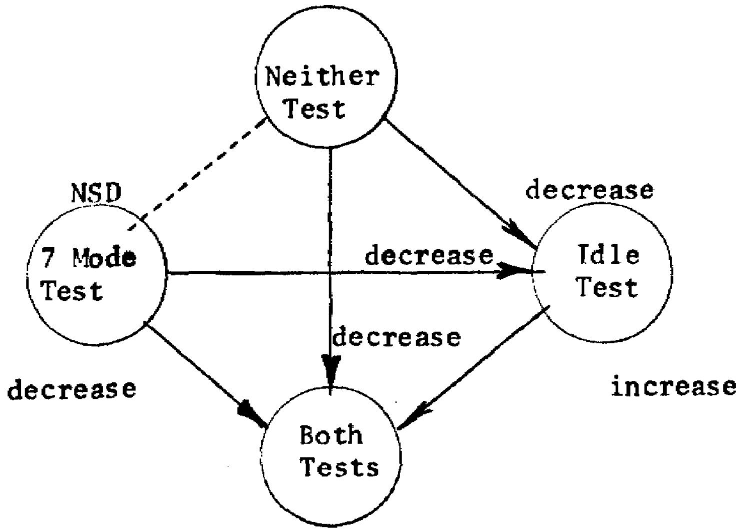

b.) Carbon Monoxide Emission Changes

Figures 4.2-5 a,b
Short Test Patterns of Emission Level Changes
1973 General Motors

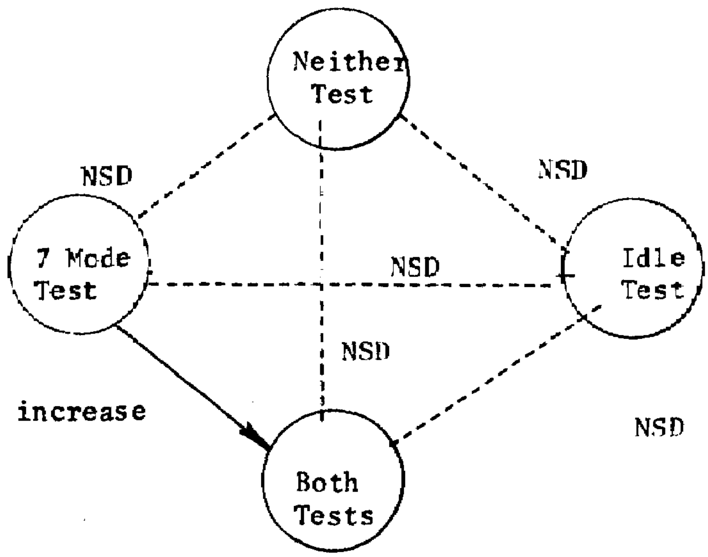



c.) Oxides of Nitrogen Emission Changes
Figure 4.2-5 c

Short Test Patterns of Emissions Level Changes
1973 General Motors




a.) Hydrocarbon Emission Changes

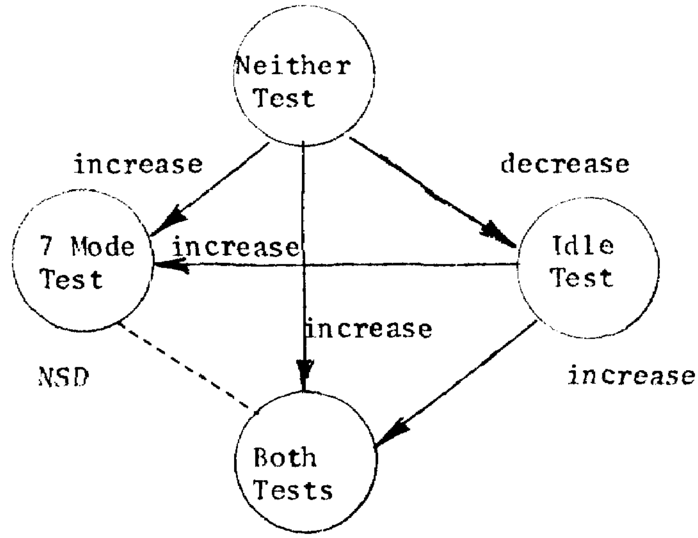



b.) Carbon Monoxide Emission Changes

Figures 4.2-6 a,b

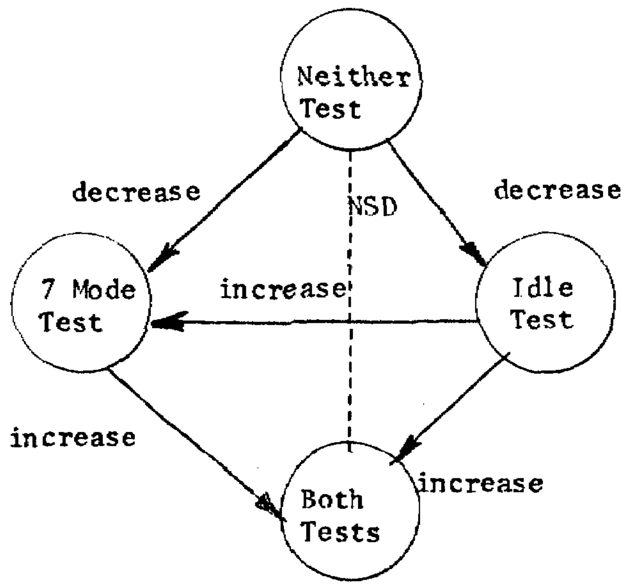
Short Test Patterns of Emissions Level Changes

1973 Ford

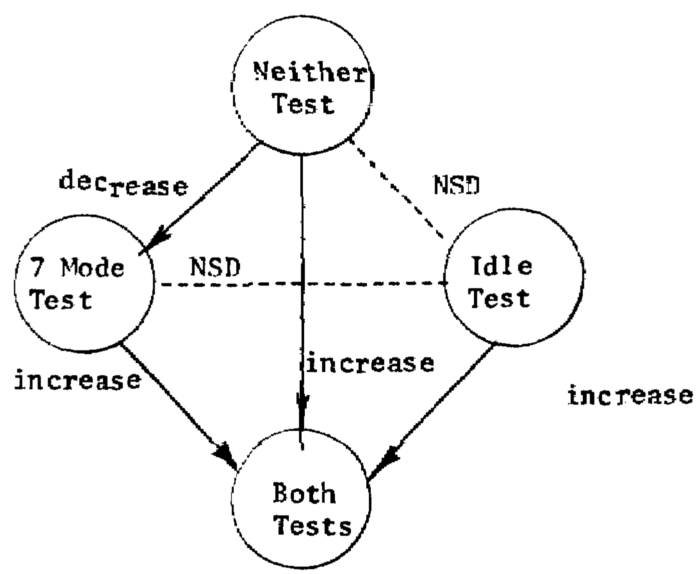



c.) Oxides of Nitrogen Emission Changes

Figure 4.2-6 c
Short Test Patterns of Emission Level Changes
1973 Ford




a.) Hydrocarbon Emission Changes

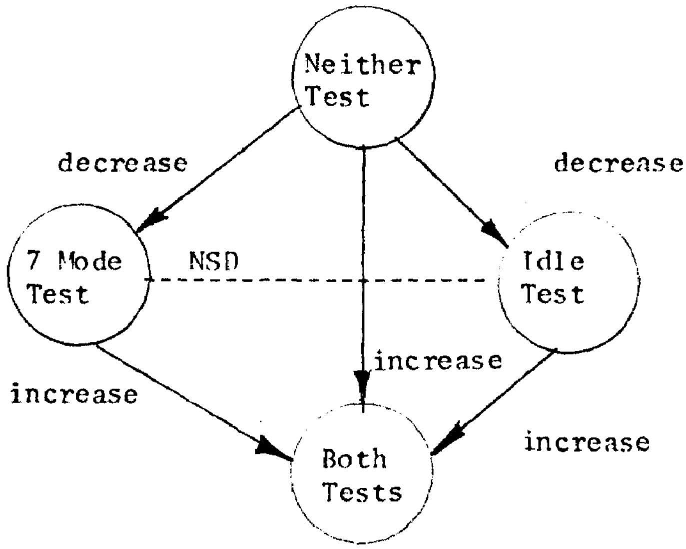



b.) Carbon Monoxide Emission Changes

Figure 4.2-7 a,b

Short Test Patterns of Emissions Level Changes

1973 Chrysler




c.) Oxides of Nitrogen Emissions Changes

Figure 4.2-7 c
Short Test Patterns of Emission Level Changes
1973 Chrysler

4.2.4 Data and Computations: Short Inspection Tests

Tables 4.2-2 thru 4.2-5 present the summary results on the samples of automobiles employed in the analyses of "hot 7-mode test" effects. The sample statistics included here are based on the original C.V.S. measurements taken on the tested automobiles (in contrast to rerun measurements on an automobile which had failed its audit test). In this sense, the statistics represent the average emissions to be anticipated upon the first C.V.S. test to be run in audit test procedures.

Table 4.2-6 summarizes the results of significance tests performed to investigate the possible existence of a significant change in average emissions (on audit test results) as a result of an automobile having been 7-mode tested prior to the audit testing.

| Emission Type | Sample Average (gm/mile) | Sample Variance ($gm/mile^2$) | Sample Size | |
|---|---|---|---|---|
| HC | 1.70 | 0.42 | 1117 | 7 Mode |
| CO | 21.24 | 95.31 | 1117 | Tested |
| NOx | NA | NA | NA | Sample |
| HC | 1.84 | 0.73 | 8167 | Not 7 Mode |
| CO | 23.0 | 172.14 | 8167 | Tested |
| NOx | NA | NA | NA | Sample |

Table 4.2-2

Audit Test Emissions Results

7-mode and Not 7-mode Tested Automobiles

1972 General Motors

(Original Measurements)

| Emission Type | Sample Average (gm/mile) | Sample Variance $(gm/mile^2)$ | Sample Size | |
|---|---|---|---|---|
| HC | 2.20 | 0.63 | 2304 | 7 Mode |
| CO | 25.43 | 244.17 | 2304 | Tested |
| NOx | 2.32 | 0.40 | 2304 | Sample |
| HC | 2.21 | 0.33 | 1781 | Not 7 Mode |
| CO | 29.10 | 180.66 | 1781 | Tested |
| NOx | 2.27 | 0.22 | 1781 | Sample |

Table 4.2-3

Audit Test Emission Results

"7-mode" and "Not 7-mode" Tested Automobiles

1973 General Motors

(original measurements)

| Emission Type | Sample Average (gm/mile) | Sample Variance ($gm/mile^2$) | Sample Size | |
|---|---|---|---|---|
| HC | 2.43 | 0.26 | 2505 | 7 Mode |
| CO | 26.90 | 48.91 | 2505 | Tested |
| NOx | 2.46 | 0.13 | 2505 | Sample |
| HC | 2.36 | 0.16 | 398 | Not 7 Mode |
| CO | 26.95 | 66.6 | 398 | Tested |
| NOx | 2.11 | 0.19 | 398 | Sample |

Table 4.2-4

Audit Test Emission Results

"7-mode" and "Not 7-mode" Tested Automobiles

1973 Ford

(original measurements)

| Emission Type | Sample Average (gm/mile) | Sample Variance ($gm/mile^2$) | Sample Size | |
|---|---|---|---|---|
| HC | 2.05 | 0.24 | 639 | 7 Mode |
| CO | 25.05 | 76.04 | 639 | Tested |
| NOx | 2.16 | 0.29 | 639 | Sample |
| HC | 2.18 | 0.39 | 823 | Not 7 Mode |
| CO | 25.92 | 99.17 | 823 | Tested |
| NOx | 2.40 | 0.42 | 823 | Sample |

Table 4.2-5

Audit Test Emission Results

7-mode and Not 7-mode Tested Automobiles

1973 Chrysler

(original measurements)

Comparison of 7-mode Tested vs. Not 7-mode Tested Automobiles

Tested Statistic Employed:

$$Z_j = (\overline{X}_{\overline{7M},j} - \overline{X}_{7M,j}) \Big/ \sqrt{\frac{S^2_{7M}}{n_1} + \frac{S^2_{\overline{7M}}}{n_2}}\ ^*$$

Summary of Results:

| Model Year | Manufacturer | Emission Type | $Z_j$ | Significant at 5% Level | Conclusion |
|---|---|---|---|---|---|
| 1972 | GM | HC | +8.092 | Yes | $\mu_{\overline{7M}} > \mu_{7M}$ |
| | | CO | +5.399 | Yes | $\mu_{\overline{7M}} > \mu_{7M}$ |
| 1973 | GM | HC | +0.578 | No | $\mu_{\overline{7M}} = \mu_{7M}$ |
| | | CO | +8.061 | Yes | $\mu_{\overline{7M}} > \mu_{7M}$ |
| | | NOx | -3.55 | Yes | $\mu_{\overline{7M}} < \mu_{7M}$ |
| 1973 | Ford | HC | -3.139 | Yes | $\mu_{\overline{7M}} < \mu_{7M}$ |
| | | CO | 0.116 | No | $\mu_{\overline{7M}} = \mu_{7M}$ |
| | | NOx | -17.50 | Yes | $\mu_{\overline{7M}} < \mu_{7M}$ |
| 1973 | Chrysler | HC | -4.924 | Yes | $\mu_{\overline{7M}} < \mu_{7M}$ |
| | | CO | -1.7778 | No | $\mu_{\overline{7M}} = \mu_{7M}$ |
| | | NOx | -1.333 | No | $\mu_{\overline{7M}} = \mu_{7M}$ |

Table 4.2-6

Summary of 7-mode Test Effects on Audit Results

* Introductory Engineering Statistics by I. Guttman and S.S. Wilks
J. Wiley and Sons

For those model years and emission type combinations for which there occured a significant change in emissions levels due to the presnece of 7-mode testing the magnitude of emissions changes (in tons per year) were computed. These computations are illustrated in the following material, and employ the relationship

$$\mathcal{E}_{\ell_j} = \Gamma M N \ell \left\{ \mu_{\overline{7M}} + \alpha \left( \mu_{7M} - \mu_{\overline{7M}} \right) \right\} \qquad (4.2.3)$$

as described earlier in this chapter (i.e., Section 4.2)

<u>1972 General Motors</u>:

I Hydrocarbon:

$$\mathcal{E}_{11} = (1.1 \times 10^{-6} \text{ tons/gram})\ (12{,}000 \text{ miles/year})\ (5 \times 10^{6} \text{ autos/year})\ [1.84 \text{ gm/mile} + \alpha\,(1.70 - 1.84) \text{ gm/mile}]$$

$$= (66 \times 10^{3})\ (1.84 - 0.14\alpha)$$

$$\mathcal{E}_{11} = 121440 - 9240\,\alpha \text{ tons per year HC}$$

With $\alpha$ = 0.25, one obtains a <u>decrease</u> of

$$\Delta_{11} = \alpha 9240 = 2310 \text{ tons/year}$$

II Carbon Monoxide:

$$\mathcal{E}_{12} = (66 \times 10^{3})\ [23.0 \text{ gm/mile} + \alpha\,(21.24 - 23.0) \text{ gm/mi}]$$

$$= 1{,}518{,}000 - 116{,}160\alpha \text{ tons per year CO}$$

With $\alpha$ = 0.25, one obtains a <u>decrease</u> of

$$\Delta_{12} = 116{,}160\alpha = 29040 \text{ tons per year CO}$$

III Oxides of Nitrogen:

Not applicable since C.V.S. measurements not available for this data base.

1973 General Motors

I Hydrocarbon

Not applicable since there is no significant difference *in the average emission level under the presence or* absence of 7-mode testing (see Table 4.2-6)

II Carbon Monoxide

$$\mathcal{E}_{12} = (66 \times 10^3)\ (29.1\ \text{gm/mile} + \alpha(25.43 - 29.1)\ \text{gm/mi})$$
$$= 1{,}920{,}600 - 242{,}000\alpha \text{ tons per year}$$

With $\alpha$ = 0.25, one obtains a decrease of

$\Delta_{12}$ = 60,500 tons per year CO

III Oxides of Nitrogen

$$\mathcal{E}_{13} = (66 \times 10^3)\ (2.27\ \text{gm/mile} + \alpha(2.32 - 2.27)\ \text{gm/mile})$$
$$= 149820 + 3300\alpha \text{ tons per year}$$

With $\alpha$ = 0.25, one obtains an increase of

$\Delta_{13}$ = 825 tons per year NOx

1973 Ford

I Hydrocarbon

$$\mathcal{E}_{21} = \Gamma M N_2 \{\mu_{\overline{7M}} + \alpha(\mu_{7M} - \mu_{7M})\}$$
$$= (1.1 \times 10^{-6}\ \text{tons/gm})\ (12{,}000\ \frac{\text{Miles}}{\text{car/yr}})\ (3.3 \times 10^6\ \frac{\text{cars}}{\text{yr}})\ \{2.36\ \text{gm/mile} + \alpha(2.43 - 2.36)\}\ \text{gm/mile}$$
$$= 102896 + 3488\alpha \text{ tons per year}$$

With $\alpha$ = 0.25, one obtains an increase of

$\Delta_{21}$ = 872 tons per year HC

II Carbon Monoxide

Not applicable since there is no significant difference in the average emission level under the presence or absence of 7-mode testing (see Table 4.2-6)

III Oxides of Nitrogen

$$\mathcal{E}_{23} = (43.6 \times 10^3)\left\{2.11 \text{ gm/mi} + \alpha(2.46 - 2.11)\right\}\text{gm/mi}$$

$$= 91996 + 15260\alpha \text{ tons per year}$$

With $\alpha$ = 0.25, one obtains an increase of

$\Delta_{23}$ = 3815 tons per year NOx

1973 Chrysler

I Hydrocarbons

$$\mathcal{E}_{31} = \Pi \cdot M \cdot N_3 \left\{\mu_{\overline{7M}} + \alpha(\mu_{7M} - \mu_{\overline{7M}})\right\}$$

$$= (1.1 \times 10^{-6} \text{ tons/gm})\ (12{,}000\ \frac{\text{miles}}{\text{car/yr}})\ (1.5 \times 10^6\ \frac{\text{cars}}{\text{yr}})$$

$$\left\{2.18 \text{ gm/mile} + \alpha(2.05 - 2.18)\right\}\text{gm/mi}$$

$$\mathcal{E}_{31} = 4316 - 257\alpha \text{ tons per year}$$

With $\alpha$ = 0.25, one obtains a decrease of

$\Delta_{31}$ = 64.25 tons per year HC

II Carbon Monoxide

Not applicable since there is no significant difference in the average emission level under the presence or absence of 7-mode testing (see Table 4.2-6)

III Oxides of Nitrogen

Not applicable, as described above.

Tables 4.2-7 thru 4.2-9 present the summary results on the samples of automobiles employed in the analyses of the "idle test" effects. As in the previous analyses of "7-mode test" effects these statistics are based on original C.V.S. measurements taken on the tested automobiles.

Table 4.2-10 summarizes the results of significance tests performed to investigate the possible existence of a significant change in average emissions (on audit test results) resulting from an automobile having been idle tested prior to the audit test.

| Emission Type | Sample Average (gm/mile) | Sample Variance (gm/mile$^2$) | Sample Size | |
|---|---|---|---|---|
| HC | 2.24 | 0.52 | 3623 | Idle |
| CO | 27.27 | 236.88 | 3623 | Tested |
| NOx | 2.31 | 0.35 | 3623 | Sample |
| HC | 1.95 | 0.25 | 462 | Not Idle |
| CO | 25.17 | 81.67 | 462 | Tested |
| NOx | 2.25 | 0.14 | 462 | Sample |

Table 4.2-7

Audit Test Emissions Results
"Idle" and "Not Idle" Tested Automobiles
1973 General Motors
(original measurements)

| Emission Type | Sample Average (gm/mile) | Sample Variance ($gm/mile^2$) | Sample Size | |
|---|---|---|---|---|
| HC | 2.36 | 0.23 | 1587 | Idle |
| CO | 27.07 | 52.3 | 1587 | Tested |
| NOx | 2.37 | 0.18 | 1587 | Sample |
| HC | 2.48 | 0.25 | 1316 | Not Idle |
| CO | 26.72 | 50.30 | 1316 | Tested |
| NOx | 2.46 | 0.12 | 1316 | Sample |

Table 4.2-8

Audit Test Emissions Results

"Idle" and "Not Idle" Tested Automobiles

1973 Ford

(original measurements)

| Emission Type | Sample Average (gm/mile) | Sample Variance (gm/mile$^2$) | Sample Size | |
|---|---|---|---|---|
| HC | 2.13 | 0.26 | 309 | Idle |
| CO | 26.89 | 80.13 | 309 | Tested |
| NOx | 2.37 | 0.29 | 309 | Sample |
| HC | 2.12 | 0.35 | 1153 | Not Idle |
| CO | 25.17 | 91.06 | 1153 | Tested |
| NOx | 2.28 | 0.40 | 1153 | Sample |

Table 4.2-9

Audit Test Emissions Results

"Idle" and "Not Idle" Tested Automobiles

1973 Chrysler

(original measurements)

*Comparison of Idle Tested vs Not Idle Tested Automobiles*

Test Statistic Employed:

$$Z_j = \left(\bar{X}_{\bar{I},j} - \bar{X}_{I,j}\right) \Big/ \sqrt{\frac{S_I^2}{n_1} + \frac{S_{\bar{I}}^2}{n_2}}$$

Summary of Results

| Model Year | Manufacturer | Emission Type | $Z_j$ | Significant at 5% Level | Conclusion |
|---|---|---|---|---|---|
| 1973 | GM | HC | -11.89 | Yes | $\mu_{\bar{I}} < \mu_I$ |
| | | CO | - 4.27 | Yes | $\mu_{\bar{I}} < \mu_I$ |
| | | NOx | - 3.47 | Yes | $\mu_{\bar{I}} < \mu_I$ |
| 1973 | Ford | HC | 8.511 | Yes | $\mu_{\bar{I}} > \mu_I$ |
| | | CO | - 1.313 | No | $\mu_{\bar{I}} = \mu_I$ |
| | | NOx | 9.000 | Yes | $\mu_{\bar{I}} > \mu_I$ |
| 1973 | Chrysler | HC | - 0.302 | No | $\mu_{\bar{I}} = \mu_I$ |
| | | CO | - 2.958 | Yes | $\mu_{\bar{I}} < \mu_I$ |
| | | NOx | - 2.601 | Yes | $\mu_{\bar{I}} < \mu_I$ |

Table 4.2-10

Summary of Idle Test Effect on Audit Results

For those emission types which revealed a significant change in emissions levels due to the presence of idle testing the magnitude of emissions changes (in tons per year) were computed. These computations are illustrated in the material which follows and employ the relationship:

$$\mathcal{E}_{\ell j} = \Gamma M N_\ell \left\{ \mu_{\bar{I},j} + \tilde{\alpha}\left( \mu_{I,j} - \mu_{\bar{I},j} \right) \right\} \quad (4.2.4)$$

1973 General Motors

I Hydrocarbons

$$\mathcal{E}_{11} = (1.1 \times 10^{-6} \text{ tons/gm})\ (12{,}000\ \frac{\text{miles}}{\text{car/yr}})\ (5 \times 10^{6}\ \frac{\text{cars}}{\text{yr}})\ [1.95 \text{ gm/mi} + \tilde{\alpha}(2.24 - 1.95) \text{ gm/mi}]$$

$$= (66 \times 10^{3})\ [1.95 \text{ gm/mi} + \alpha(2.24 - 1.95) \text{ gm/mi}]$$

$$\mathcal{E}_{11} = 128700 + 19140\tilde{\alpha} \text{ tons per year HC}$$

With $\tilde{\alpha} = 0.75$, one obtains an increase of

$$\Delta_{11} = 14355 \text{ tons per year}$$

II Carbon Monoxide

$$\mathcal{E}_{12} = (66 \times 10^{3})\ [25.17 \text{ gm/mi} + \tilde{\alpha}\ (27.27 - 25.17) \text{ gm/mi}]$$

$$= 1{,}661{,}220 + 138{,}600\tilde{\alpha} \text{ tons per year CO}$$

With $\tilde{\alpha} = 0.75$, one obtains an increase of

$$\Delta_{12} = 103{,}950 \text{ tons per year}$$

III Oxides of Nitrogen

$$\mathcal{E}_{13} = (66 \times 10^{3})\ [2.25 \text{ gm/mi} + \tilde{\alpha}\ (2.31 - 2.24) \text{ gm/mi}]$$

$$= 148{,}500 + 3960\tilde{\alpha} \text{ tons per year NOx}$$

With $\tilde{\alpha} = 0.75$, one obtains an increase of

$$\Delta_{12} = 2970 \text{ tons per year}$$

1973 Ford

I Hydrocarbons

$$\mathcal{E}_{21} = (1.1 \times 10^{-6} \text{ tons/gm}) (12{,}000 \frac{\text{miles}}{\text{car/yr}}) (3.3 \times 10^{6} \frac{\text{cars}}{\text{yr}}) [2.48 \text{ gm/mi} + \tilde{\alpha} (2.36 - 2.48) \text{ gm/mi}]$$

$$\mathcal{E}_{21} = 108{,}128 - 5580\tilde{\alpha} \text{ tons per year HC}$$

With $\tilde{\alpha}$ = 0.75, one obtains a decrease of

$$\Delta_{21} = 4185 \text{ tons per year}$$

II Carbon Monoxide

Not applicable since there is no significant difference in the average emission level under the presence or absence of idle testing (see Table 4.2-10)

III Oxides of Nitrogen

$$\mathcal{E}_{23} = (43.6 \times 10^{3}) \left\{2.46 \text{ gm/mi} + \tilde{\alpha} (2.37 - 2.46)\right\} \text{gm/mi}$$

$$\mathcal{E}_{23} = 107256 - 3924\tilde{\alpha} \text{ tons per year NOx}$$

With $\tilde{\alpha}$ = 0.75, one obtains a decrease of

$$\Delta_{23} = 2943 \text{ tons per year}$$

1973 Chrysler

I Hydrocarbons

Not applicable since there is no significant difference in the average emission level under the presence or absence of idle testing (see Table 4.2-10)

II Carbon Monoxide

$$\mathcal{E}_{32} = (1.1 \times 10^{-6} \text{ tons/gm}) (12{,}000 \frac{\text{miles}}{\text{car/yr}}) (1.5 \times 10^{6} \frac{\text{cars}}{\text{yr}}) [25.17 \text{ gm/mile} + \tilde{\alpha} (26.89 - 25.17)]$$

$$\mathcal{E}_{32} = 49836 + 3405\tilde{\alpha} \text{ tons per year CO}$$

With $\tilde{\alpha}$ = 0.75, one obtains an increase of

$$\Delta_{32} = 851.25 \text{ tons per year}$$

III Oxides of Nitrogen

$$\mathcal{E}_{33} = (1.98 \times 10^3)\left\{(2.28 \text{ gm/mi} + \tilde{\alpha}\,(2.37 - 2.28)\right\}\text{gm/mi})$$

$$= 4514 + 178.2\tilde{\alpha} \text{ tons per year NOx}$$

With $\tilde{\alpha} = 0.75$, one obtains an increase of

$$A_{33} = 44.5 \text{ tons per year}$$

The current Assembly Line Test program calls for 100% of California production to be "Inspection Tested", with 25% being 7-mode tested and 75% being idle tested. In theory, then, there would be no overlap of these testing procedures. In practice, however, it occurs that there is considerable overlap (i.e., some automobiles receive both 7-mode and idle tests), and there are large numbers which are either 7 Mode tested only or Idle tested only.* The occurrence of these four exhaustive and mutually exclusive combinations of testing permits an investigation of further, and more specific, patterns which may occur in emission level changes as a function of testing combinations.

Tables 4.2-11 thru 4.2-13 present the summary results, by manufacturer, on the samples of automobiles employed in the analysis of "hot 7-mode and/or idle test" effects on C.V.S. audit test emissions levels. It should be noted that the data of these tables represents a further decomposition of the samples, and consequently the statistics, contained in Tables 4.2-2 thru 4.2-5 as well as Tables 4.2-7 thru 4.2-9.

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* Further, for the 1973 data base employed in this study (i.e. - the first two production quarters), only 25% of production was required by California to be idle tested; thus, some autos in the data base received no inspection testing.

| Inspection Test Combination | Emissions Type | Sample Average (gm/mile) | Sample Variance (gm/mile$^2$) | Sample Size |
|---|---|---|---|---|
| 7 Mode Only | HC | 1.92 | 0.23 | 217 |
| | CO | 24.17 | 89.93 | 217 |
| | NOX | 2.24 | 0.16 | 217 |
| Idle Test Only | HC | 2.24 | 0.33 | 1536 |
| | CO | 29.58 | 196.18 | 1536 |
| | NOX | 2.28 | 0.24 | 1536 |
| Both Types | HC | 2.23 | 0.66 | 2087 |
| | CO | 25.56 | 260.08 | 2087 |
| | NOX | 2.33 | 0.42 | 2087 |
| Neither Type | HC | 1.97 | 0.26 | 245 |
| | CO | 26.06 | 73.0 | 245 |
| | NOX | 2.26 | 0.13 | 245 |

Table 4.2- 11

Audit Test Emission Results

7-mode/Idle Test Combinations

1973 General Motors

(original measurements)

| Inspection Test Combination | Emission Type | Sample Average (gm/mile) | Sample Variance ($gm/mile^2$) | Sample Size |
|---|---|---|---|---|
| 7 Mode Only | HC | 2.48 | 0.25 | 1242 |
| | CO | 26.62 | 48.74 | 1242 |
| | NOX | 2.48 | 0.11 | 1242 |
| Idle Only | HC | 2.32 | 0.15 | 324 |
| | CO | 26.63 | 64.42 | 324 |
| | NOX | 2.08 | 0.17 | 324 |
| Both Types | HC | 2.38 | 0.51 | 1263 |
| | CO | 27.19 | 49.24 | 1263 |
| | NOX | 2.45 | 0.15 | 1263 |
| Neither Type | HC | 2.51 | 0.17 | 74 |
| | CO | 28.36 | 74.63 | 74 |
| | NOX | 2.22 | 0.25 | 74 |

Table 4.2-12

Audit Test Emission Results

7-mode/Idle Test Combinations

1973 Ford

(original measurements)

| Inspection Test Combinations | Emission Type | Sample Average (gm/mile) | Sample Variance (gm/mile$^2$) | Sample Size |
|---|---|---|---|---|
| 7 Mode Only | HC | 1.96 | 0.20 | 385 |
| | CO | 23.39 | 66.32 | 385 |
| | NOX | 1.97 | 0.21 | 385 |
| Idle Only | HC | 1.83 | 0.14 | 55 |
| | CO | 23.85 | 67.92 | 55 |
| | NOX | 1.97 | 0.19 | 55 |
| Both Types | HC | 2.20 | 0.26 | 254 |
| | CO | 27.55 | 80.59 | 254 |
| | NOX | 2.46 | 0.27 | 254 |
| Neither Type | HC | 2.21 | 0.40 | 768 |
| | CO | 26.07 | 101.17 | 768 |
| | NOX | 2.43 | 0.43 | 768 |

Table 4.2- 13
Audit Test Emission Results
7-mode/Idle Test Combinations
1973 Chrysler
(original measurements)

## 4.3 Emission Level Changes Associated With Audit Tests

### 4.3.0 Introduction

The methodology for assessing changes in emission levels associated with the audit procedures was described in Chapter 2, Section 2.4. Application of this methodology to the particular data base available is presented here. For the 1972 model year such analysis was possible for the General Motors Corporation only, since this was the only available data set which contained final measurements of emission levels for those automobiles which failed the audit tests originally. Further, within this model year, analyses were only possible for Hydrocarbon and Carbon Monoxide emissions (since NOx was measured by 7 Mode rather than C.V.S. techniques).

For the 1973 model year analyses were possible for both General Motors and Chrysler data, and further, since C.V.S. techniques were employed on NOx measurements for this model year it was possible to consider all three types of emissions (i.e., HC; CO; and NOx).

### 4.3.1 Methodology

The basic estimation procedure employed is the relation:

$$\mathcal{E}_{\ell j} = \Gamma \cdot M_\ell N_\ell \left\{ \beta \bar{e}^{(0)}_{\ell j} - \beta(1-p_\ell)\bar{e}^{(1)}_{\ell j} - \beta p_\ell \bar{e}^{(2)}_{\ell j} \right\} \qquad (4.3.1)$$

as discussed in Section 2.4. From the data base available it is not possible to estimate $\bar{e}^{(1)}_{\ell j}$ and consequently it was assumed that

$$\bar{e}^{(1)}_{\ell j} = \bar{e}^{(0),P}_{\ell j}$$

for each manufacturer and emission type. Under this assumption, and coupled with the fact that $\bar{e}^{(0)}_{\ell j} = p\,\bar{e}^{(0),f}_{\ell j} + (1-p)\,\bar{e}^{(0),P}_{\ell j}$, *substitution* into expression 4.3.1 reduces to

$$\mathcal{E}_{\ell j} = \Gamma M_\ell N_\ell \beta p_\ell \left( \bar{e}^{(0),f}_{\ell j} - \bar{e}^{(2)}_{\ell j} \right) \qquad (4.3.2)$$

The components of this expression were derived as follows:

I $\Gamma$ = $(1.1 \times 10^{-6}$ tons/gram)

II $M_\ell$ = 12,000 miles per year (assumed as a plausible yearly average mileage for a typical automobile). This was further assumed to be constant for all manufacturers (i.e., $\ell$ = 1, 2, 3).

III $N_\ell$ = yearly nationwide production for manufacturer $\ell$.

IV $\beta$ = 0.02 (i.e., current procedures employed in California call for 2% audit sampling)

V $P_\ell$ = For the $\ell$-th manufacturer this was taken as the ratio of the number of failures on original audit tests divided by the number of original audit tests.

VI $\bar{e}^{(o),f}_{\ell_j}$ = The average level of emissions of type $j$ for cars *originally failing for the $\ell$-th manufacturer, from all* available original emissions measurements from the audit tests.

VII $\bar{e}^{(o),p}$ = The average level of emissions of type $j$ for cars originally passing for the $\ell$-th manufacturer, from all available original emissions measurements from the audit tests.

VIII $\bar{e}^{(2)}_{\ell_j}$ = The average of the final emissions measurements from the audit tests of manufacturer 1 (on emission type $j$).

4.3.2 Data Base Employed

The data and information needed to estimate the parameters employed in expression 4.3.2 were based on appropriately selected subsets of the 1972 and 1973 General Motors Audit Test data and the 1973 Chrysler Audit Test dat.

*Estimation of the "original average emissions level for failing cars* - $\bar{e}^{(o),f}$ was conducted by using the set of original audit test results for the manufacturers involved. These sets included both passing as well as original measurements on failing cars and in that sense were representative of a population of measurements taken on first tests of cars which failed off the production line. For the data bases involved this included (I) 656 original measurements on 1972 General Motors cars, (II) 643 original measurements on 1973 General Motors cars, and (III) 254 original measurements on 1973 Chrysler Corporation cars.

Estimation of the "final average emissions level of rectified cars which had originally failed the audit test" $\overline{C}^{(2)}$ was conducted by using the set of final audit test results for the manufacturers involved. For the data base involved this included: (1) 650 final measurements on 1972 General Motors cars which originally failed, (II) 640 final measurements on 1973 General Motors cars which originally failed and (III) 254 final measurements on 1973 Chrysler cars which had originally failed.

### 4.3.3 Summary of Results

Table 4.3-1 presents a summary of the estimated emission level changes which would result from a nationwide application of 2% Audit Sampling as is currently being performed on California production.

| Model Year | Manufacturer | Emission Type | Emissions Level Change (tons per year) |
|---|---|---|---|
| 1972 | General Motors | Hydrocarbon | 122 (decrease) |
| | | Carbon Monoxide | 39 (decrease) |
| 1973 | General Motors | Hydrocarbon | 121 (decrease) |
| | | Carbon Monoxide | 2317 (decrease) |
| | | Oxides of Nitrogen | 62 (decrease) |
| 1973 | Chrysler | Hydrocarbon | 30 (decrease) |
| | | Carbon Monoxide | 589 (decrease) |
| | | Oxides of Nitrogen | 34 (decrease) |

Table 4.3-1

Estimated Emission Level Changes From Nationwide Audit Testing at 2% Sampling Level

4.3.4

The specific data and computations upon which the results of Table 4.3-1 are based are presented here.

I Conversion Factor: $\Gamma = 1.1 \times 10^{-6}$ tons per gram

II Average Yearly Mileage: 12,000 miles per year per car assumed constant for all manufacturers

III Nationwide Productions

| Manufacturer | $\ell$ | $N_\ell$ (automobiles/year) |
|---|---|---|
| General Motors Corporation | 1 | $5.0 \times 10^6$ |
| Ford Motor Company | 2 | $3.3 \times 10^6$ |
| Chrysler Corporation | 3 | $1.5 \times 10^6$ |

IV Sampling Rate: $\beta$ = .02 assumed constant for all manufacturers

V Failure Rates

| Manufacturer | $\ell$ | $P_\ell$ (%) | |
|---|---|---|---|
| | | 1972 | 1973 |
| General Motors Corporation | 1 | 7.06 | 15.74 |
| Ford Motor Company | 2 | NA | NA |
| Chrysler Corporation | 3 | NA | 17.37 |

VI Average Emissions Levels: Original Measurements

| Manufacturer | $\ell$ | Emittant | $j$ | Average Emissions $\bar{e}^{(o)}_{\ell j}$ (gm/mile) 1972 | 1973 |
|---|---|---|---|---|---|
| General Motors Corp. | 1 | HC | 1 | 3.01 | 2.75 |
| | | CO | 2 | 38.59 | 38.78 |
| | | NOx | 3 | NA | 2.57 |
| Ford Motor Co. | 2 | HC | 1 | NA | NA |
| | | CO | 2 | NA | NA |
| | | NOx | 3 | NA | NA |
| Chrysler Corp. | 3 | HC | 1 | NA | 2.61 |
| | | CO | 2 | NA | 34.44 |
| | | NOx | 3 | NA | 2.82 |

VII Average Emissions Levels: Final Measurements for Cars which Originally Failed

| Manufacturer | $\ell$ | Emittant | $\gamma$ | Average Emissions $\overline{e}^{(2)}_{\ell\gamma}$ (gm/mile) 1972 | 1973 |
|---|---|---|---|---|---|
| General Motors Corp. | 1 | HC | 1 | 1.70 | 2.17 |
| | | CO | 2 | 22.64 | 27.63 |
| | | NOx | 3 | NA | 2.27 |
| Ford Motor Co. | 2 | HC | 1 | NA | NA |
| | | CO | 2 | NA | NA |
| | | NOx | 3 | NA | NA |
| Chrysler Corp. | 3 | HC | 1 | NA | 2.12 |
| | | CO | 2 | NA | 25.88 |
| | | NOx | 3 | NA | 2.33 |

Substitution of the data of I - VII above into expression 4.3.2 yields.

1972 General Motors

I $\mathcal{E}_{11} = \Gamma M_1 N_1 \beta P_1 (\overline{e}^{(0)}_{11} - \overline{e}^{(2)}_{11})$

$= (1.1 \times 10^{-6}$ gm/mile) · $(12 \times 10^3$ miles/yr) · $(5 \times 10^6$ cass) · (0.02) (.0706) (3.01 - 1.70 gm/mi)

= 122.08 tons per year decrease in HC

II $\mathcal{E}_{12} = \Gamma M_1 N_1 \beta P_1 (\overline{e}^{(0)}_{12} - \overline{e}^{(2)}_{12})$

$= (1.1 \times 10^{-6}) (12 \times 10^3) (5 \times 10^6)$ (.02) (.0706) (38.59 - 22.64)

=1486.41 tons per year decrease in CO

1973 General Motors

I $\mathcal{E}_{11} = \Gamma M_1 N_1 \beta P_1 (\overline{\mathcal{E}}_{11}^{(0)} - \overline{\mathcal{E}}_{11}^{(2)})$

$= (1.1 \times 10^{-6}) (12 \times 10^{3}) (5 \times 10^{6}) (.02) (.1574) (2.75 - 2.17)$

$= 120.51$ tons per year decrease in HC

II $\mathcal{E}_{12} = \Gamma M_1 N_1 \beta P_1 (\overline{\mathcal{E}}_{12}^{(0)} - \overline{\mathcal{E}}_{12}^{(2)})$

$= (1.1 \times 10^{-6}) (12 \times 10^{3}) (5 \times 10^{6}) (.02) (.1574) (38.78 - 27.63)$

$= 2316.61$ tons per year decrease in CO

III $\mathcal{E}_{13} = \Gamma M_1 N_1 \beta P_1 (\overline{\mathcal{E}}_{13}^{(0)} - \overline{\mathcal{E}}_{13}^{(2)})$

$= (1.1 \times 10^{-6}) (12 \times 10^{3}) (5 \times 10^{6}) (.02) (.1574) (2.57 - 2.27)$

$= 62.33$ tons per year decrease in NOx

1973 Chrysler

I $\mathcal{E}_{31} = \Gamma M_3 N_3 \beta P_3 (\overline{\mathcal{E}}_{31}^{(0)} - \overline{\mathcal{E}}_{31}^{(2)})$

$= (1.1 \times 10^{-6}) (12 \times 10^{3}) (1.5 \times 10^{6}) (.02) (.1737) (2.61 - 2.17)$

$= 30.27$ tons per year decrease in HC

II $\mathcal{E}_{32} = \Gamma M_3 N_3 \beta P_3 (\overline{\mathcal{E}}_{32}^{(0)} - \overline{\mathcal{E}}_{32}^{(2)})$

$= (1.1 \times 10^{-6}) (12 \times 10^{3}) (1.5 \times 10^{6}) (.02) (.1737) (34.44 - 25.88)$

$= 588.80$ tons per year decrease in CO

III $\mathcal{E}_{33} = \Gamma M_3 N_3 \beta P_3 (\overline{\mathcal{E}}_{33}^{(0)} - \overline{\mathcal{E}}_{33}^{(2)})$

$= (1.1 \times 10^{-6}) (12 \times 10^{3}) (1.5 \times 10^{6}) (.02) (.1737) (2.82 - 2.33)$

$= 33.70$ tons per year decrease in NOx

## 4.4 An Analysis of Gross Emitters

One facet of emissions patterns which is likely to be of some interest and utility is that of outliers or gross emitters. While the statistical pattern of emissions for a particular engine may be at an acceptable average level one may still be concerned about the "high tail" of the distribution, namely what percentage of autos produced will have emissions beyond some "tolerance limit", so to speak. In an attempt to develop some insight into the extreme values resulting from audit test emissions measurements, the 1972 General Motors data base was analyzed. Because of time and funding limitations this restricted subset of data was employed to analyze gross emitters, rather than using the entire data set available during the project. At the request of the Environmental Protection Agency a lower bound for defining a "Gross Emitter" was defined as that point which was both two standard deviations above the average level of the emission type under analysis and higher than the applicable emission standard. For the three emittants the development of the "Gross Emitter Limits" is shown below:

| Emission Type | Sample Average (gm/mile) | Sample Std. Dev. | Gross Emitter Limit | California Standard |
|---|---|---|---|---|
| HC | 1.82 | 0.83 | 3.48 | 3.2 |
| CO | 22.79 | 12.78 | 58.35 | 39 |
| NOX | 1.93 | 0.67 | 3.27 | 3.2 |

Since these limits exceed, for each emission type, the applicable standard these limits will serve to define the gross emitters.

Working with the set of original measurements on 1972 General Motors Audit Test results those values of HC, CO and NOX emissions measurements which exceeded the limits were determined. (It should be recalled here that for the data subset under consideration, the NOX data was obtained by 7-mode tests.) The failures were classified according to whether only the HC limit was exceeded, only the CO limit, etc. For the second thru fifth quarter, as well as yearly totals the overall failure rates are shown in Table 4.4-1, the failure rates by Gross Emitter Category are shown in Table 4.4-2 and Table 4.4-3 summarizes the averages and standard deviations of Gross Emitters (by category) for the 1972 General Motors data.

| Production Quarter | Number Original Measurements | Number Gross Emitters | Percentage Gross Emitters |
|---|---|---|---|
| 2 | 2504 | 118 | 4.71 |
| 3 | 3656 | 112 | 3.06 |
| 4 | 2878 | 92 | 3.20 |
| 5 | 246 | 37 | 15.04 |
| TOTAL | 9284 | 359 | 3.87 |

Table 4.4-1

Overall Gross Emitter Rates
1972 General Motors

| Gross Emitter Type | Number of Gross Emitters | Category Rate (%) | % of All Gross Emitters |
|---|---|---|---|
| HC | 201 | 2.17 | 56 |
| CO | 35 | 0.38 | 10 |
| NOX | 104 | 1.12 | 29 |
| HC & CO | 13 | 0.14 | 4 |
| HC & NOX | 5 | 0.05 | 1.5 |
| CO & NOX | 0 | 0.0 | 0.0 |
| HC, CO & NOX | 1 | 0.01 | 0.5 |
| TOTAL | 359 | 3.87 | 100.0 |

Table 4.4-2
Gross Emitter Rates - by Category
1972 General Motors

| Gross Emitter Category | Hydrocarbon | | Carbon Monoxide | | NOX | | "n" |
|---|---|---|---|---|---|---|---|
| | $\bar{x}$ | s | $\bar{x}$ | s | $\bar{x}$ | s | |
| HC | 4.52 | 1.22 | 26.88 | 9.78 | 1.73 | 0.44 | 201 |
| CO | 2.10 | 0.58 | 85.03 | 62.44 | 1.93 | 0.57 | 35 |
| NOX | 1.86 | 0.56 | 22.90 | 6.85 | 3.70 | 0.45 | 104 |
| HC & CO | 5.38 | 2.65 | 90.54 | 16.93 | 1.76 | 0.30 | 13 |
| HC & NOX | 4.44 | 0.38 | 28.0 | 8.49 | 5.46 | 3.99 | 5 |
| CO & NOX | -- | -- | -- | -- | -- | -- | 0 |
| HC, CO & NOX | 3.91 | -- | 76.0 | -- | 41.0 | -- | 1 |

Table 4.4-3

Average and Standard Deviations of Gross Emitters

(by category)

1972 General Motors

(grams per mile)

# 5 ALTERNATE ASSEMBLY LINE TEST PROCEDURES AND THEIR IMPACT ON EMISSIONS

## 5.1 Introduction

Having observed the magnitudes of emissions changes which may be related to segments of the assembly line testing as currently employed in California and considering the assessment of changes in emissions which might occur if such procedures were employed on a nationwide basis, the next logical step is to consider how and to what extent variations in the structure of an assembly line testing program may be devised and what emissions changes might be obtained from alternate approaches. This chapter focuses on that issue.

A number of potential alternate assembly line testing structures are discussed in Section 5.2. Essentially these focus on possible variations in some of the controllable characterisitcs of the currently employed California procedure. Specifically, variations in (I) the acceptable audit test failure rate, (II) level of hot 7-mode testing, (III) level of idle testing, and (III) level of audit sampling will be considered. Further, a modification in the audit sampling procedures will be discussed in an attempt to consider how alternate sampling strategies, within the confines of a fixed sampling rate, may offer some promise of substantial improvements in the rectifying capabilities of the audit testing phase of assembly line testing programs.

## 5.2 Methodology and Analyses

### 5.2.1 Considerations of Modified Failure Rate Standards

We shall first consider the issue of varying the acceptable audit test failure rate associated with an assembly line testing program design. Recall that the current California procedure has specified a 10% failure rate limit. It is instructive to consider what might happen if this failure criterion were modified, say to 5%, or 15%, etc. Suppose an assembly line program specifies an audit failure rate limit of $\rho_o$ (not necessarily equal to 10%), and further assume that audit sampling occurs at the rate $\beta$. If, for a given engine family of a manufacturer, the actual failure rate prevailing is $\rho$ , then subsequent to audit sampling (and the concomitant adjustment to passing levels of automobiles which failed), the rectified fraction of failing automobiles will be,

$$\tilde{\rho} = (1-\beta)\rho \tag{5.2.1}$$

This relationship merely reflects the fact that the audit screening, to the extend that it only affects the environment by removing detected failing cars, misses a fraction $(1-\beta)$ of those autos which are failures to begin with. It follows that if one seeks to assure that, on the average, outgoing failure rates of "audited" engine families satisfy the legislated limit, $\rho_o$, then necessarily

$$\rho_o \geq \tilde{\rho} = \rho(1-\beta) \tag{5.2.2}$$

or alternately,

$$\beta \geq 1-(\rho_o/\rho) = \beta_o \tag{5.2.3}$$

Expression 5.2.3 suggests that for a given engine family with incoming audit failure rate $\rho$, a minimum audit sampling rate $\beta_o$ is necessary if the audit process is to screen enough failures from the incoming process to satisfy the maximum failure rate $\rho_o$. Given audit test failure rates, by engine category within a manufacturer, as are summarized in Chapter 3, one can assess how well or poorly the current audit rates (i.e., $\beta$ = 2%) screen the input failure levels and consequently contribute to meeting the 10% desired failure rate limit. Perhaps a more central issue, regarding variations in the magnitude of $\rho_o$, is how changes in its level would be reacted to by the manufacturers in so far as modifying process averages and variabilities so as to satisfy the limit on failure rates.

Appropriate data was clearly not available during this project to adequately characterize the manner in which emission distributions would "adapt" to varying failure rate limits; thus this facet of alternate assembly line programs is not pursued further.

5.2.2 Consideration of Alternate 7-mode and Idle Test Rates

A second aspect of alternate assembly line program design is the possible variation of 7-mode and/or idle test rates. Presumably, in an attempt to decrease emission levels by manipulating testing rates one would seek to increase test rates for those test types for which the rate of change in emissions is most negative. The analyses of 7-mode, idle, or 7-mode and idle test effects on audit test results yielded very mixed results, and consequently, it is not at all clear that increasing levels of 7-mode testing, or levels of idle testing would yield a discernable improvement in emissions levels.

Since combinations of both 7-mode and idle tests on a single automobile appear to interact with one another and, more often than not (as indicated, based on the preliminary analyses of Chapter 4), combine to increase emissions levels, we shall consider only testing levels for which 7-mode testing and idle testing are mutually exclusive. Further, the results from idle tests alone suggest that the presence of idle tests appear to increase audit test emissions levels (i.e., 1973 data for idle tested cars suggest increased levels of HC, CO and NOx in contrast to no Idle testing). These factors suggest that the most likely candidate for reducing emissions, based on the analyses of data from this study, is to increase the testing rates on hot 7-mode tests. It was observed in Section 4.2.1 that, as a function of 7-mode testing rate, $\alpha$, the average emissions level can be expressed as

$$\mathcal{E} = \Gamma M \cdot N \left\{ \mu_{\overline{7M}} + \alpha \left( \mu_{\cdot 7M} - \mu_{\overline{7M}} \right) \right\} \qquad (5.2.4)$$

From the 1972 model year data base Ford and Chrysler analyses reflected no appreciable changes in emissions levels (i.e., HC and CO) resulting from the presence of 7-mode tests, and while the General Motors Data yielded a significant trend, this was somewhat suspect in that the 7-mode tested cars were from a restricted set of engine classes and assembly plants raising some question of whether or not this trend is really attributable to the 7-mode test or to some other correlated factor. The 1973 data base yields more promising results. While HC and NOx are seen to increase with 7-mode testing, CO decreases substantially. The question then is how to "balance" increases in HC and NOx against decreases in CO. Clearly, some value judgments will be needed to finalize this.

Employing expression (5.2.4) and denoting the total emissions changes after summing over manufacturers, one obtains:

I Hydrocarbons

$$\mathcal{E}^{(HC)} = \sum_{\ell=1}^{3} \Gamma M N_\ell \left\{ \mathcal{U}_{\overline{7M}}^{\ell} + \alpha\left(\mathcal{U}_{7M}^{\ell} - \mathcal{U}_{\overline{7M}}^{\ell}\right)\right\} \quad (5.2.5)$$

where the superscript denotes the manufacturer. This reduces to:

$$\begin{aligned} &= [121440 + 0.\alpha] \\ &\quad + [102,896 + 3488\alpha] \\ &\quad + [4316 - 257\alpha] \\ \mathcal{E}^{HC} &= 228652 + 3231\alpha \text{ tons per year} \end{aligned} \quad (5.2.6a)$$

II Carbon Monoxide

$$\begin{aligned} \mathcal{E}^{CO} &= [1,920,600 - 242,000\alpha] \\ &\quad + [1,165,020 + 0.\alpha] \\ &\quad + [51,322 + 0.\alpha] \\ \mathcal{E}^{CO} &= 3,136,942 - 242,000\alpha \text{ tons per year} \end{aligned} \quad (5.2.6b)$$

III Oxides of Nitrogen

$$\begin{aligned} \mathcal{E}^{NOx} &= [149,820 + 3,300\alpha] \\ &\quad + [91,996 + 15,260\alpha] \\ &\quad + [4752 + 0.\alpha] \\ \mathcal{E}^{HC} &= 246,568 + 18,560\alpha \text{ tons per year} \end{aligned} \quad (5.2.6c)$$

In summary then, based upon available data, it would appear that increasing 7-mode test rates would modify HC, CO and NOx emissions levels as indicated in expressions 5.2.6a-c. Emissions level changes at a representative set of test rates ($\alpha$) for 7-mode testing are presented in Table 5.2.1.

| 7 Mode Test Rate Nationwide | Emission Level Changes (tons per year) | | |
|---|---|---|---|
| | HC | CO | NOx |
| 25% | + 808 | - 60,500 | + 4,640 |
| 50% | +1616 | -121,000 | + 9,280 |
| 75% | +2424 | -181,500 | +13,920 |
| 100% | +3231 | -242,000 | +18,560 |

Table 5.2-1

7-mode Test Related Emissions Changes

5.2.3 Consideration of Alternate Audit Sampling Procedures

A third area of possible variation in the assembly line testing procedure is centered on the audit testing segment. On the one hand, the audit rate, $\beta$, might be varied and on the other hand the audit rate might be held fixed, but the manner in which the total sample of autos to be audited may be altered.

Regarding the former approach, an assessment of the emissions level changes is relatively straight forward. From expression (4.3.2) we have

$$\mathcal{E}_{\ell j} \equiv \Gamma M N_\ell \beta P_\ell \left( \bar{\mathcal{E}}_{\ell j}^{(o),f} - \bar{\mathcal{E}}_{\ell j}^{(a)} \right) \tag{5.2.7}$$

and from this it is readily apparent that by varying $\beta$, the audit rate, the emissions level varies linearly with $\beta$. For each emission type we can express a combined effect on emissions by summing over those manufacturers for which data is available. From the 1973 data base, estimates were attainable for General Motors and Chrysler. These results are:

I Hydrocarbon

$$\mathcal{E}_{\cdot 1} \equiv \mathcal{E}_{11} + \mathcal{E}_{31}$$

$= +6025.5\beta + 30.27$

$= 6055.77\beta$ tons per year <u>decrease</u> in HC

II Carbon Monoxide

$$\mathcal{E}_{\cdot 2} = \mathcal{E}_{12} + \mathcal{E}_{32}$$

$= 115830.50\beta + 29440\ \beta$

$= 145270.5\beta$ tons per year <u>decrease</u> in CO

III Oxides of Nitrogen

$$\mathcal{E}_{\cdot 3} = \mathcal{E}_{13} + \mathcal{E}_{33}$$

$= 3116.50\ \beta + 1685.00\ \beta$

$= 4801.50\beta$ tons per year <u>decrease</u> in NOx

Emission level changes at a representative set of audit rates are presented in Table 5.2-2.

| Audit Rate ($\beta$) | Emission Level Changes (tons per year) | | |
|---|---|---|---|
| | HC | CO | NOx |
| 1% | - 60.56 | - 1452.71 | - 58.01 |
| 2% | -121.12 | - 2905.41 | - 96.02 |
| 3% | -181.67 | - 4358.12 | -144.03 |
| 5% | -302.79 | - 7263.56 | -240.05 |
| 10% | -605.58 | -14527.05 | -480.10 |

Table 5.2-2

Audit Rate Related Emission Changes

Recognizing that the data of Table 5.2-2 represents estimates based only on General Motors and Chrysler data, it may be helpful to extrapolate to what these levels might be if Ford data were available. Given that General motors and Chrysler account for approximately 66% of the total production of the "Big Three" manufacturers and assuming that Ford experience on audit tests would "approximate" the GM/Chrysler results, we can divide each entry of Table 5.2-2 to estimate the emissions changes, on a nationwide basis, when extended (under the limitations of the above assumptions) to all three manufacturers. This result is summarized in Table 5.2-3.

| Audit Rate | Emission Level Changes (tons per year) | | |
|---|---|---|---|
| | HC | CO | NOX |
| 1% | - 91.76 | - 2201.08 | 72.74 |
| 2% | -183.52 | - 4402.14 | -145.45 |
| 3% | -275.26 | - 6603.21 | -218.23 |
| 5% | -458.77 | -11005.39 | -363.71 |
| 10% | -917.55 | -22010.68 | -727.42 |

Table 5.2-3
Extrapolated Audit Rate Related
Emission Changes

Thus far we have discussed anticipated emission level changes if the rate of audit sampling ($\beta$) is varied, but the manner of sampling is retained as currently done. For example, at a 2% audit rate General Motors would audit test approximately 100,000 automobiles on a nationwide basis and these are tested on a pro-rated basis splitting them proportionally in each production quarter of the year (i.e. 17%, 25%, 25%, 25% and 8%) and within each quarter auditing 2% of each engine categories' production. The emissions changes shown in Tables 5.2-2 and 5.2-3 are premised on this sampling procedure.

We will now focus on an alternate approach to how one might "allocate" the 100,000 automobiles to be audited, thereby retaining the equivalent of 2% sampling, yet hoping to improve upon the emissions reduction attained. Consider a manufacturer with, say, $\mathcal{C}$ different engine categories and let $n_{ij}$ denote the number of automobiles produced in engine category i during production quarter j. Further, let $S_{ij}$ represent the number of automobiles "audit tested" by the manufacturer from engine category i in production quarter j.

Define

$$\beta_{ij} \equiv S_{ij}/n_{ij} \qquad \begin{array}{l} j = 1,2,\ldots 5 \\ = 1,2,\ldots C \end{array} \qquad (5.2.8)$$

It is seen that $\beta_{ij}$ represents the fraction of production in category i and quarter j which *is audit tested. As assembly line testing* is currently applied it is true that $\beta_{ij} = 0.02 = \beta$ for all i, j; that is, 2% of production is audited on a category/quarter basis. Since $N = \sum_{j=1}^{5} \sum_{i=1}^{C} n_{ij}$ equals the yearly total production for this manufacturer and since $S_{ij} = \beta n_{ij}$ for all i, j in the current scheme, it is clear that

$$\begin{aligned} S &= \sum_{j=1}^{5} \sum_{i=1}^{C} S_{ij} \\ &= \beta \sum_{j=1}^{5} \sum_{i=1}^{C} n_{ij} \\ &= \beta N \end{aligned} \qquad (5.2.9)$$

represents the total audit sample size for the manufacturer (e.g. - equals 100,000 for G.M. when $N = 5 \times 10^6$, $\beta = 0.02$). Consider an allocation of the $S$ automobiles to be audit tested in a manner other than a fixed percentage of each category/quarter production level; that is, consider sampling only subject to the constraints

$$\text{(i)} \quad 0 \leq S_{ij} \leq n_{ij} \qquad \text{for all i, j}$$

$$\text{(ii)} \quad \sum_{j=1}^{5} \sum_{i=1}^{C} S_{ij} = \beta N \qquad (5.2.10)$$

The question is, can a set $\{S_{ij}\}$ be selected which can improve upon emissions reductions in contrast to the situation where $\{S_{ij} = \beta n_{ij}\}$ To be more specific, consider category i and quarter j. The potential *emissions change attributable to* audit *sampling such autos is*

$$\mathcal{E}_{ij} = \Gamma M S_{ij} p_{ij} (\bar{e}_{ij}^{(0),f} - \bar{e}_{ij}^{(2)})$$

$$= \Gamma M \beta_{ij} N p_{ij} (\bar{e}_{ij}^{(0),f} - \bar{e}_{ij}^{(2)})$$

(5.2.11)

and summing over all engine category and production quarter combinations

$$\mathcal{E} \equiv \sum_{j=1}^{5} \sum_{i=1}^{C} \mathcal{E}_{ij}$$

$$= \Gamma M N \sum_{j=1}^{5} \sum_{i=1}^{C} \beta_{ij} p_{ij} (\bar{e}_{ij}^{(0),f} - \bar{e}_{ij}^{(2)})$$

(5.2.12)

What one would ideally seek is to define $\{\beta_{ij}^{*}\}$ (or equivalently $S_{ij}^{*}$ ) which would maximize

$$\mathcal{E}^{*} = \Gamma M N \sum_{j=1}^{5} \sum_{i=1}^{C} \beta_{ij}^{*} p_{ij} (\bar{e}_{ij}^{(0),f} - \bar{e}_{ij}^{(2)})$$

$$\equiv \max_{\{\beta_{ij}\}} \sum_{j=1}^{5} \sum_{i=1}^{C} \beta_{ij} p_{ij} (\bar{e}_{ij}^{(0),f} - \bar{e}_{ij}^{(2)}) \quad (5.2.13)$$

Now conceptually it is one thing to consider the idea of selecting $\beta$ ij's to extremize $\mathcal{E}$, but operationally it is another question, for the coefficients of $\beta_{ij}$ in expression (5.2.13) are random variables which, at the beginning of a production year, are unknown.

Let us consider the possibility of estimating the maximum emissions reduction which could be attainable, a-posteriori to a production year, had sampling levels been decided upon at the beginning of a production year.

Define $$\delta_{ij} \equiv p_{ij} (\bar{e}_{ij}^{(0),f} - \bar{e}_{ij}^{(2)}) \qquad \begin{matrix} i = 1,2,\ldots,C \\ j = 1,2,\ldots 5 \end{matrix}$$

(5.2.14)

and let $\{\delta_{i_\ell j_\ell} : \ell = 1, 2, \ldots, W\}$ be defined so that

$$\delta_{i_1 j_1} \geq \delta_{i_2 j_2} \geq \cdots \geq \delta_{i_W j_W} \qquad (W = 5 \times C)$$

(5.2.15)

That is to say, $(i_1\ j_1)$ is the engine category cell which contains the maximum $\delta_{ij}$ value; cell $(L_2, j_2)$ contains the second largest value, etc. The $\delta_{ij}$ term can be interpreted as an exptected or average change in emissions rate (in grams per mile) resulting from detecting and correcting failing cars. The component $(\bar{e}_{ij}^{(0),f} - \bar{e}_{ij}^{(2)})$ is the magnitude of improvement to be attained conditional on detecting (and correcting) a car whose emission level exceeds standards. The component $p_{ij}$ is the probability of detecting such a car.

Further define

$$S^*_{i_1 j_1} \equiv \max\left\{0, \min\left[S, n_{i_1, j_1}\right]\right\}$$

$$S^*_{i_2, j_2} \equiv \max\left\{0, \min\left[S - S^*_{i_1, j_1} ; n_{i_2, j_2}\right]\right\}$$

$$S^*_{i_3, j_3} \equiv \max\left\{0, \min\left[S - \sum_{\ell=1}^{2} S^*_{i_\ell j_\ell} ; n_{i_3, j_3}\right]\right\}$$

and in general

$$S^*_{i_K j_K} \equiv \max\left\{0, \min\left[S - \sum_{\ell=1}^{K-1} S^*_{i_\ell, j_\ell}, n_{i_K, j_K}\right]\right\} \quad (5.2.16)$$

$K = 1, 2, \ldots W$

Expression (5.2.16) merely implies that one assigns as much audit sampling as possible (without exceeding planned production levels) to those cells with the largest, second largest, ... etc. $\delta_{ij}$ values until one has either exhausted the permissible total audit sampling level (i.e. - $S = \beta N$ ) or audited all cells fully, whichever occurs first.

One can demonstrate that for the emissions type corresponding to the given set $\{\delta_{ij}\}$ for a particular production year allocating the audit sampling as described in (5.2.16) maximizes the total emissions change as in (5.2.13).

Let us illustrate with an example. Consider the 1972 General Motors data. Tables 5.2-5 through 5.2-7 contain, for HC, CO and NOX emissions respectively, the values of $\delta_{ij} = p_{ij}(\bar{e}_{ij}^{(o),f} - \bar{e}_{ij}^{(i)})$ indexed by engine category (i) and production quarter (j). We shall consider an "allocation" of audit inspected cars at a rate of $\beta = 2\%$. Estimating 1972 General Motors nationwide production at 5,000,000 automobiles this yields 100,000 automobiles to be audit tested. We shall select engine category/production quarter combinations on the basis of the hydrocarbon values of $\delta_{ij}$. Ranking the $\delta_{ij}$ values from maximum to minimum and allocating the $\mathcal{J}$ autos to be audited according to (5.2.16) one obtains:

| Engine Category/ Production Quarter | $\delta_{ij}$ | $n_{ij}$ | $S_{ij}^*$ |
|---|---|---|---|
| Chevrolet 140-1,2; 05 | 0.8250 | 29090 | 29040 |
| Pontiac 350-2; 05 | 0.7200 | 17160 | 17160 |
| Chevrolet 250-1; 03 | 0.5494 | 75625 | 53800 |

Table 5.2-4
Audit Sample Allocations
1972 General Motors

Observe that this allocation would audit all automobiles produced in the 5th quarter in the first 2 rows of Table 5.2-4, but only 53800 of the

| Division | Engine Category | Class Code (i) | Production Quarter (j) | | | |
|---|---|---|---|---|---|---|
| | | | | 3 | 4 | 5 |
| Chevrolet | 140-1,2 | 1 | .2979 | .1102 | .1001 | .8250 |
| | 250-1 | 2 | .0275 | .5494 | .0567 | 0.0 |
| | 350-2 | 3 | .0529 | .0469 | .0789 | .0695 |
| | 350-4 | 4 | .0852 | .0432 | .1353 | .4675 |
| | 400-2 | 5 | .0292 | .0473 | .0442 | 0.0 |
| Pontiac | 350-2 | 6 | .1193 | .0094 | .0426 | .7200 |
| | 400-2 | 7 | .0076 | .0100 | .0589 | 0.0 |
| | 400-4 | 8 | .0628 | .2785 | .1672 | .1918 |
| | 455-4 | 9 | .1287 | .1184 | .000 | .00 |
| Oldsmobile | 350-2 | 10 | .0112 | | .0675 | .4020 |
| | 350-4 | 11 | .0324 | .0603 | .0413 | .1000 |
| | 455-4 | 12 | | .0211 | .0702 | .1365 |
| Buick | 350-2 | 13 | .0172 | .0936 | .0287 | |
| | 350-4 | 14 | .0665 | .0797 | .0070 | |
| | 455-4 | 15 | .0319 | .0419 | .0489 | .3097 |
| Cadillac | 472-2 | 16 | .0355 | .0153 | .0611 | .400 |
| | 500-4 | 17 | .0764 | -.0560 | .0020 | |

Table 5.2-5

Hydrocarbon $\delta_{ij}$ Values

1972 General Motors

| Division | Engine Category | Class Code (i) | Production Quarter (j) | | | |
|---|---|---|---|---|---|---|
| | | | 2 | 3 | 4 | 5 |
| Chevrolet | 140-1,2 | 1 | 1.0651 | .4204 | .4421 | .8250 |
| | 250-1 | 2 | 1.7500 | 13.216 | 1.2077 | .0 |
| | 350-2 | 3 | .7614 | .9411 | 1.9666 | 2.123 |
| | 350-4 | 4 | 1.2837 | .9204 | 1.6135 | 2.7325 |
| | 400-2 | 5 | .7779 | .7175 | 1.1477 | .0 |
| Pontiac | 350-2 | 6 | 1.97 | 1.339 | .5472 | 4.0 |
| | 400-2 | 7 | .7600 | .3600 | .6787 | .0 |
| | 400-4 | 8 | 3.3488 | 4.0460 | 1.6724 | 5.3778 |
| | 455-4 | 9 | .4620 | .9065 | .0 | -.25 |
| Oldsmobile | 350-2 | 10 | .084 | | .4590 | 13.002 |
| | 350-4 | 11 | .4082 | .2385 | 1.2925 | -.6000 |
| | 455-4 | 12 | | .7508 | 6.588 | 3.4125 |
| Buick | 350-2 | 13 | .2054 | 1.2267 | .0615 | |
| | 350-4 | 14 | .1330 | .6154 | -.0528 | |
| | 455-4 | 15 | .3440 | 1.4904 | 2.112 | 1.7749 |
| Cadillac | 472-2 | 16 | 1.3065 | 1.1590 | 3.4437 | 20.0 |
| | 500-4 | 17 | .0 | .2080 | .120 | |

Table 5.2-6

Carbon Monoxide $\delta_{ij}$ Values

1972 General Motors

| Division | Engine Category | Class Code (i) | Production Quarter (j) | | | |
|---|---|---|---|---|---|---|
| | | | 1 | 3 | 4 | 5 |
| Chevrolet | 140-1,2 | 1 | .0605 | .0551 | .0835 | .6171 |
| | 250-1 | 2 | - .0150 | .4134 | .0164 | .0 |
| | 350-2 | 3 | .0033 | .0051 | .0218 | .0521 |
| | 350-4 | 4 | .0039 | .0027 | .0108 | +.025 |
| | 400-2 | 5 | .0082 | .0046 | .0139 | .2529 |
| Pontiac | 350-2 | 6 | .0141 | .0094 | .0198 | .0200 |
| | 400-2 | 7 | .0076 | .0120 | .0110 | .0 |
| | 400-4 | 8 | .0157 | .0643 | -.0113 | -0.0056 |
| | 455-4 | 9 | .0132 | .0444 | .0 | .60 |
| Oldsmobile | 350-2 | 10 | -.0028 | | .0027 | -.0780 |
| | 350-4 | 11 | .0180 | .0158 | -.0055 | .0600 |
| | 455-4 | 12 | | .0277 | .0275 | .3528 |
| Buick | 350-2 | 13 | .0080 | .0270 | .0390 | |
| | 350-4 | 14 | .0350 | .0561 | .0458 | |
| | 455-4 | 15 | .0794 | .0064 | .0530 | .0966 |
| Cadillac | 472-2 | 16 | .0275 | .0098 | -.0134 | .20 |
| | 500-4 | 17 | .1793 | .0280 | .0 | |

Table 5.2-7

NOX $\delta_{ij}$ Values

1972 General Motors

75625 Chevrolet 250-1's to be produced in quarter 3 since we are constrained to a total of 100,000 autos to be audited.

Employing expression (5.2.13) with the allocations $\delta^*_{ij}$ of Table 5.2-4 we obtain the estimated nationwide emissions reduction associated with this audit program, as shown below:

| Emission Type | Reduction in Tons per year |
|---|---|
| HC | 874 |
| CO | 10,608 |
| NOX | 535 |

Table 5.2-8
Emission Reduction From Optimal
2% Audit Sampling Allocation
1972 General Motors

Two points are noteworthy here: First, since 1972 test procedures employed seven mode testing for NOX, the emission reductions noted in Table 5.2-8 for NOX correspond to 7M results whereas, the HC and CO results are from C.V.S. tests. The second point is more critical and centers on the interpretation of the estimates of Table 5.2-8. As described earlier in this section, these emissions changes represent upper bounds on the maximum attainable emissions reduction from 2% audit testing during 1972. Had one, <u>at the beginning</u> of the 1972 model year, made the choice to allocate the 100,000 audit tests as shown in Table 5.2-4, the reductions of Table 5.2-8 would have been attained. Most likely, such an allocation would not be selected a priori. The utility, however of this computation is that it demonstrates a rather dramatic <u>potential</u> for improvement from audit testing in contrast to the currently employed scheme where the 2% sample is pro-rated across all engine categories and production quarters. This is seen more clearly from a comparison of the estimated nationwide reductions from the current procedure (See Table 4.3-1), and is summarized below:

| | Emissions Reductions | |
|---|---|---|
| | HC | CO |
| Current "2%" Audit Sampling | 122 tons/yr. | 39 tons/yr. |
| Optional 2% Audit Sampling | 874 tons/yr. | 10608 tons/yr. |

Table 5.2-9

Comparative Audit Sampling Emission Levels

The 1973 data base available facilitated a somewhat more satisfactory application of this technique. Such data was available from General Motors and Chrysler Corporation. Further, C.V.S. tests yielded NOX as well as HC and CO test measurements, hence estimates for all three emittent types were possible here. Without including all the tabular data (i.e. - $\delta_{ij}$'s, production levels, etc.) Table 5.2-10 presents the emissions changes attainable from an optional audit test allocation during the first 2 production quarters of the 1973 model year.

| Manufacturer | Emission Reduction (tons per year) | | |
|---|---|---|---|
| | HC | CO | NOX |
| G. M. | 70 | 1326 | 45 |
| Chrysler | 58 | 915 | 42 |
| TOTAL | 128 | 2241 | 87 |

Table 5.2-10
Emission Reductions From Optimal
2% Audit Sampling Allocation
1973 Model Year: Quarters 1 and 2

Since these estimated maximum attainable reductions were based on data from the first 2 production quarters (i.e. - on approximately 42% of the total years production), one can project this data to a full year's impact-assuming that similar attainable improvements might be attainable in the remainder of the year. Further, since Ford data was not available here, these numbers were based on 66% of nationwide prodution (i.e. - G.M. and Chrysler constitute roughly 66% of the "Big Three" total production); one might extrapolate from this data assuming that the Ford experience, if available, would be comparable to the G.M. and Chrysler results. These steps, combined, would result in dividing the entries of Table 5.2-10 by the constant (0.42) (0.66) and yield estimated yearly total changes for G.M., Ford and Chrysler. These estimates are shown below:

| Emission | Extrapolated Nationwide Emission Reduction (tons/yr.) |
|---|---|
| HC | 461 |
| CO | 8084 |
| NOX | 314 |

Table 5.2-11

Extrapolated Emission Reduction Levels

6. ASSESSMENT OF EMISSIONS REDUCTIONS ATTAINABLE WITH CATALYST CONVERTER EMISSION CONTROL SYSTEMS PLANNED FOR THE 1976 MODEL YEAR

## 6.1 Introduction

This chapter focuses on a consideration of what changes may result from some form of assembly line testing program applied, on a nationwide basis, to automobiles which will have the 1976 catalytic converter emission control systems as they are currently anticipated.

## 6.2 Methodology and Results

The catalytic converter emission control systems to be considered in this study will be limited to those planned for the 1976 model year automobiles, and the corresponding standards (as of the recent E.P.A. ruling which granted a one year delay of the 1975 emissions standards). The 1976 (and later) Federal Standards for emissions which will be employed in this analysis are shown below:

| Emission Type | Federal Standard |
|---|---|
| Hydrocarbon (H.C.) | 0.41 grams per mile |
| Carbon Monoxide (C.O.) | 3.4 grams per mile |
| Oxides of Nitrogen (NOX) | 0.40 grams per mile |

In attempting to draw upon the empirical evidence available from the 1972, 1973 data base on emissions experience in California and infer from this, and supplementary information, the potential emissions levels from a "catalytic system", a number of key issues and assumptions must be considered.

i.) It is assumed for this analysis, that the 1976 engine/catalytic converter systems will be typical of a 1973 type engine design feeding into a catalytic converter. In light of this, it appears reasonable to utilize the characterization of emissions levels obtained from the 1973 data base available to this project as descriptive of the "inputs" to the catalytic convertors which will be on 1976 automobiles. Consequently the average emission levels, variabilities, patterns of distribution of HC, CO and NOX emissions as derived from the 1973 California data base will be employed.

ii.) Considering the operational characteristics it appears reasonable to argue that any form of "hot start test" will be essentially useless in assessing emissions reduction attributable to the presence of a catalytic converter system. The very nature of a catalytic converter is such that when hot it is extremely efficient and removes the vast majority of emittants contained in the input stream. The emissions which, it is anticipated, will pass through the convertor will do so during the "cold phase". Because of this characteristic, this analysis will not consider assessing any changes in emissions which may result under "hot 7-mode tests" or "idle tests" since these would really be hot start tests. Consequently, of the alternate tests considered in earlier segments of this report, there remains the various audit tests applied. The remaining portions of this chapter will concentrate on the audit tests.

iii.) It is assumed that the catalytic converters to be employed on 1976 model year automobiles are "fixed percentage" reducers of emissions. That is to say, a functiona catalytic converter appears to be capable of removing a constant percentage of emissions input to the converter. Further this property will be assumed to hold over all ranges of emissions levels input to the converter.

iv.) Fresh catalysts on cars are assumed fully operable and effective.

In light of assumptions ((i) - (iv)) discussed above, there are essentially two steps which must be taken to assess the emissions reductions associated with catalytic systems. The first is to estimate the "reduction rate" at which anticipated catalytic converters will remove emissions from a typical (i.e. - 1973 level) input stream; and secondly to apply these "reduction rates" to the 1973 levels estimated earlier in this report. Let us consider these steps presently:

### Catalytic Converter System Reduction Factors

Our task here is to determine a "reduction rate" for each emission type (i.e. - HC, CO and NOX) which will describe the percentage reduction, from an input stream, of emissions going through a catalytic converter.

Since test procedures have been modified for 1976 C.V.S. tests in contrast to 1973 C.V.S. tests, a test procedure scaling factor, $\phi$ , is necessary due to the different weighting of the "hot bag" and "cold bag" emissions components in the 1973 versus 1976 C.V.S. procedures. Empirical data and analyses supplied to E.P.A. by various manufacturers have facilitated the determination of a multiplicative relationship between the emissions level which would be obtained by testing the same auto with the "1973 procedure" as compared to testing it with the "1976 procedure". We shall consider this to be

" 1976 Procedure Emissions Level Measurement" $\approx$

$\phi$ x

"1973 Procedure Emissions Level Measurement"

where $\phi$ varies according as we are measuring HC, CO and NOX. The specific scaling factor values supplied by E.P.A. and to be employed in this study are as follows:

| Emission Type | Scaling Factor |
|---|---|
| H.C. | 0.7 |
| C.O | 0.6 |
| N.O.X. | 1.0 |

Table 6.2-1

Emissions Scaling Factors

Applying the scaling factor to the 1973 emission standard, one obtains the "Comparable Standard" which should apply to a 1973 automobile C.V.S. tested under the 1976 test procedure. These values are seen in Table 6.2-2:

| Emission Type | 1973 California Standard (1973 Test Procedure) | Scaling Factor | 1973 Standard (1976 Test Procedure |
|---|---|---|---|
| HC | 3.2 gm/mile | 0.7 | 2.24 gm/mile |
| CO | 39 gm/mile | 0.6 | 27.3 gm/mile |
| NOX | 3.0 gm/mile | 1.0 | 3.0 gm/mile |

Table 6.2-2

1973 Emissions Standards:

Scaled to 1976 Test Procedure

In order to determine the "reduction factor" for a specific emission type, under the "constant reduction assumption", we compute the ratio of the "1976 standard for catalyst systems" to the "1973 standard adjusted to the 1976 test procedure". This is shown in Table 6.2-3:

| Emission Type | 1976 Standard (Catalyst System) | 1973 Standard (1976 test procedure) | Catalytic Converters Reduction Factor ( $\rho$ ) |
|---|---|---|---|
| HC | 0.41 gm/mi. | 2.24 gm/mile | 0.183 |
| CO | 3.40 gm/mi. | 27.3 gm/mile | 0.145 |
| NOX | 0.40 gm/mi. | 3.0 gm/mile | 0.133 |

Table 6.2-3

Reduction Factors For Catalytic Converters

The rationale underlying the development of these "Reduction Factors" contained in the rightmost column of Table 6.2-3 is that the 1973 and 1976 standards are feasibly attainable levels, and, given that the 1976 systems are essentially 1973 inputs to a catalytic converter, the degree to which 1976 standards are lower than 1973 standards is attributable to the % reduction of the catalytic converter output stream relative to the input stream. The results in Table 6.2-3 imply that HC emissions leaving the converter are approximately 18.3% of the input levels; C.O. output is 14.5% of CO input, and NOX output is 13.3% of input.

## Emission Levels Leaving Catalytic Converters: Audit Tests

It will be recalled that according to the development of Chapter 4, the emissions level change resulting from an audit test applied to 1973 systems at the rate $\beta$ is:

$$\mathcal{E} = \Gamma M N \beta P \left( \bar{e}^{(o)} - \bar{e}^{(2)} \right) \qquad (6.2.1)$$

Here, subscripts denoting manufacturer, engine category, emissions type, etc. have been deleted to facilitate discussion; however, the definitions of terms contained in expression 6.2.1 are as before. Earlier discussion has implied that if:

$e \equiv$ emission level measured on a test of a 1973 auto, or equivalently, at <u>input</u> to a 1976 catalytic converter

$\epsilon =$ emission level measured at the <u>output</u> of a 1976 catalytic converter

then

$$\epsilon = \rho e \qquad (6.2.2)$$

where $\rho =$ Catalytic Converter Reduction Factor, as developed in Table 6.2-3

It appears to be plausible that -

$$\begin{aligned} p &= P\{e \geq S_{1973}\} \\ &= P\{\rho e \geq \rho S_{1973}\} \\ &= P\{\varepsilon \geq \tilde{S}_{1976}\} \\ &= \pi \end{aligned} \qquad (6.2.3)$$

that is to say, under the "constant reduction rate assumption" one would expect the failure rate to remain approximately constant. Further, since $\varepsilon = \rho e$ it follows readily that

$$\begin{aligned} \bar{\varepsilon}^{(0),f} &= \rho \bar{e}^{(0),f} \\ \bar{\varepsilon}^{(2)} &= \rho \bar{e}^{(2)} \end{aligned} \qquad (6.2.4)$$

That is, the average emissions upon first audit testing of catalyst systems (i.e. - $\bar{\varepsilon}^{(0),f}$), and average emissions of failing cars which have been rectified (i.e. - $\bar{\varepsilon}^{(2)}$) are related to their empirically estimable counterparts $\bar{e}^{(0),f}$ and $\bar{e}^{(2)}$.

Substituting the results of 6.2.3 and 6.2.4 into 6.2.1, one obtains

$$\begin{aligned} E &= \Gamma M N \beta \pi (\bar{\varepsilon}^{(0),f} - \bar{\varepsilon}^{(2)}) \\ E &= \Gamma M N \beta p (\rho \bar{e}^{(0),f} - \rho \bar{e}^{(2)}) \\ E &= \rho \{\Gamma M N \beta p (\bar{e}^{(0),f} - \bar{e}^{(2)})\} \\ E &= \rho \mathcal{E} \end{aligned} \qquad (6.2.5)$$

That is, the emissions changes anticipated with the 1976 catalytic converter systems are linearly related to the results of the 1973 systems, the reduction factor $\rho$ being the multiplicative constant.

Applying the relation of (6.2.5) to the emission level changes attributable to $\beta$ % audit sampling (as $\beta$ varies) which were illustrated in Table 5.2-2 (see page 5-7) we obtain the following levels which would prevail under a catalyst system

| Audit Rate ( β ) | Emission Level Changes (tons per year) | | |
|---|---|---|---|
| | HC | CO | NOX |
| 1 % | - 11.08 | - 210.64 | - 6.39 |
| 2 % | - 22.16 | - 421.28 | -12.77 |
| 3 % | - 33.25 | - 631.93 | -19.16 |
| 5 % | - 55.41 | -1053.22 | -31.93 |
| 10 % | -110.82 | -2106.42 | -63.85 |

Table 6.2-4

Audit Rate Related Emission Changes

with Catalytic Converter Emission Systems

*(Nationwide for GM and Chrysler)*

Recalling that these levels were based on General Motors and Chrysler data only, if we were to extrapolate to all three manufacturers by pro-rating according to nationwide production levels (i.e. - GM and Chrysler constituting 66% of the "Big Three" production) we obtain the estimates of Table 6.2-5.

| Audit Rate ( β ) | Emission Level Changes (tons per year) | | |
|---|---|---|---|
| | HC | CO | NOX |
| 1 % | - 16.79 | - 319.16 | - 9.67 |
| 2 % | - 33.58 | - 638.31 | -19.34 |
| 3 % | - 50.37 | - 957.47 | -29.02 |
| 5 % | - 83.95 | -1595.78 | -48.37 |
| 10 % | -167.91 | -3191.55 | -96.75 |

Table 6.2-5

Audit Rate Related Emission Changes
with Catalytic Converter System
(extrapolated to all three manufacturers, nationwide)

# 7. COST ANALYSES OF NATIONWIDE ASSEMBLY LINE TEST PROGRAMS

## 7.1 Introduction

Assessing the costs, on a nationwide basis, of alternate configurations of assembly line test programs is, at best, a difficult task for at least two reasons. First, there is a sparcity of cost data available and that which is available is quite variable in terms of estimates of performing a given test. Secondly, there are many ways in which one can characterize and/or interpret costs of a testing program.

Regarding the first issue, cost data was obtained from a variety of sources, largely estimates of unit costs of 7-mode, idle and audit tests by various personnel within E.P.A., various manufacturers, the California Air Resources Board, etc. The reported costs were widely spread but the range of costs ultimately developed were as follows:

1. 7-mode test Unit Costs: $8.00 - $20.00 per test
2. Idle tests: $.32 - $1.20 per test
3. Audit tests: $68.00 - $350.00 per test

For most of the analyses performed in this chapter average costs of $16.00, $1.00 and $120.00 per test for 7-mode, idle and audit tests, respectively, are employed in subsequent computation.

Regarding the second issue, two basic approaches were adopted in assessing costs. On the one hand, for a given assembly line test configuration one can determine an average test cost per automobile and extrapolate this to nationwide production levels to develop a single total yearly cost. Additionally, one can consider the cost/effectiveness of a test configuration in the sense of assessing the estimated nationwide yearly cost per unit (i.e. tons per year) change in emissions level. Both such approaches were undertaken.

## 7.2 Nationwide Cost of California Assembly Line Test Procedures

Given a unit cost for each 7-mode, idle and audit test, the determination of the nationwide cost of applying the California procedures is straight forward. Let us assume the following average unit costs for testing.

i. 7 Mode Test - \$16.00 per test
ii. Idle Test - \$1.00 per test
iii. Audit Test - \$120.00 per test

On a nationwide basis the total cost would be

Total Cost = (9,800,000 cars/yr) x
\$16.00(0.25) + \$1.00(0.75) + \$120.00(0.02)
= (9,800,000 cars/year) (\$7.15)
Total Cost = \$70,070,000.00 per year

This amounts to an average of \$7.15 per car produced for testing costs.

## 7.3 Nationwide Cost of Alternate Assembly Line Test Procedures

The alternate assembly line test procedures considered were, with the exception of audit test variations on sampling strategies, of a nature such that the nationwide costs are linear functions of the sampling or testing rates. Let us define

i) $C_j$ ≡ unit cost of the $j$-th test type ($j$ = 1,2,3)
ii) $\alpha_j$ ≡ sampling or test rate of $j$-th test type ($j$ = 1,2,3)
iii) $\eta$ ≡ nationwide automobile production per year

The total cost of a specified testing program is readily specified as

$$\text{Total Cost Per Year} = \eta \times (\alpha_1 C_1 + \alpha_2 C_2 + \alpha_3 C_3)$$

where $(\alpha_1 C_1 + \alpha_2 C_2 + \alpha_3 C_3)$ is interpreted as the average test cost per car.

If the testing rates or unit costs of tests are varied one will obtain a range of total costs varying linearly in these parameters. The current California procedures represent one special case of this situation, namely $\alpha_1 = 0.25$, $\alpha_2 = 0.75$ and $\alpha_3 = 0.02$ for 7 Mode, Idle and Audit tests respectively.

In Chapter 5, a number of alternates were considered, these having test rates of the form

$$[\alpha_1 > 0 \ , \ \alpha_2 \equiv 0 \ , \ \alpha_3 > 0 \ ]$$

that is, some level of 7-mode testing ($\alpha_1 > 0$) and audit testing ($\alpha_3 > 0$) but no idle testing (i.e. - $\alpha_2 \equiv 0$). For the representative ranges of 7-mode test rates and audit test rates incorporated in Tables 5.2-1 and 5.2-2, the average testing costs per car using the representative costs of $16.00 per 7-mode test and $120 per audit test are as follows:

| 7 Mode Test Rate (%) | Audit Test Rate (%) | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 5 | 10 |
| 0 | 0.00 | 1.20 | 2.40 | 3.60 | 6.00 | 12.00 |
| 25 | 4.00 | 5.20 | 6.40 | 7.60 | 10.00 | 16.00 |
| 50 | 8.00 | 9.20 | 10.40 | 11.60 | 14.00 | 20.00 |
| 75 | 12.00 | 13.20 | 14.40 | 15.60 | 18.00 | 24.00 |
| 100 | 16.00 | 17.20 | 18.40 | 19.60 | 22.00 | 28.00 |

Table 7.2-1

Average Assembly Line Test Costs Per Car

For Various 7 Mode/Audit Test Rates (Dollars)

Assuming a nationwide auto production of 9,800,000 automobiles per year, the corresponding total costs per year on a nationwide basis would be as shown below, in Table 7.2-2.

| 7 Mode Test Rate (%) | Audit Test Rate (%) | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 5 | 10 |
| 0 | 0 | 12 | 24 | 35 | 59 | 118 |
| 25 | 39 | 51 | 63 | 74 | 98 | 157 |
| 50 | 78 | 90 | 102 | 114 | 137 | 196 |
| 75 | 118 | 129 | 141 | 153 | 176 | 235 |
| 100 | 157 | 169 | 180 | 192 | 215 | 274 |

Table 7.2-2
Nationwide Costs of Assembly Line Test Programs
For Various 7 Mode/Audit Test Rates
(in millions of dollars per year)

If the nationwide testing cost for a particular combination of 7-mode and audit test rates is divided by the corresponding magnitude of emission level changes, one obtains some insight into the estimated cost per ton of emission change for a particular test configuration. These results are shown in Table 7.2-3 a through c. In reviewing these tables one should be careful to recall that, based on the data analyses presented earlier in this report, the combined effect of 7-mode and audit tests together are estimated to increase HC and NOX levels while decreasing CO levels. Consequently, these tables reflect the "cost per ton per year change" in emissions levels where the change is an increase for HC and NOX but a decrease in CO. It is clear that in this situation a judgement will need to be made to determine if the improvement in the CO situation counters the degradation in the HC and NOX situation for a given test level.

| 7 Mode Test Rate (%) | Audit Test Rate (%) | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 5 | 10 |
| 25 | 71,229 | 100,962 | 138,837 | 280,802 | -1,440,367 |
| 50 | 59,055 | 71,229 | 85,011 | 118,410 | 280,802 |
| 75 | 55,317 | 62,946 | 71,196 | 89,567 | 156,042 |
| 100 | 53,839 | 59,074 | 64,953 | 77,561 | 118,461 |

Table 7.2-3a

Cost of Hydrocarbon Increases

(Dollars per Ton per Year)

| 7 Mode Test Rate (%) | Audit Test Rate (%) | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 5 | 10 |
| 25 | 813 | 971 | 1103 | 1370 | 1903 |
| 50 | 731 | 813 | 893 | 1038 | 1371 |
| 75 | 702 | 758 | 813 | 914 | 1155 |
| 100 | 692 | 731 | 772 | 850 | 1038 |

Table 7.2-3b

Cost of Carbon Monoxide Decreases

(Dollars per Ton per Year)

| 7 Mode Test Rate (%) | Audit Test Rate (%) | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 5 | 10 |
| 25 | 11,167 | 14,016 | 16,735 | 22,919 | 40,123 |
| 50 | 9,775 | 11,166 | 12,580 | 15,366 | 22,916 |
| 75 | 9,316 | 10,236 | 11,166 | 12,983 | 17,812 |
| 100 | 9,142 | 9,775 | 10,468 | 11,816 | 15,365 |

Table 7.2-3c

Cost of NOX Increases

(Dollars per Ton per Year)

## 8. REFERENCES


1. CALIFORNIA ASSEMBLY-LINE TEST PROCEDURES, State of California Air Resources Board, Adopted September 16, 1970, Amended February 17, 1971

2. CALIFORNIA ASSEMBLY LINE TEST PROCEDURES FOR 1973 AND SUBSEQUENT MODEL LIGHT DUTY VEHICLES, State of California, Air Resources Board; December 15, 1971 Amended December 20, 1972

3. CALIFORNIA EXHAUST EMISSION STANDARDS AND TEST PROCEDURES FOR 1973 THROUGH 1976 MODELS GASOLINE POWERED MOTOR VEHICLES UNDER 6001 POUNDS GROSS VEHICLE WEIGHT, State of California, Air Resources Board, Adopted September 15, 1971 Amended December 18, 1972

4. PUBLIC HEARING ON CHANGES TO ASSEMBLY-LINE TEST PROCEDURES FOR 1973 MODEL YEAR LIGHT DUTY VEHICLE, State of California, Air Resources Board, October 17, 1972

5. REPORT TO LEGISLATURE: ASSEMBLY LINE TESTING, State of California, Air Resources Board May 10, 1972

6. MOTOR VEHICLE ASSEMBLY LINE TESTING, Statistics Research Division Research Triangle Institute; August, 1970

7. REPORT ON ASSEMBLY LINE EMISSION TESTING OF MOTOR VEHICLES, National Air Pollution Control Administration, Bureau of Abatement and Control, April, 1970

8. Final Report: Status of Industry Progress Towards Achievement of The 1975 Federal Emission Standards For Light-Duty Vehicles; Urban Systems Division, The Aerospace Corporation, El Segando, California July, 1972

9. AUTOMOBILE EMISSION CONTROL - THE STATE OF THE ART AS OF DECEMBER 1972; Environmental Protection Agency, February, 1973

10. REPORT BY THE COMMITTEE ON MOTOR VEHICLE EMISSIONS, National Academy of Sciences, February, 1973

APPENDIX A

LISTING OF SOURCE DOCUMENTS FOR DATA USED
IN THIS STUDY

GENERAL MOTORS CORPORATION

Reports 1 through 17 were all supplied to the indicated agencies by:

Environmental Activities Staff
*General Motors Corporation*
General Motors Technical Center
Warren, Michigan 48090

1. Report of Assembly Line or Pre-Delivery Testing of Motor Vehicle Exhaust Emissions. Period Covered October 1, 1971 Through December 31, 1971.
   To: California Air Resources Board
   January 28, 1972

2. Report of Assembly Line or Pre-Delivery Testing of Light Duty Motor Vehicle Exhaust Emissions. Period Covered January 1, 1972 Through March 31, 1972.
   To: California Air Resources Board
   May 3, 1972

3. Revisions to (2) above, dated July 7, 1972.

4. Report of Assembly Line or Pre-Delivery Testing of Light Duty Motor Vehicle Exhaust Emissions. Third Quarter April 1, 1972 Through June 30, 1972.
   To: California Air Resources Board
   September 14, 1972

5. Report of Assembly Line or Pre-Delivery Testing of Light Duty Motor Vehicle Exhaust Emissions. Fourth Quarter July 1, 1972 Through September 30, 1972.
   To: California Air Resources Board
   November 16, 1972

6. Report of Assembly Line or Pre-Delivery Testing of Light Duty Motor Vehicle Exhaust Emissions. Period Covered Year to Date September 1, 1971 Through March 31, 1972.
   To: California Air Resources Board
   July 10, 1972

7. Report of 1973 Assembly Line or Pre-Delivery Testing of Light Duty Motor Vehicle Exhaust Emissions: Start of Production Through September 30, 1972.
To: California Air Resources Board
November 16, 1972

8. Report of 1973 Assembly Line or Pre-Delivery Testing of Light Duty Motor Vehicle Exhaust Emissions for the State of California: Fourth Calendar Quarter October 1 - December 31, 1972.
To: California Air Resources Board
February 1, 1973

9. Report of 1973 Assembly Line Pre-Delivery Testing of Light Duty Motor Vehicle Exhaust Emissions for the State of California: Year to Date September 1 - December 31, 1972.
To: California Air Resources Board
February 6, 1973

10. Report of 1972 Light Duty Vehicle Production: 1972 Model Year.
To: California Air Resources Board
November 16, 1972

11. Report of 1972 Model Production: Period Covered Start of 1972 Production Through September 30, 1971.
To: Environmental Protection Agency
October 27, 1971

12. Report of 1972 Model Production: Period Covered October 1, 1971 Through December 31, 1971.
To: Environmental Protection Agency
January 28, 1972

13. Report of 1972 Light Duty Model Production: Period Covered January 1, 1972 Through March 31, 1972.
To: Environmental Protection Agency
July 24, 1972

14. Report of Light Duty Model Production: Start of Production Through June 30, 1972.
To: Environmental Protection Agency
August 31, 1972

15. Report of 1972 Light Duty Model Production: 1972 Model Year.
To: Environmental Protection Agency
November 16, 1972

16. Report of 1973 Light Duty Model Production: Start of Production Through September 30, 1972.
To: Environmental Protection Agency
November 16, 1972

17. Report of 1973 Light Duty Model National Production: Start of Production Through December 31, 1972.
To: Environmental Protection Agency
February 1, 1973

FORD MOTOR COMPANY

Reports 18 through 29 were supplied by:

Automotive Emissions Office, Environmental and
Safety Engineering Staff
Ford Motor Company
The American Road
Dearborn, Michigan 48121

18. Second Quarterly 1972 California Assembly Line Testing Report; January 25, 1972.

19. Third Quarterly 1972 California Assembly Line Testing Report; April 25, 1972.

20. Fourth Quarterly 1972 California Assembly Line Testing Report; Undated.

21. Final Quarterly 1972 California Assembly Line Testing Report; October 24, 1972.

22. First Quarterly 1973 California Assembly Line Testing Report; October 24, 1972.

23. Second Quarterly 1973 California Assembly Line Testing Report; January 1973.

24. First 1972 Quarterly Report of the Number of Light Duty Vehicles and Heavy Duty Engines Built for Sale in the United States; November 30, 1971.

25. Second 1972 Quarterly Report of the Number of Light Duty Vehicles and Heavy Duty Engines Built for Sale in the United States; January 31, 1971.

26. Third 1972 Quarterly Report of the Number of Light Duty Vehicles and Heavy Duty Engines Built for Sale in the United States; April 28, 1972.

27. Fourth 1972 Quarterly Report of the Number of Light Duty Vehicles and Heavy Duty Engines Built for Sale in the United States; September 21, 1972.

28. 1972 Model Year Nationwide Production Report; March 13, 1973.

29. Production Reports: 1973 Model Light Duty Vehicles Produced for Sale in the United States; March 12, 1973.

CHRYSLER CORPORATION

Reports 30 through 38 were supplied by the:

Engineering and Research Office
Chrysler Corporation
Detroit, Michigan

30. Chrysler Corporation 1972 First Quarterly Report California Assembly Line Test Report; October 29, 1971.

31. Chrysler Corporation 1972 Second Quarterly Report California Assembly Line Test Report; January 26, 1972.

32. Chrysler Corporation 1972 Third Quarterly Report California Assembly Line Test Report; April 26, 1972.

33. Chrysler Corporation 1972 Fourth Quarterly Report California Assembly Line Test Report; August 9, 1972.

34. Chrysler Corporation 1972 Final Quarterly Report California Assembly Line Test Report; September 29, 1972.

35. Chrysler Corporation 1973 First Quarter Report California Assembly Line Test Report; November 30, 1972.

36. Chrysler Corporation 1973 Second Quarter Report California Assembly Line Test Report; January 31, 1973.

37. 1973 Light Duty Vehicle and Heavy Duty Gasoline Engine Production Report for Quarter Ending September 30, 1972; November 1, 1972.

38. 1973 Light Duty Vehicle and Heavy Duty Gasoline Engine Production Report for Quarter Ending December 31, 1972; February 5, 1973.