ANALYSES OF TRAFFIC AND AIR QUALITY TRENDS, TCP EFFECTIVENESS, AND A VOLUNTARY I/M PROGRAM IN WASHINGTON AND OREGON

GCA/TECHNOLOGY DIVISION

Prepared for

ENVIRONMENTAL PROTECTION AGENCY
REGION X
1200 Sixth Avenue
Seattle, Washington 98101

Project Officer: Betty A. Wiese, Air Programs Branch
Contract No. 68-02-1376
Task Order No. 13

ANALYSES OF TRAFFIC AND AIR QUALITY TRENDS, TCP EFFECTIVENESS, AND A VOLUNTARY I/M PROGRAM IN WASHINGTON AND OREGON

DRAFT FINAL REPORT

by

Rebecca C. Galkiewicz
Maureen T. O'Berg
Robert M. Patterson
Frank A. Record

GCA CORPORATION
GCA/TECHNOLOGY DIVISION
Bedford, Massachusetts

DISCLAIMER

This report was furnished to the Environmental Protection Agency by the GCA/Technology Division in fulfillment of Contract Number 68-02-1376, Task Order No. 13. The contents of this report are reproduced herein as received from the contractor. The opinions, findings and conclusions are those of the authors and not necessarily those of the Environmental Protection Agency.

CONTENTS

		Page
List of Figures		iii
List of Tables		v
Acknowledgements		vii
Sections		
I	Introduction	I-1
II	Recent Trends in Traffic and Air Quality Measurements (In Preparation)	II-1
III	Impact of Transportation Control Measures	III-1
IV	Statistical Analysis of Emissions Data from the Portland Inspection/Maintenance Program	IV-1

FIGURES

No.		Page
IV-1	Sample Age Distribution	IV-7
IV-2	Sample Make Distribution	IV-8
IV-3	Sample Weight Class Distribution	IV-9
IV-4	Sample Engine Displacement Distribution	IV-9
IV-5	Sample Cylinders Distribution	IV-10
IV-6	Sample County Distribution	IV-10
IV-7	Carbon Monoxide Mean Emissions	IV-18
IV-8	Hydrocarbons Mean Emissions	IV-19
IV-9	Carbon Dioxide Mean Emissions	IV-20
IV-10	Relative Frequency of Hydrocarbons (Idle Mode)	IV-23
IV-11	Relative Frequency of Carbon Monoxide (Idle Mean)	IV-23
IV-12	Relative Frequency of Log Hydrocarbons (Idle Mode)	IV-24
IV-13	Relative Frequency of Log Carbon Monoxide (Idle Mode)	IV-25
IV-14	Carbon Monoxide (Idle Mode) by Age	IV-31
IV-15	Hydrocarbons (Idle Mode) by Age	IV-32
IV-16	Carbon Monoxide (Idle Mode) by Make	IV-33
IV-17	Hydrocarbons (Idle Mode) by Make	IV-34
IV-18	Carbon Monoxide (Idle Mode) by Control	IV-35
IV-19	Hydrocarbons (Idle Mode) by Control	IV-36
IV-20	Carbon Monoxide (Idle Mode) by Mileage	IV-37
IV-21	Hydrocarbons (Idle Mode) by Mileage	IV-38
IV-22	Hydrocarbons Mean Emissions - Sample, Before Retest, Retest	IV-40

FIGURES (continued)

No.		Page
IV-23	Carbon Monoxide Mean Emissions - Sample, Before Retest, Retest	IV-41
IV-24	Hydrocarbons Mean Emissions - Sample, Before Retest, Retest and Repair Cost < 0	IV-42
IV-25	Carbon Monoxide Mean Emissions - Sample, Before Retest, Retest and Repair < 0	IV-43
IV-26	Cumulative Frequency of Carbon Monoxide (Idle Mode) - Sample, Before Retest, Retest	IV-45
IV-27	Cumulative Frequency of Hycrocarbons (Idle Mode) - Sample, Before Retest, Retest	IV-46
IV-28	Cumulative Frequency of Carbon Monoxide (Idle Mode) by Control	IV-47
IV-29	Cumulative Frequency of Hycrocarbons (Idle Mode by Control	IV-48
IV-30	Cumulative Frequency of Carbon Monoxide (2500 rpm) by Control	IV-49
IV-31	Cumulative Frequency of Hydrocarbons (2500 rpm) by Control	IV-50
IV-32	Cumulative Frequency of Carbon Monoxide (30 mph) by Control	IV-51
IV-33	Cumulative Frequency of Hydrocarbons (30 mph) by Control	IV-52
IV-34	Cumulative Frequency of Carbon Monoxide (50 mph) by Control	IV-53
IV-35	Cumulative Frequency of Hydrocarbons (50 mph) by Control	IV-54

TABLES

No.		Page
III-1	8-Hour VMT Estimates, Seattle CBD	III-5
III-2	8-Hour CO Emission Estimates, Seattle CBD	III-11
III-3	Fraction of Annual Miles Driven by Vehicle Age for	III-12
III-4	1976 CO Emission Estimates for Light-Duty Gasoline Vehicles by Model Year, Seattle CBD	III-14
III-5	8-Hour VMT Estimates, Spokane CBD	III-15
III-6	8-Hour CO Emission Estimates, Spokane CBD	III-18
III-7	Fraction of Annual Miles Driven by Vehicle Age for Spokane, Washington	III-19
III-8	1976 CO Emission Estimates for Light-Duty Gasoline Vehicles by Model Year, Spokane CBD	III-20
III-9	8-Hour VMT Estimates, Portland CBD	III-22
III-10	8-Hour CO Emission Estimates, Portland CBD	III-25
III-11	Fraction of Annual Miles Driven by Vehicle Age for Portland, Oregon	III-26
III-12	1976 CO Emission Estimates for Light-Duty Gasoline Vehicles by Model Year, Portland CBD	III-27
IV-1	Vehicle Data Format	IV-3
IV-2	Data Transformation	IV-5
IV-3	Sample Age by Make Distribution	IV-11
IV-4	Age Distribution of Sample and Population	IV-12
IV-5	Make Distribution of Sample and Population	IV-12
IV-6	Control By Make Distribution of Sample and Population	IV-13
IV-7	Age Distribution of Sample and Fail Subsample	IV-15
IV-8	Make Distribution of Sample and Fail Subsample	IV-15

TABLES (continued)

No.		Page
IV-9	Weight Class Distribution of Sample and Fail Subsample	IV-16
IV-10	Cylinder Distribution of Sample and Fail Subsample	IV-16
IV-11	Control Distribution of Sample and Fail Subsample	IV-16
IV-12	Fail Criteria	IV-17
IV-13	Weighting for Age	IV-26
IV-14	Weighting for Make	IV-27
IV-15	Weighting for Control by Make	IV-28
IV-16	Analysis of Variance	IV-30
IV-17	T-Test	IV-30
IV-18	Failure Rate and Failure Levels	IV-55
IV-19	Stepwise Regression	IV-57
IV-20	Correlation Coefficient Matrices	IV-58
IV-21	Engine Tampering	IV-59
IV-22	Under Hood Tampering	IV-60
IV-23	Correlation of FTP and Short Test Procedures	IV-65
IV-24	Estimation of Idle Emissions Reductions for a 50 Percent Failure Rate	IV-67

ACKNOWLEDGEMENTS

e wish to acknowledge the assistance of Alan M. Voorhees, Inc. who cted as subcontractor to GCA/Technology Division and, under the direction of Mr. Keith Gilbert, provided traffic related data and analyzed ne effect of the transportation control measures on VMT and speed.

s. Betty Wiese, Project Officer, provided continuing guidance and ssistance throughout the program. We wish to thank her and all cooperting agencies for supplying the air quality and meteorological data. inally, we would like to acknowledge the Oregon Department of nvironmental Quality, and especially Mr. William Jasper, for providing ata and insight on the voluntary inspection/maintenance program in ortland.

SECTION I

INTRODUCTION

This report describes work carried out to assist the States of Washington and Oregon in developing background information for the preparation of Transportation Control Plans to achieve air quality standards in Seattle, Spokane, and Portland. The report has been organized into three major sections, each covering one of the principal work areas of the study.

Section II presents an analysis of vehicle miles of travel (VMT) and related transportation statistics to determine recent trends and the degree to which these trends have been reflected in changes in air quality (carbon monoxide concentrations) as measured by ambient monitors in the three cities. Apart from the general requirement to document these changes, it was hoped that such an analysis would provide insight into the adequacy of current monitoring procedures for the evaluation of the effectiveness of transportation control strategies.

Section III provides estimates of the effect of implementing various transportation control strategies on 1976 carbon monoxide concentrations within the central business districts (CBD's) of the three cities. These estimates are made by predicting the changes in VMT and average speed expected to result from each strategy, and then converting the resulting VMT-speed data to carbon monoxide emissions. Ambient concentrations of carbon monoxide within the CBD's are assumed to be directly proportional to emissions.

Section IV presents the results of a statistical analysis of emission data collected from a voluntary inspection/maintenance program in Portland. The emission testing was performed by the Oregon Department of Environmental Quality. Emission data from idle, 2500 rpm, 30 mph and 50 mph loaded dynamometer tests were available for about 6000 vehicles. The analysis includes development of basic statistics of the sample, significance tests of various sample parameters, and a comparison of the sample distributions of age and make against those of the entire population of the Portland area. Cumulative frequency distributions of emissions broken down by control group are presented as an aid to setting pass/fail criteria. Only 100 vehicles were identified as having had inspection, maintenance, and a second inspection, and no definitive conclusions could be drawn regarding post-inspection/maintenance emission levels.

SECTION II

RECENT TRENDS IN TRAFFIC AND AIR QUALITY MEASUREMENTS

(In preparation)

SECTION III
IMPACT OF TRANSPORTATION CONTROL MEASURES

METHODOLOGY

The transportation control measures evaluated in this section are grouped into basic packages comprised of those measures currently being implemented in each city, plus other selected measures under active consideration. The selection of measures for evaluation was made by EPA, Region X, in consultation with the Department of Ecology of the State of Washington and the Department of Environmental Quality of Oregon. The basic package of strategies for each city includes signal improvements, transit improvements, carpooling, and parking management. An inspection and maintenance program is also considered part of the basic package for Portland, as is the use of skywalks in Spokane.

The impact on VMT and speed of the measures included in each strategy package has been estimated in a cumulative manner. Then, the additional measures have been added one at a time, and the combined effect of the package plus each individual strategy has been estimated. The analysis of the control measures is described separately for each city, although the analysis techniques and some of the factors applied are common to more than one area. These analyses result in estimates of VMT by speed and vehicle classification and thus provide requisite inputs to emission calculations. Initially, the VMT for each city was estimated by various speed levels, as shown previously in Table II- . To simplify the emissions calculations needed in this section, weighted average speeds have been calculated for the lower

speed categories shown in Table II- . Also VMT have been split into vehicle classifications used by EPA in its current emission calculation procedures. VMT estimates are for the peak 8-hour traffic period of the day.

It must be kept in mind that this evaluation is undertaken from a "sketch planning" approach rather than through detailed analysis. Each central business district is treated as a unit and is not subdivided by activity groupings such as land use. Estimates of the effects of strategies are made using general factors, guideline values, and rules of thumb. In some instances, limited confidence could be placed in some of the basic counts and other input data. Because of these limitations, it is, in our judgment, appropriate to use the results of these analyses for general planning purposes only. The actual effectiveness of strategy packages can only be ascertained by carefully designed monitoring programs which provide data for before- and- after comparisons.

The emission calculations were carried out using procedures described by EPA in the following two draft documents, dated October 1974: (1) Supplement No. 5 for Compilation of Air Pollutant Emission Factors, Second Edition, and (2) Attachment No. 1 for Compilation of Air Pollutant Emission Factors, Second Edition, Projected Mobile Source Emission Factors, prepared by Kircher and Masser. These draft documents were made available for use prior to publication in AP-42 so that the latest emission factors and recommended calculation procedures could be incorporated into the strategy evaluation methodology employed in this study. The overall methodology used in calculating carbon monoxide emissions is nearly identical with that outlined by Kircher and Armstrong as presented in AP-42 and so is not described in detail here. The principal procedural changes incorporated in the revised methodology are:

1. A redefinition of vehicle class. The revised classification is as follows:

   - Light-duty gasoline vehicles (passenger cars)
   - Light-duty gasoline trucks (gross weight of 8,500 pounds or less)
   - Light-duty diesel vehicles (passenger cars)
   - Heavy-duty gasoline vehicles (gross weight over 8,500 pounds)
   - Heavy-duty diesel vehicles (trucks and buses)
   - Motorcycles

2. The use of separate sets of emission factors for each calendar year instead of the use of deterioration factors. Emission factors are tabulated by model year for various calendar years for light- and heavy-duty gasoline-powered vehicles.

3. The use of separate speed correction factors for different model years. Speed correction factors are presented mathematically by model year for light-duty gasoline vehicles operating between 15 and 45 miles per hour. It is recommended that, until other data are available, these factors be used for light-duty trucks. It is also recommended that pre-1968 light-duty vehicle correction factors be used for pre-1970 heavy-duty vehicles, and that 1968 light-duty vehicle factors be used for post-1969 model years of heavy duty vehicles. These recommendations have been followed in calculating the emissions presented in this section.

The fraction of total vehicles in use by age was calculated using passenger car and truck registration data compiled by R.L. Polk and Company for the three urban areas. King County data were used for Seattle; Spokane County data were used for Spokane; and the data for the counties of Clackamus, Multnomah, and Washington were combined for Portland. Passenger car registration data were used directly in the calculations of light-duty gasoline vehicles for the years 1971 and 1972. Average values for 1971, 1972, and 1973 were used for the 1976 calculations. The Polk statistics do not separate light-duty and heavy-duty trucks. The procedure adopted for trucks was to use

the Polk truck data for calculations of light-duty gasoline truck emissions, and the nationwide statistics for heavy-duty vehicles given in the draft copy of Supplement No. 5 for Compilation of Air Pollution Emission Factors. Nationwide statistics of average annual miles driven by vehicle age have been used in all cases.

This analysis has not been prepared in the form of a Transportation Control Plan. Its purpose is only to estimate the emission reductions that can be expected from strategy packages currently being implemented plus probable reductions from other selected strategies. It does not provide a total cumulative estimate of emission reduction or discussion of social, economic, and other impacts.

SEATTLE

VMT Estimates

Table III-1 lists the estimated 8-hour VMT for Seattle's CBD after implementation of the various transportation control measures. The 1971 and 1976 totals are based upon daily estimates made by the city in 1974 for the area bounded by Virginia Street, 8th Avenue, I-5, Yesler Way, and the Alaskan Way Viaduct. The growth trend follows that of the 2nd Avenue permanent counting station. Speeds reflect 1974 survey data. The breakdown by class is based on registration data, Origin-Destination survey data (including trip length), and vehicle classification counts. In this class breakdown, lowest confidence must be attached to the motorcycle estimates. The 1976 base is an approximation of data along pre-energy crisis trends. It does not represent an expected condition, but rather is a starting point for estimating the changes expected by 1976 if the strategies take effect by then.

Tab le III-1. 8-HOUR VMT ESTIMATES, SEATTLE CBD

	VMT						
	Avg. speed (mph)	Light-duty autos	Light-duty trucks	Heavy-duty trucks	Diesel	Motor-cycles	Total
1971 Base	12.9	44,021	3,988	1,023	1,074	1,023	51,128
1976 Base	12.9	46,616	4,303	1,103	1,159	1,986	55,167
SIGOP	14.9	46,616	4,303	1,103	1,159	1,986	55,167
Transit program	14.9	43,268	4,303	1,103	1,159	1,986	51,820
Car pool (max.)	14.9	41,620	4,303	1,103	1,159	1,986	50,171
Parking Management	14.9	41,620	4,303	1,103	1,159	1,486	50,171
Reduce Parking 20% (a)	13.5	58,299	4,303	1,103	1,159	1,986	66,850
(b)	14.9	40,620	4,303	1,103	1,159	1,986	49,171
Replace 20% curb with off-street	14.9	41,532	4,303	1,103	1,159	1,986	50,083
Flex-time	15.1	41,620	4,303	1,103	1,159	1,986	50,171
Road pricing	15.2	36,938	4,303	1,103	1,159	1,986	45,489
Delivery Restrictions	15.0	41,620	2,797	717	753	1,986	47,873
I and M	See text						
Exclude nonretrofit	See text						
Predictive exclusion	See text						

The following paragraphs discuss the rationale used in preparing the VMT estimates presented in Table III-1.

SIGOP - The city's before and after studies did not detect average speed changes but found sharp reductions in delay and numbers of stops. The survey method ("floating car") may not be sensitive to small speed changes. Therefore, the effect of this signal timing improvement is taken as a 2 mph step in average speed.

Transit - METRO has embarked upon a transit improvement plan including more buses, better levels of service, park-ride and express facilities, downtown flow improvements, free downtown bus rides, and other steps. Success in terms of increased patronage is already seen. A delay from initial development schedules is expected, however, largely due to delivery of new buses at a time later than originally expected.

Previous calculations of transit impact on CBD VMT used estimates of service improvements and mode use modeling techniques. If the present trends of increasing patronage hold until 1976, the previously estimated VMT reduction will be achieved. However, in view of probable delays in bus deliveries, the present trends were truncated to reflect a delay in 1975 program completion to about 1977. This made a difference of about 7 percent in the VMT reduction due to transit as compared to previous estimates. The transit impact is estimated as an overall reduction of about 6 percent from the 1976 base.

Car Pools - The Federal Department of Transportation has sponsored significant car pool programs in nearly all urban areas. These programs have typically concentrated on contacting potential employee groups and providing matching and publicity services. Follow-up surveys of effectiveness have not yet become available in sufficient quantity for use in this study. However, if an active program such as Seattle's is maintained, the share of employees in car pools might be doubled. If

so, VMT's would be reduced by 3 or 4 percent. Since influences such as energy prices and availability can strongly affect car-pooling, this estimate is probable close to a maximum reduction.

Parking Management - This strategy embodies two measures, preconstruction review and a prohibition on increasing the CBD parking supply above November 1973 levels. Preconstruction review of parking proposals should not affect VMT. It is viewed as a means of monitoring and enforcing a "lid" on parking supply. For Seattle, if no strategies were implemented, the parking demand would meet the "lid" in 1975 or 1976. However, effective transit and car pool programs should reduce VMT and parking demand in parallel, so that the closest approach of demand to the lid may have already been reached. Therefore, no impact has been estimated for this measure.

Reduction in Parking Supply - If the "lid" on parking supply were dropped, say to 80 percent of its present value, two effects would be expected. First, since demand for parking could not be expected to drop in the short run and if only short-term parkers are affected, additional search-for-parking VMT would be created along with idling while waiting for a parking space. Analysis of parking arrival and accumulation patterns, as related to available supply, shows nearly 17,000 VMT created at an estimated 10 mph. (This is reflected in Table III-1, estimate (a).) On the other hand, scarcity of supply could lead to higher costs. It is estimated that an increase in parking fees of 78 percent would counter-balance the new VMT through diversion to transit or to new destinations.

A reduction in employee spaces could be effected through deletion of reduced rates for all-day parking. A rough doubling of long-term costs for employees could drop light-duty auto VMT from 41,621, to 40,621 increasing the average speed to 14.9 mph (estimate (b)).

Replace Curb Parking with Off-Street - Replacement of curb parking with off-street could increase street capacity (and possibly speed), might reduce the search-for-parking VMT if the new spaces are easy to locate, and would be costly. This measure was analyzed by assuming that 20 percent of the curb spaces were displaced in the most congested areas. A 1-mph speed increase was assumed (the difference between peak and off-peak) for those travelling at 15 mph for the peak 2 hours only.

Staggered Hours and Days - Staggered hours is referred to in this study as "flex-time" denoting that employees would choose their own travel hours within limits set by employers (as opposed to a rigid staggered hours concept). This approach is desirable from a labor relations point of view and has been demonstrated to reduce peak vehicle and transit loadings. A 1-mph increase in peak hour speeds for employees was assumed as a maximum impact of such a program. VMT probably would not be shifted significantly out of the critical 8-hour period.

No additional effect is estimated for "staggered days." Present "4-40" plans would impact Mondays and Fridays only unless major disruptions are imposed on employee work patterns.

Road-Pricing - This concept calls for some manner of charging for use of roadways. The charge could be higher during periods when demand is high, and low when demand is low. Methods of charging include bridge tolls, special vehicle licenses or stickers, increases in parking costs, and various means of automatically detecting and billing. Problems with the concept range from technology (in detection) to lack of applicability for bridge tolls (impact too few CBD trips and too many others). Parking cost increases may not be effective unless of a very large order.

To estimate a probable reduction from this strategy, it has been assumed that the cost of auto use to and from downtown could be

increased four times. This assumption, when used with a mode use model, results in an approximate 11-percent reduction in automobile VMT.

Daylight Delivery Restrictions - Prohibition of truck curb use during the day would reduce VMT, increase speeds, and cause disruptions in present business schedules. About 35 percent of truck travel in downtown may be associated with delivery and service. This share of the three truck categories is deleted for this strategy and a slight speed gain is estimated for the peak travel of remaining vehicles.

Inspection and Maintenance - This measure does not affect VMT or speed.

Exclusion of Nonretrofit Vehicles - Such a strategy assumes some sort of retrofit program in operation, a method for identification of modified vehicles, and enforcement. The effects of an exclusion would depend on the devices and model years specified.

Predictive Exclusion - This strategy would call for the exclusion of classes or all vehicles from the CBD on days when an episode is predicted. Exclusion could be based on vehicle type (such as trucks), vehicle age and equipment (retrofit), CBD employment (with a license or pass), or time of day. The amount of exclusion required would depend upon the demonstrated effectiveness of other measures being used and the predicted severity of the episode. It could be achieved by adjusting the time period of exclusion and/or the type and number of vehicles excluded. Prohibitions on entering downtown from 10 a.m. or 11 a.m. onward would allow employees in and might reduce VMT by 36 percent. Prohibition starting earlier, say 6 a.m., would exclude employees and effectively shut down the CBD for the day.

Problems, other than economic impact, include the cost of the exclusion operation (barricades, detour, personnel, publicity, etc.),

predictive ability, and potential traffic confusion and congestion just outside of the CBD.

CO Emission Estimates

Table III-2 presents estimates of carbon monoxide emissions within the Seattle CBD over the 8-hour period of maximum travel during the day by vehicle class. These estimates were made using the procedures described earlier in this section, and the VMT-speed data given in Table III-1. Table III-3 gives the fraction of annual miles driven by vehicle age data used in making these calculations.

It can be seen from these estimates that the strategy package currently being implemented will fail by a wide margin to achieve allowable emissions by 1976. Specifically, if a 55 percent reduction from 1971 baseline levels is required to achieve the allowable emissions level an additional reduction of 1097 kg per 8 hours will be required beyond those attained with the strategy package (i.e. 3482 kg - 2385 kg). Table III-2 also shows that none of the additional strategies when added singly to the basic package, is sufficient to achieve the allowable emissions level.

The probable effect of an inspection and maintenance program on carbon monoxide emissions from light-duty automobiles has been estimated by EPA to be a 10 percent reduction, assuming a 50 percent initial failure rate and annual inspection using an idle emissions test. The use of loaded emissions tests has been estimated to achieve a 12 percent reduction in carbon monoxide emissions. Current EPA policy, as expressed in the draft Attachment No. 1 for Compilation of Air Pollution Emission Factors, October 1974, also allows a 10 percent reduction per pre-1975 light-duty trucks. Since over 90 percent of emissions from light-duty trucks will come from pre-1975 vehicles in 1976 (see Table III-4), an overall credit of 10 percent is a reasonable value to apply to light-duty vehicle emissions for an inspection and maintenace program. This

Table III-2. 8-HOUR CO EMISSION ESTIMATES, SEATTLE CBD

		Emissions (kg/8 hours)						
		Light-duty autos	Light-duty trucks	Heavy-duty trucks	Diesel	Motor-cycles	Total	Additional reduction needed
1971 Base		4,407	522	309	31	32	5,301	
1976 Base		3,454	395	290	33	62	4,234	1,849
SIGOP		3,100	355	264	33	62	3,814	1,429
Transit Program		2,877	355	264	33	62	3,591	1,206
Car Pool (max.)		2,768	355	264	33	62	3,482	1,097
Parking Management		2,768	355	264	33	62	3,482	1,097
Reduce parking 20%	(a)	4,180	383	281	33	62	4,939	2,554
	(b)	2,701	355	264	33	62	3,415	1,030
Replace 20% curb with off-street		2,762	355	264	33	62	3,476	1,091
Flex-time		2,739	351	260	33	62	3,446	1,061
Road pricing		2,419	350	260	33	62	3,124	739
Delivery restrictions		2,754	228	171	22	62	3,240	855
I and M								
Exclude nonretrofit		See text						
Predictive exclusion								

NOTE: Allowable emissions, assuming a 55 percent reduction from 1971 base levels, are 2,385 kg/8 hours.

figure assumes that all such vehicles entering the CBD are covered by the program, however, and must be reduced appropriately if this is not the case. Calculations based on the estimates provided in Table III-2 and a 10 percent reduction in emissions from the first two vehicle classes show that an inspection and maintenance program will provide, very roughly, one-third of the reduction required beyond that achieved by the combinations of strategies analyzed. It should be noted that in the case of the parking reduction strategy (a), emissions are estimated to increase substantially as a result of increased search time. In this case, an inspection and maintenance program would provide only 18 percent of the additional reduction required.

Table III-3. FRACTION OF ANNUAL MILES DRIVEN BY VEHICLE AGE FOR SEATTLE

	Light-duty autos		Light-duty trucks		Heavy-duty vehicles
Vehicle age	1971	1976[a]	1971	1976[a]	1972[b]
0	0	0	0	0	0
1	0.063	0.089	0.056	0.097	0.130
2	0.108	0.116	0.114	0.122	0.133
3	0.128	0.107	0.147	0.107	0.123
4	0.119	0.106	0.121	0.106	0.124
5	0.108	0.105	0.108	0.103	0.085
6	0.104	0.097	0.089	0.087	0.068
7	0.089	0.086	0.065	0.071	0.058
8	0.067	0.073	0.047	0.054	0.050
9	0.057	0.058	0.039	0.041	0.040
10	0.043	0.044	0.030	0.030	0.031
11	0.025	0.030	0.019	0.022	0.024
12	0.021	0.023	0.020	0.019	0.017
≥ 13	0.068	0.066	0.145	0.141	0.117

[a]Average for calendar years 1971, 1972, and 1973

[b]Nationwide

Table III-4 provides a breakdown of emissions by model year for the sequence of strategies shown in Tables III-1 and III-2. Estimates of the reduction likely to be achieved by selected retrofit and exclusion measures can be worked out by means of this table.

SPOKANE

VMT Estimates

Table III-5 presents the estimated 8-hour VMT for the Spokane CBD, defined for this study as the area bounded by Spokane Falls Boulevard, 3rd Avenue, Monroe Street, and Division Street. This area includes considerable through traffic, perhaps half of the total. The analysis for Spokane was approached in the same manner as for Seattle, and so many of the same general comments apply. The rationale used in preparing the VMT estimates is discussed in the following paragraphs.

Signal Improvements - By the end of 1975, it is likely that all CBD intersections will be controlled by the ity's computer system. Upon implementation of this system for the present 68 intersections, improvements in flow were observed. The previous estimate of a 2-mph speed increase was applied in this analysis.

Transit - Interim park-ride facilities proved to be very successful during EXPO, and a grant application has been submitted for permanent development. The extension of present transit patronage trends to 1976 shows a reduction of some 3 percent in VMT for the 1976 base.

Car Pools - Although the enthusiasm (and potential) for carpooling in Spokane is less than in Seattle, a similar doubling of present employee pooling forms a frame of reference. An increase in average auto occupancy from 1.19 to 1.24 is assumed as a measure of a successful program in Spokane.

Table III-4. 1976 CO EMISSION ESTIMATES FOR LIGHT-DUTY GASOLINE VEHICLES BY MODEL YEAR, SEATTLE CBD

Model year	Strategy package	Reduce parking, option (a)	Reduce parking, option (b)	Replace 20% curb with off-street	Flex-time	Road pricing	Delivery Restrictions
	Light-duty autos						
Pre-1968	796	1,187	777	794	790	698	793
1968	228	342	222	228	226	199	227
1969	292	444	285	291	288	254	290
1970	295	448	288	295	291	257	293
1971	318	483	310	317	315	277	316
1972	254	386	248	253	251	222	253
1973	245	372	239	245	242	214	244
1974	236	359	230	235	233	206	234
1975	61	94	60	61	61	54	61
1976	43	65	42	43	42	38	43
Total	2,768	4,180	2,701	2,762	2,739	2,419	2,754
	Light-duty trucks						
Pre-1968	138	147	138	138	137	136	89
1968	17	19	18	18	17	17	11
1969	23	25	24	24	23	23	15
1970	25	27	25	25	25	25	16
1971	31	33	31	31	30	30	20
1972	30	32	30	30	29	29	19
1973	29	32	29	29	29	29	19
1974	28	31	28	28	28	28	18
1975	19	21	19	19	19	19	12
1976	15	16	15	15	14	14	9
Total	355	383	355	355	351	350	228

Table III-5. 8-HOUR VMT ESTIMATES, SPOKANE CBD

	VMT						
	Avg. speed (mph)	Light-duty autos	Light-duty trucks	Heavy-duty trucks	Diesel	Motor-cycles	Total
1971 Base	13.9	53,586	3,823	910	1,032	1,335	60,686
1976 Base	13.9	56,710	4,121	981	1,112	2,486	65,410
Signal improvement	15.9	56,710	4,121	981	1,112	2,486	65,410
Transit program	15.9	54,828	4,121	981	1,112	2,486	63,528
Car pool (max.)	15.9	53,786	4,121	981	1,112	2,486	62,486
Skywalks	15.9	53,786	4,121	981	1,112	2,486	62,486
Parking management	15.9	53,786	4,121	981	1,112	2,486	62,486
Reduce 20% curb with off-street	15.9	53,625	4,121	981	1,112	2,486	63,325
Flex-time	16.0	53,786	4,121	981	1,112	2,486	62,486
Road pricing	16.0	44,610	4,121	981	1,112	2,486	53,310
Delivery restrictions	16.1	53,786	3,442	819	929	2,486	61,462
I and M	See text						
Exclude nonretrofit	See text						
Predictive exclusion	See text						
Reduce parking	See text						

Parking Management - The difference between demand and the Spokane "lid" (30 percent) is greater than in Seattle (6 percent). Therefore, the "lid" (and preconstruction review) has no effect on VMT or speed.

Skywalks - This program has been implemented in Spokane, reducing pedestrian volumes in at least five intersections. More inter-building bridges are being considered. Assuming that 20 percent of approaching vehicles turn more smoothly due to reduced pedestrian interference, a small share of CBD VMT is assumed to feel a 2-mph speed increase. This share is so small, however, that no effect occurs in the weighted average speed. Continued skywalk development would be expected to lead to a significant impact, however. Many benefits can be seen for skywalk development and their construction should be encouraged.

Replace Curb Parking With Off-Street - If 20 percent of curb parking is shifted in congested areas and a 1-mph increase is felt during peak hours in the 15-mph range, the overall impact is so slight that it does not affect the weighted average speed. To achieve a significant impact in Spokane, a larger share would have to be displaced, and no plans exist for such a program.

Flex-time - As assumed for Seattle, a voluntary adjustment of work hours around a core time period of mandatory attendance was envisioned leading to a peak hour 1-mph speed increase but no change in VMT.

"Staggered days" were assumed to have no effect on VMT except on Monday and Friday and no additional speed impact.

Road Pricing - Although there are more bridges closer to downtown Spokane than in Seattle, the high share of through traffic creates additional complications in the imposition of tolls. The technical problems of automated charges for CBD street use exist as do policy problems of special CBD licenses. As for Seattle, an impact of some type of pricing

program (tolls, special licenses, etc.) leading to four times the automobile operating cost was assumed. This assumption results in a 15-percent VMT reduction. The realism of such an increase in cost has not been analyzed.

Delivery Restrictions - If merchant objections could be overcome, and a 35-percent share of truck delivery traffic be deleted, VMT would be reduced and a slight speed increase seen during peak hours. Because of the high percentage of through truck traffic, the impact of this measure amounts of a 16.5-percent reduction in total truck VMT.

Inspection and Maintenance - This measure does not affect VMT or speed.

Exclusion of Nonretrofit vehicles - Again, as discussed for Seattle, the reduction in Spokane depends upon the type of retrofit program, the share of vehicles covered, and enforcement. One maximum value could be the share of VMT contributed by pre-1968 vehicles.

Predictive Exclusion - A time exclusion, as compared to exclusion of classes of vehicles, would probably be required to achieve high percentage reductions in VMT. Although an exclusion between 12 noon and 6 p.m. would delete some 40.5 percent of 8-hour VMT, a more complete shutdown would occur by starting early enough to exclude employees.

Reduce Parking Supply - This strategy has little application to Spokane. If the "lid" were dropped to 80 percent of present value, little or no impact is estimated due to present excess of supply over demand.

CO Emission Estimates

Table III-6 shows the 8-hour carbon monoxide emissions computed from the VMT-speed data given in Table III-5. The fraction of annual miles driven by vehicle age data used for these calculations are given in Table III-7.

Table III-6. 8-HOUR CO EMISSION ESTIMATES, SPOKANE CBD

	Emissions (kg/8 hours)						
	Light-duty autos	Light-duty trucks	Heavy-duty trucks	Diesel	Motor-cycles	Total	Additional reduction needed
1971 Base	5,155	493	263	30	32	5,973	2,987
1976 Base	4,174	385	246	32	62	4,899	1,913
Signal improvement	3,766	349	224	32	62	4,433	1,447
Transit program	3,641	349	224	32	62	4,308	1,322
Car pool (max.)	3,571	349	224	32	62	4,238	1,252
Skywalks	3,571	349	224	32	62	4,238	1,252
Parking management	3,571	349	224	32	62	4,238	1,252
Replace 20% curb with off-street	3,561	349	224	32	62	4,228	1,242
Flex-time	3,555	347	223	32	62	4,219	1,233
Road pricing	2,949	347	223	32	62	3,613	627
Delivery restrictions	3,539	288	185	27	62	4,101	1,115
I and M	See text						
Exclude nonretrofit	See text						
Predictive exclusion	See text						
Reduce parking	See text						

Table III-7. FRACTION OF ANNUAL MILES DRIVEN BY VEHICLE AGE FOR SPOKANE, WASHINGTON.

Vehicle age	Light-duty autos		Light-duty trucks		Heavy-duty vehicles
	1971	1976[a]	1971	1976[a]	1972[b]
0	0	0	0	0	0
1	0.063	0.082	0.068	0.097	0.130
2	0.105	0.107	0.103	0.114	0.133
3	0.113	0.100	0.113	0.096	0.123
4	0.106	0.099	0.093	0.089	0.124
5	0.093	0.096	0.082	0.083	0.085
6	0.093	0.089	0.080	0.073	0.068
7	0.092	0.083	0.070	0.065	0.058
8	0.070	0.075	0.050	0.054	0.050
9	0.060	0.063	0.041	0.044	0.040
10	0.046	0.048	0.031	0.033	0.031
11	0.030	0.035	0.022	0.025	0.024
12	0.028	0.028	0.025	0.022	0.017
$\geq$ 13	0.101	0.095	0.222	0.205	0.117

[a]Average for calendar years 1971, 1972, and 1973.

[b]Nationwide

As in Seattle, large reductions beyond those provided by the basic strategy package are required to meet the allowable emissions level. Of the first four individual strategies, only road pricing is estimated to have a really large impact. The probable effect of an annual inspection and maintenance program can be estimated at any step by reducing light-duty automobile and truck emissions by 10 percent. Table III-8 provides a breakdown of emissions by model year for use in estimating the effectiveness of various retrofit and exclusion measures.

Table III-8. 1976 CO EMISSION ESTIMATES FOR LIGHT-DUTY GASOLINE VEHICLES BY MODEL YEAR, SPOKANE CBD

Model Year	Strategy package	Replace 20% curb with off-street	Flex-time	Road pricing	Delivery restrictions
	Light-duty autos				
Pre-1968	1,247	1,243	1,241	1,030	1,236
1968	305	305	304	252	303
1969	366	365	364	302	362
1970	347	346	345	286	343
1971	357	356	354	294	353
1972	283	283	282	234	281
1973	280	279	278	231	276
1974	269	269	268	222	266
1975	69	69	69	58	69
1976	48	48	48	40	48
Total	3,571	3,563	3,553	2,949	3,537
	Light-duty trucks				
Pre-1968	170	170	170	170	141
1968	17	17	17	17	14
1969	21	21	21	21	18
1970	21	21	21	21	17
1971	23	23	23	23	19
1972	21	21	21	21	18
1973	22	22	22	22	18
1974	23	23	23	23	19
1975	16	16	16	16	13
1976	13	13	13	13	11
Total	347	347	347	347	288

PORTLAND

VMT Estimates

VMT's for Portland's CBD were calculated from 1972 counts. The area defined by the CBD is larger than that used in Seattle or Spokane, and is bounded by Hoyt Street, the Willamette River, and I-405. Three or four average speeds are used to cover the range of speeds present in the Portland CBD. The estimated 8-hour VMT's for each speed level are presented in Table III-9 for the two baseline periods and for the various strategy combinations. The rationale used in preparing the VMT estimates follows.

Signal Improvements - Computer control of signals was implemented in 1971. The program has reduced the worst congestion points and improved off-peak speeds. A 2-mph speed increase has been assumed from base conditions for the lower speed ranges.

Transit - Interim park-ride development is underway, new routes are being implemented, and a new fare policy eliminating zone fares and providing free CBD riding (among other items) will start January 1975. The coming downtown transit mall will facilitate system use. Extrapolation of present trends and mode use modeling both indicate that the goal of doubling 1970 transit use in downtown is within reach.

Carpools - A vigorous carpool program exists in Portland. If the number of worker pools doubles (a rule-of-thumb), average occupancy could increase from 1.36 to 1.44 with a consequent reduction in VMT. The reduction shown in Table III-9 is based on this assumption.

Parking Management - The "lid" on parking supply can be monitored and enforced through preconstruction review. The lid itself should have no effect on VMT and speed if other strategies are successful. (Supply

Table III-9. 8-HOUR VMT ESTIMATES, PORTLAND CBD

		VMT					
	Avg. speed (mph)	Light duty autos	Light duty trucks	Heavy-duty trucks	Diesel	Motor-cycles	Total
1972 Base	50.0	1,287	105	25	28	29	1,474
	25.0	31,810	2,587	619	692	729	36,437
	13.2	114,034	9,274	2,221	2,482	2,612	130,623
		147,131	11,966	2,865	3,202	3,370	168,534
1976 Base	50.0	1,378	114	27	31	60	1,610
	25.0	34,069	2,826	677	756	1,473	39,801
	13.2	122,134	10,130	2,426	2,711	5,279	142,680
		157,581	13,070	3,130	3,498	6,812	184,091
Signal improvement	50.0	1,378	114	27	31	60	1,610
	25.0	34,069	2,826	677	756	1,473	39,801
	15.2	122,134	10,130	2,426	2,711	5,279	142,680
		157,581	13,070	3,130	3,498	6,812	184,091
Transit program	50.0	1,295	114	27	31	60	1,527
	25.0	32,015	2,826	677	756	1,473	37,747
	15.2	114,769	10,130	2,426	2,711	5,279	135,315
		148,079	13,070	3,130	3,498	6,812	174,589
Car pool (max.)	50.0	1,220	114	27	31	60	1,452
	25.0	30,158	2,826	677	756	1,473	35,890
	15.2	108,112	10,130	2,426	2,711	5,279	128,658
		139,490	13,070	3,130	3,498	6,812	166,000
Parking management	50.0	1,220	114	27	31	60	1,452
	25.0	30,158	2,286	677	756	1,473	35,890
	15.2	108,112	10,130	2,426	2,711	5,279	128,658
		139,490	13,070	3,130	3,498	6,812	166,000
Reduce 20% curb with off-street	(a) 50.0	1,220	114	27	31	60	1,452
	25.0	30,158	2,286	677	756	1,473	35,890
	14.8	118,685	10,130	2,426	2,711	5,279	139,231
		150,063	13,070	3,130	3,498	6,812	176,573
	(b) 50.0	1,105	114	27	31	60	1,337
	25.0	27,308	2,286	677	756	1,473	33,040
	15.2	97,895	10,130	2,426	2,711	5,279	118,441
		126,308	13,070	3,130	3,498	6,812	152,818
Flex-time	50.0	1,220	114	27	31	60	1,452
	26.0	6,756					6,756
	25.0	23,402	2,826	677	756	1,473	29,134
	15.4	108,112	10,130	2,426	2,711	5,279	128,658
		139,490	13,070	3,130	3,498	6,812	166,000
I and M		See text					

probably exceeds demand by 4 percent today, with demand decreasing.) Otherwise, a VMT increase could occur as described in the next paragraph.

Parking Supply Reductions - A 20-percent drop in the "lid" would cause demand to exceed supply. Short-range reduction in travel demand is not likely. Therefore, the impact of a parking shortage would depend upon who is affected.

If the reduction hits the peak of demand, short-term parkers would be impacted with a resulting increase in "searching" VMT at low speeds. This impact appears in Table III-9, estimate (a).

If the reduction in spaces affects only employees (long-term spaces) through rate increases to the short-term level, a reduction in light-duty auto VMT to 1,105 at 50 mph, 27,308 at 25 mph, and 97,895 at 15 mph might be achieved if employees shift to transit, park-shuttle, or park-walk from outside the CBD. This is shown in Table III-9, estimate (b).

Flex-time - Again, as with Seattle and Spokane, the "flex-time" approach to staggered hours is assumed because of its many advantages over a rigid program. The impact is estimated as a 1-mph speed increase for peak hours only.

"Staggered days" are not included as an effective strategy because of their limited impact (or no impact) on mid-week days.

Inspection and Maintenance - This program has no impact on VMT or speed.

CO Emission Estimates

Table III-10 shows the emissions calculated for the Portland CBD from the VMT-speed data given in Table III-9. The fraction of annual miles driven by vehicle age data for Portland are given in Table III-11.

Again, none of the strategy combinations tested reduce emissions to the allowable level even after applying a 10 percent reduction to light-duty vehicle emissions. Table III-12 gives the breakdown of emissions by model year for various strategy combinations.

SUMMARY COMMENTS ON METHODOLOGY

Many of the characteristics and impacts of the transportation control measures that have been analyzed have been assumed to be similar for all three cities. Thus, to avoid repetition, procedures used in developing VMT and speed change estimates have been discussed in more detail for the first city studied, Seattle, than for Spokane or Portland. Through necessity, these analyses have made use of many gross factors and assumptions, and the possibility for substantial errors exists. Even more detailed planning techniques may involve errors up to 15 percent.

Current deficiencies in data and projection techniques point out the need for increased planning, transportation modeling, and monitoring. CBD network modeling would allow strategy impacts on speeds to be tested more thoroughly, and modal split modeling with regional networks would allow a better evaluation of transit. Specific programs, such as parking reductions or predictive exclusion, need to be laid out in more detail and reviewed for feasibility so that impact analysis can be more realistic. Also, the economic and social impacts of candidate strategies should be reviewed in detail as well as their impact on VMT and air quality.

Table III-10. 8-HOUR CO EMISSION ESTIMATES, PORTLAND CBD

	Emissions (kg/8 hours)						
	Light-duty autos	Light-duty trucks	Heavy-duty trucks	Diesel	Motor-cycles	Total	Additional reduction needed
1972 Base	12,754	1,241	760	92	104	14,951	
1976 Base	9,814	1,022	1,049	100	211	12,196	5,468
Signal improvement	8,960	935	683	100	211	10,889	4,161
Transit program	8,420	935	683	100	211	10,349	3,621
Car pool (max.)	7,931	935	683	100	211	9,860	3,132
Parking Management	7,931	935	683	100	211	9,860	3,132
Reduce 20% curb with off-street	(a) 8,742	949	693	100	211	10,695	3,967
	(b) 7,182	935	683	100	211	9,111	2,383
Flex-time	7,845	927	678	100	211	9,761	3,033
I and M	See text						

NOTE: Allowable emissions, assuming a 55 percent reduction from 1972 base levels, are 6728 kg/8 hours.

GCA/TECHNOLOGY DIVISION

Table III-11. FRACTION OF ANNUAL MILES DRIVEN BY VEHICLE AGE FOR PORTLAND, OREGON

Vehicle age	Light-duty autos		Light-duty trucks		Heavy-duty vehicles
	1972	1976[a]	1972	1976[a]	1972[b]
0	0	0	0	0	0
1	0.116	0.114	0.118	0.110	0.130
2	0.129	0.132	0.107	0.140	0.133
3	0.109	0.114	0.132	0.125	0.123
4	0.115	0.106	0.138	0.117	0.124
5	0.098	0.098	0.085	0.098	0.085
6	0.085	0.086	0.076	0.073	0.068
7	0.077	0.078	0.061	0.058	0.058
8	0.071	0.067	0.050	0.048	0.050
9	0.054	0.056	0.038	0.038	0.040
10	0.042	0.041	0.028	0.028	0.031
11	0.028	0.028	0.020	0.020	0.024
12	0.018	0.021	0.015	0.017	0.017
≥ 13	0.058	0.059	0.132	0.128	0.117

[a]Average for calendar years 1971, 1972, and 1973.

[b]Nationwide.

Table III-12. 1976 CO EMISSION ESTIMATES FOR LIGHT-DUTY GASOLINE VEHICLES BY MODEL YEAR, PORTLAND CBD

Model year	Strategy package	Reduce parking option (a)	Reduce parking option (b)	Flex-time
	Light-duty autos			
Pre-1968	2,237	2,455	2,027	2,219
1968	672	739	608	667
1969	802	886	727	794
1970	799	884	724	791
1971	844	932	765	835
1972	710	785	643	703
1973	734	811	665	725
1974	753	831	682	744
1975	210	233	192	209
1976	165	182	149	162
Total	7,926	8,738	7,182	7,849
	Light-duty trucks			
Pre-1968	349	352	349	347
1968	45	45	45	44
1969	56	57	56	56
1970	56	57	56	55
1971	70	71	70	69
1972	76	78	76	75
1973	87	89	87	87
1974	89	91	89	88
1975	60	61	60	60
1976	44	45	44	44
Total	932	946	932	925

Because of the lack of accurate predictive techniques, expanded monitoring during program implementation is needed. Suggested parameters and items for detailed monitoring include: numbers of bus passengers, budget items, VMT and speed, meteorology, and pollutant concentrations. If plans go awry, or standards and deadlines change, appropriate modifications to the control measures can be made. Regular trend vehicle counts and speed measurements are beginning to be made. If these are carefully tabulated by route and speed, any new or better data could be included as it became available and used to update impact calculations. CBD cordon counts identifying hour, traffic class (including motorcycles), occupancy, and through travel would be useful on a regular schedule. Employment inventory data and parking demand checks on an annual basis would be helpful. Carpool follow-up surveys and counts are needed.

Detailed methods for such monitoring and evaluation of the effectiveness of transportation control plans are now being developed for the U.S. Environmental Protection Agency by GCA/Technology Division. When completed, this work will include procedures for using traffic data - such as the vehicle counts and speed measurements suggested here - to provide an early and continuing indicator of how well the control plan is working.

SECTION IV

STATISTICAL ANALYSIS OF EMISSIONS DATA FROM THE PORTLAND INSPECTION/MAINTENANCE PROGRAM

INTRODUCTION

The Department of Environmental Quality of the State of Oregon has been conducting a voluntary emissions testing program for gasoline-powered vehicles. The purpose of the program is to assess the effectiveness of the inspection/maintenance program adopted by the State as part of its Transportation Control Plan. According to Oregon's present plan, this program would include all motor vehicles registered in three Oregon Counties - Clackamas, Multnomah, and Washington. The emissions inspection would be performed using idle and loaded (dynamometer) emissions tests at State inspection stations. Large fleets may be inspected at stations privately operated under State supervision.

The voluntary test program operated by the Department of Environmental Quality has tested over 12,000 vehicles to date, using measurements of emissions during idle, 2500 rpm, and 30 and 50 mph light load conditions. Emissions measurements were volumetric - ppm of hydrocarbons, percent of carbon monoxide, and percent of carbon dioxide. When a vehicle failed the prescribed emissions test, the need for corrective action was suggested by the inspector, and the driver was encouraged to return for a follow-up inspection. Data on vehicle characteristics and testing results were collected for each vehicle, keypunched, then made available on computer tape.

This section presents an analysis of the data collected for a sample of 5900 vehicles. Approximately 400 of the 5900 vehicles returned for a retest, so the sample contained 5900 initial tests and 400 retests - 6300 tests in all. It was difficult to determine which cars retested had received maintenance between the first and second tests. Some of the retested cars passed the first test and required no maintenance. Of the retested cars which failed the first test, some did not receive maintenance. Others did receive maintenance but the only indication of this was the reported repair cost. It is possible that a repair cost was not given for some vehicles even though they had gone in for repairs. The method used to determine some of the retested cars which had received maintenance was to select those cars having a repair cost greater than zero - there were 104 in this subsample.

Table IV-1 shows the information which was collected for each vehicle and the location of the information in each line of data on the tape. Table IV-2 shows the transformations and computations which were performed on some of the data to prepare them for analysis.

The program package SPSS (Statistical Package for the Social Sciences) was used to summarize and evaluate the data. The package contained programs which permitted the following computations and analyses to be performed:

1. descriptive statistics for the entire sample
2. frequency tables and histograms of categorical data
3. n-way frequency tables of categorical data
4. basic statistics and analysis of variance for subgroups
5. t-test
6. stepwise regression
7. Pearson correlation and nonparametric correlations

Table IV-1. VEHICLE DATA FORMAT

Columns	Variable name	Values
1	Format number	1. First of two lines
2-6	DATE	Year and Julian day
7-13	LICENSE	
14-15	MODELYR	Model year
16-19	MAKE	Manufacturer
20-23	LINE	
24-29	MILEAGE	
30	EXHAUST	1. Single
		2. Dual, left
		3. Dual, right
31	RETEST	1. Retest
		Blank not retest
32-35	REPRCOST	Repair cost
36-39	HC1	Hydrocarbons at idle
40-43	HC2	Hydrocarbons at 2500 rpm
44-47	HC3	Hydrocarbons at idle
48-51	HC4	Hydrocarbons at 30 mph
52-55	HC5	Hydrocarbons at 50 mph
56-59	HC6	Hydrocarbons at idle
60-62	CO1	Carbon monoxide at idle
63-65	CO2	Carbon monoxide at 2500 rpm
66-68	CO3	Carbon monoxide at idle
69-71	CO4	Carbon monoxide at 30 mph
72-74	CO5	Carbon monoxide at 50 mph
75-77	CO6	Carbon monoxide at idle
1	Format number	2. Second of two lines
2-35	Same as line 1	
36	Registration	0. Available 1. Not available

Table IV-1 (Continued). VEHICLE DATA FORMAT

Columns	Variable name	Values
37-38	COUNTY	3. Clackamas 26. Multnomah 34. Washington 99. Out of state and others
39	SMOKE	1. Fail 0. Pass
40-42	NOISE	
43-46	ENGDISPL	Engine displacement in cubic centimeters or cubic inches.
47	CYLIN	Number of cylinders - 2, 4, 6, or 8.
48	TRANSM	Transmission type 1. Manual 2. Automatic
49	WGTCLASS	Weight class 1. Under 2800 2. 2800-3800 3. Over 3800
50-56	Under hood inspection	0. Not present 1. One present 2. Present and disconnected 3. Both 1 and 2
	50 PCV	Positive crankcase ventilation
	51 AIRPUMP	
	52 EGR	Exhaust gas recirculation
	53 EVAP	
	54 DISTRIB	Distributor
	55 PREHEAT	
	56 CATMUF	Catalytic muffler
57-61	Engine modification inspection	0. No tampering 1. Tampering
	57 CARB	Carburetor
	58 INMANI	Intake manifold
	59 EXH	Exhaust

Table IV-1 (Continued). VEHICLE DATA FORMAT

Columns	Variable name	Values
	60 ADDON	Addon devices
	61 OTHER	
62-64	CO21	Carbon dioxide at idle
65-67	CO22	Carbon dioxide at 2500 rpm
68-70	CO23	Carbon dioxide at idle
71-73	CO24	Carbon dioxide at 30 mph
74-76	CO25	Carbon dioxide at 50 mph
77-79	CO26	Carbon dioxide at idle

Table IV-2. DATA TRANSFORMATION

Variable	Transformations
Make	The 145 different values were recoded to 9 values: (1) GM (2) Ford (3) Chrysler (4) Japanese (5) Other foreign (6) Volkswagen (7) AMC (8) Other domestic (9) Other.
Modelyr	Recoded to age: (0) 75 (1) 74 (2) 73 (3) 72 (4) 71 (5) 70 (6) 69 (7) 68 (8) 67 (9) pre 67.
Modelyr	Recoded to control: (0) pre 68 (1) 68-69 (2) 70-71 (3) 72-75.
Engdispl	Recoded to CI (cubic inches): (1) less than 150 (2) 150-250 (3) 250-350 (4) greater than 350.
Mileage	Recoded to 5 values: (1) less than 20,000 (2) 20,000-40,000 (3) 40,000-60,000 (4) 60,000-80,000 (5) greater than 80,000.

DESCRIPTION OF SAMPLE VEHICLE CHARACTERISTICS

The vehicle characteristics of the sample are described by determining the distributions within the categories of age, make, weight class, engine displacement, number of cylinders, and county. Figures IV-1 through IV-6 show the numerical distributions of vehicles among the categories. Table IV-3 is a two-way frequency distribution of vehicles in age and make categories.

In addition to describing the characteristics of the sample, the frequency distributions of the sample vehicles can be compared with information available for the population of vehicles in the three counties - Clackamas, Multnomah, and Washington - from which the sample was drawn. It should then be determined if the sample is representative of the population and what inferences about the population can be drawn. Tables IV-4 through IV-6 show, respectively, the age distribution, the make distribution, and the control by make distribution of the vehicle population and the sample. A χ^2 goodness of fit test was performed comparing the number of sample vehicles in each age category (observed) with the number of the population vehicles in the same category (expected). In the same manner, a χ^2 goodness of fit was performed on the sample and population distributions in the make categories and the control by make categories. Results showed that the sample was significantly different from the population for all three characteristics. In general, there were more vehicles built in recent model years in the sample than there were in the population. This would tend to decrease the average emissions of the whole sample. Some makes of cars were overrepresented in the sample while others were underrepresented. The effect on the average emissions of the whole sample, then, depends on the difference in emissions among makes and age groups which will be discussed in EMISSIONS OF GROUPS.

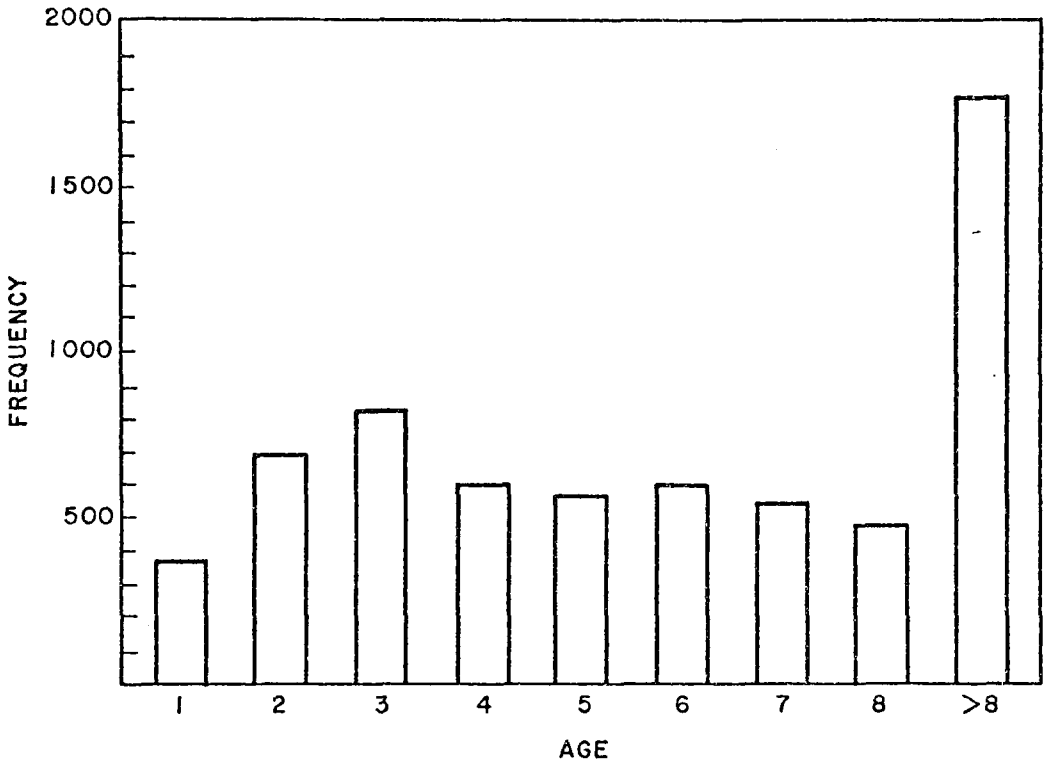

Figure IV-1. Sample age distribution

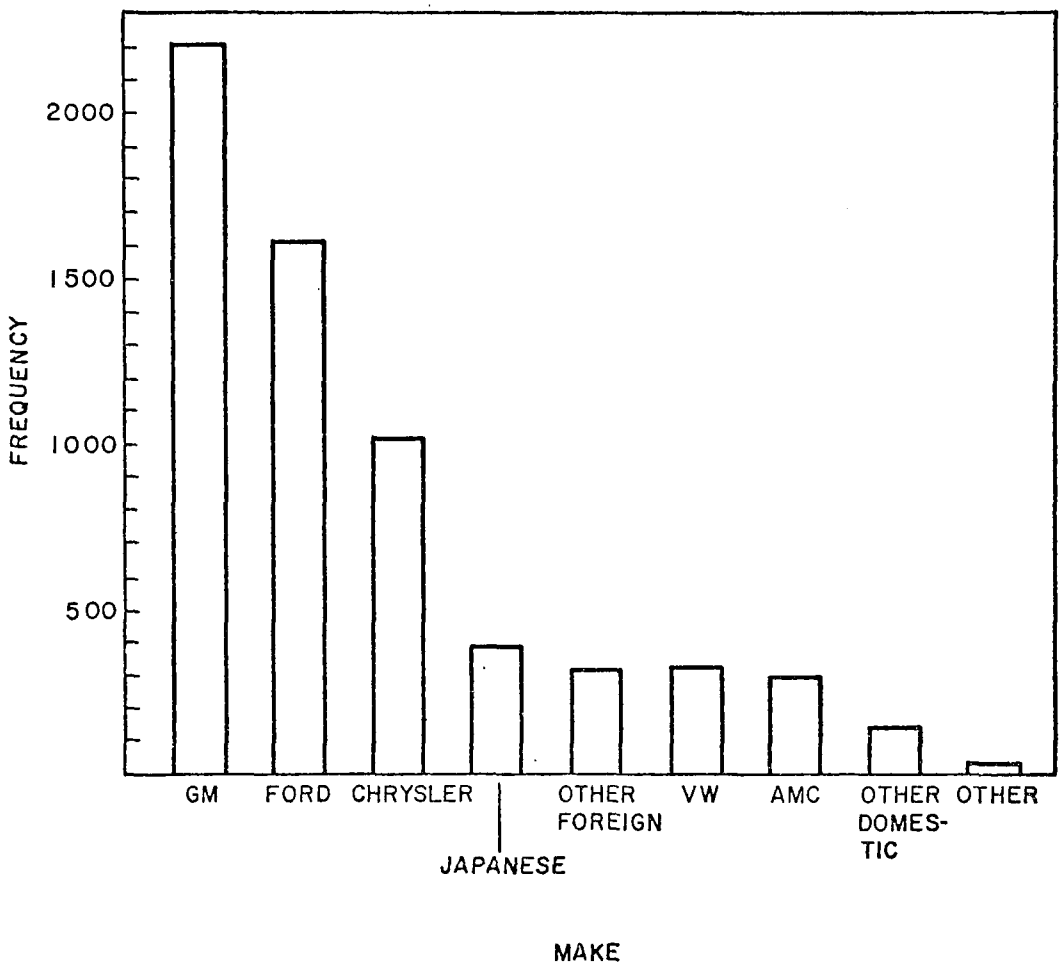

Figure IV-2. Sample make distribution

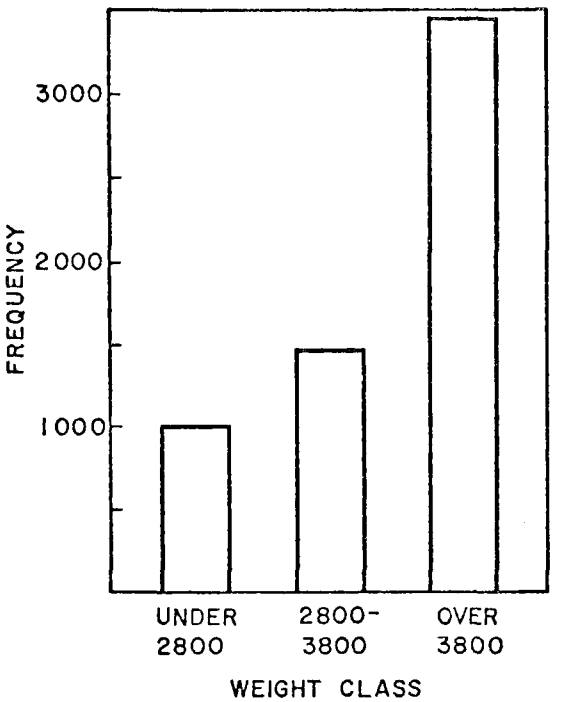

Figure IV-3. Sample weight class distribution

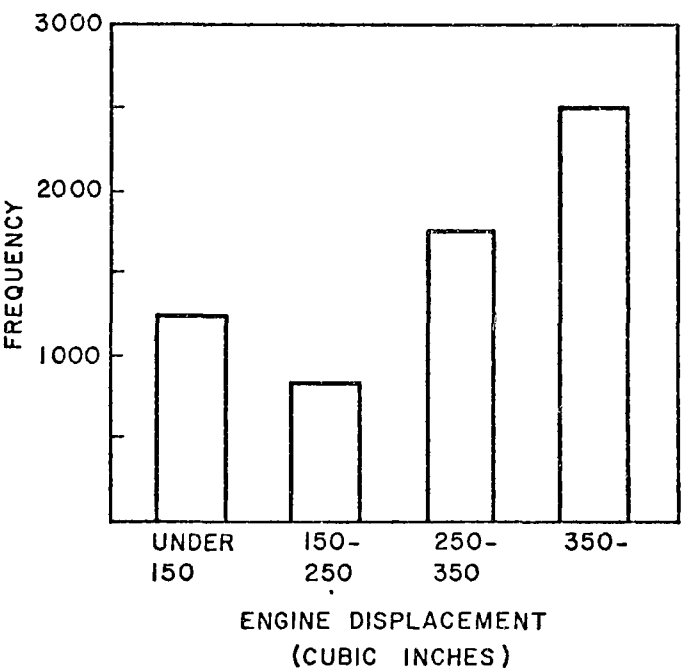

Figure IV-4. Sample engine displacement distribution

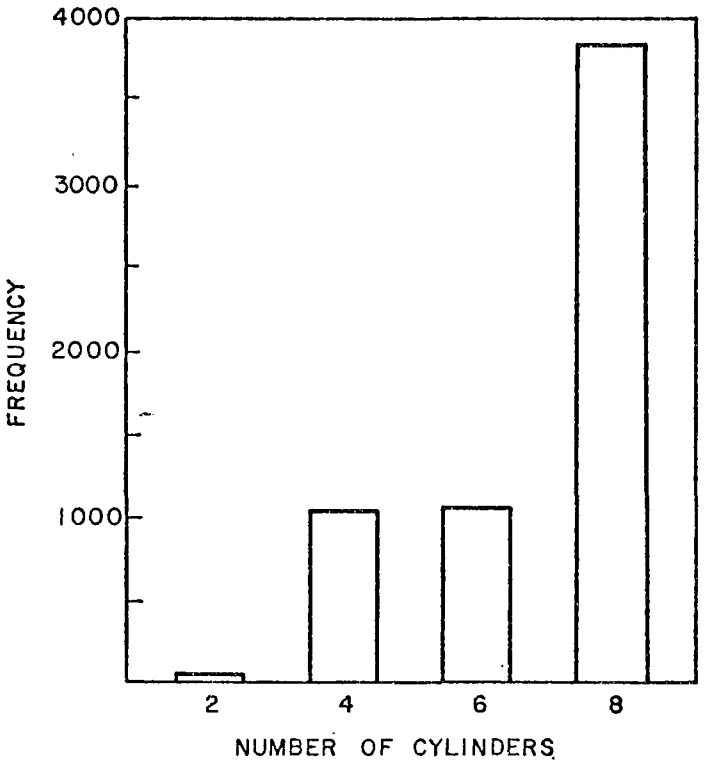

Figure IV-5. Sample cylinders distribution

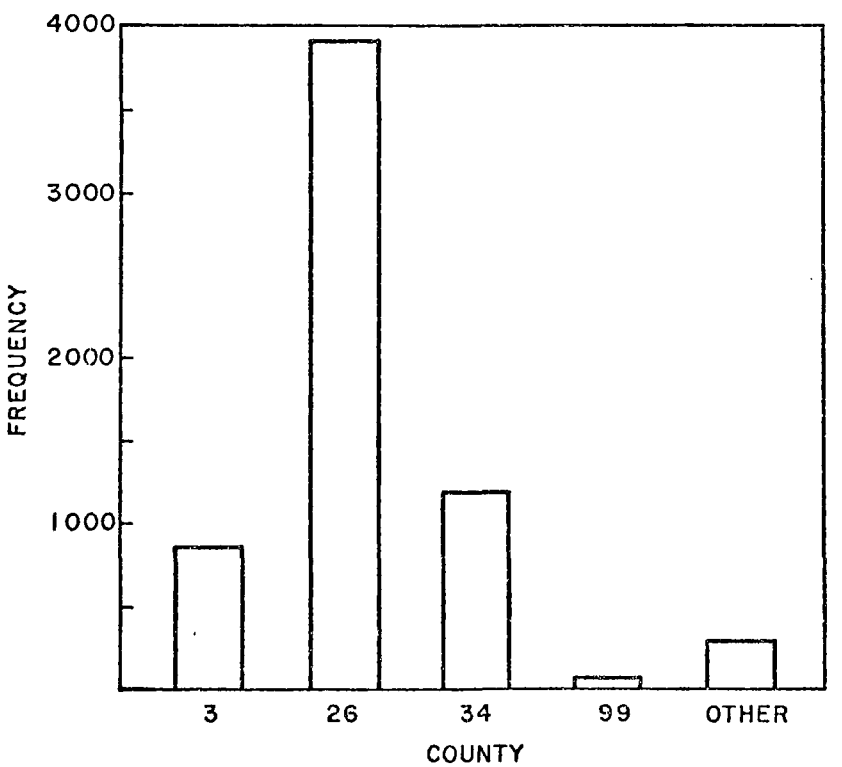

Figure IV-6. Sample county distribution

Table IV-3. SAMPLE AGE BY MAKE DISTRIBUTION

Age/make	GM	Ford	Chrysler	Japanese	Other foreign	Volkswagen	AMC	Other domestic	Total
0	0	3	1	0	0	0	0	0	5
1	105	92	63	49	23	19	11	5	367
2	195	172	120	89	28	24	30	22	683
3	208	210	111	85	35	25	26	25	726
4	167	158	81	78	46	34	20	3	592
5	191	158	83	31	33	28	24	10	560
6	202	155	108	21	35	37	24	6	592
7	187	156	96	11	16	30	36	9	541
8	175	133	74	11	23	29	15	6	469
9^+	771	373	273	10	70	89	108	55	1763
Total	2201	1610	1010	385	309	315	294	141	6298

Table IV-4. AGE DISTRIBUTION OF SAMPLE AND POPULATION

Age	3 county July, 1974 population	Sample	Observed	Expected
1	0.036	0.058	367	227
2	0.09	0.109	683	566
3	0.086	0.115	726	541
4	0.067	0.094	592	421
5	0.063	0.089	560	396
6	0.072	0.094	592	453
7	0.065	0.086	541	409
8	0.061	0.075	469	384
9^+	0.46	0.28	1763	2895
			6293	6293

$\chi^2 = 459.6$ $\chi^2_{8,\ 0.95} = 15.51$

Table IV-5. MAKE DISTRIBUTION OF SAMPLE AND POPULATION

Make	Multnomah county 1972 population	Sample	Observed	Expected
GM	0.39	0.351	2201	2443
Ford	0.278	0.257	1610	1742
Chrysler	0.126	0.161	1010	789
Japanese	0.073	0.061	385	457
Other foreign	0.045	0.049	309	282
Volkswagen	0.041	0.050	315	257
AMC	0.032	0.047	294	200
Other domestic	0.015	0.024	141	63
			6265	6265

$\chi^2 = 263.7$ $\chi^2_{7,\ 0.95} = 14.07$

Table IV-6. CONTROL BY MAKE DISTRIBUTION OF SAMPLE AND POPULATION

Control	Make	Population	Sample	Observed	Expected
0	1	0.205	0.151	946	1284
0	2	0.115	0.081	506	720
0	3	0.067	0.055	347	420
0	7	0.026	0.020	123	163
0	0	0.065	0.047	293	407
1	1	0.067	0.062	389	420
1	2	0.038	0.050	311	230
1	3	0.027	0.033	204	169
1	7	0.006	0.010	60	38
1	0	0.036	0.026	165	226
2	1	0.049	0.057	358	307
2	2	0.041	0.050	316	257
2	3	0.021	0.026	164	132
2	7	0.005	0.007	44	31
2	0	0.048	0.042	263	301
3	1	0.065	0.081	508	407
3	2	0.044	0.076	477	276
3	3	0.022	0.047	295	138
3	7	0.066	0.011	67	38
3	0	0.048	0.068	429	301
				6265	6265

$\chi^2 = 740.929 \quad \chi^2_{19,\ 0.95} \cong 30.1$

Note: Control: (0) pre 68 (1) 68-69 (2) 70-71 (3) 72-75.
Make: (1) GM (2) Ford (3) Chrysler (7) AMC
(0) Other foreign and domestic.

The sample frequency distributions can also be compared with those of certain subsamples which are of interest. The age, make, weight class, cylinder, and control distributions of the subsample of cars which failed at least one of the carbon monoxide, hydrocarbons, and smoke tests are shown and compared with those distributions of the entire sample in Tables IV-7 through IV-11. The fail subsample differed significantly from the sample with respect to age, make, weight class, and number of cylinders. There were more older cars, more of Japanese and other foreign make, more cars under 2800 pounds, and more four-cylinder cars in the fail subsample than were expected when comparing it with the entire sample. The fail subsample did not differ significantly from the sample with respect to control. Control is a grouping of cars by age according to the level of emissions controls present in cars of a particular model year - from no controls, pre-68, to extensive controls, 72 to 75, with intermediate increases from 68 to 69 and 70 to 71. Failure levels were set according to the control categories so that approximately 50 percent of the cars in a particular control category would fail the emissions tests. Therefore, it is expected that the sample and the fail subsample would not differ significantly with respect to control.

DESCRIPTION OF SAMPLE EMISSIONS

During emissions testing, readings of carbon monoxide, hydrocarbons, and carbon dioxide were taken at either three or six modes. The modes are:

1. idle
2. 2500 rpm
3. idle
4. 30 mph, light load
5. 50 mph, light load
6. idle

Table IV-7. AGE DISTRIBUTION OF SAMPLE AND FAIL SUBSAMPLE

Age	Sample	Subsample fail	Observed	Expected
1	0.058	0.045	134	173
2	0.109	0.100	298	325
3	0.115	0.132	394	343
4	0.094	0.095	283	280
5	0.089	0.099	296	265
6	0.094	0.089	265	280
7	0.086	0.091	271	256
8	0.075	0.071	211	224
9^+	0.28	0.278	830	835
			2982	2982

$\chi^2 = 24.743$ $\chi^2_{8,\ 0.95} = 15.51$

Table IV-8. MAKE DISTRIBUTION OF SAMPLE AND FAIL SUBSAMPLE

Make	Sample	Subsample fail	Observed	Expected
GM	0.351	0.335	1001	1042
Ford	0.257	0.260	776	763
Chrysler	0.161	0.158	473	478
Japanese	0.061	0.068	203	181
Other foreign	0.049	0.059	177	145
Volkswagen	0.050	0.053	159	148
AMC	0.047	0.041	122	139
Other domestic	0.023	0.019	57	68
			2968	2964

$\chi^2 = 16.298$ $\chi^2_{7,\ 0.95} = 14.07$

Table IV-9. WEIGHT CLASS DISTRIBUTION OF SAMPLE AND FAIL SUBSAMPLE

	Sample	Subsample fail	Observed	Expected
under 2800	0.169	0.187	524	473
2800 - 3800	0.247	0.234	656	691
over 3800	0.584	0.578	1619	1635
			2799	2799

$\chi^2 = 7.429$ $\chi^2_{2,\ 0.95} = 5.99$

Table IV-10. CYLINDER DISTRIBUTION OF SAMPLE AND FAIL SUBSAMPLE

	Sample	Subsample fail	Observed	Expected
2	0.006	0.005	13	17
4	0.174	0.197	544	489
6	0.177	0.155	435	498
8	0.643	0.644	1810	1808
			2812	2812

$\chi^2 = 17.553$ $\chi^2_{3,\ 0.95} = 7.81$

Table IV-11. CONTROL DISTRIBUTION OF SAMPLE AND FAIL SUBSAMPLE

	Sample	Subsample fail	Observed	Expected
pre 68	0.354	0.349	1041	1057
69 - 70	0.180	0.180	536	537
70 - 71	0.183	0.194	579	546
72 +	0.283	0.278	829	845
			2985	2985

$\chi^2 = 2.542$ $\chi^2_{3,\ 0.95} = 7.81$

All of the cars were tested at the first three modes - the idle test. About one-third of the sample was tested in addition at the second three modes - the dynamic test. The third mode (second idle) emissions were compared with the fail criteria to determine passing or failure. See Table IV-12.

Table IV-12. FAIL CRITERIA

Control	Fail Criteria (idle mode)
pre 68	HC $\geq$ 1200 ppm
	CO $\geq$ 6 percent
68-69	HC $\geq$ 600 ppm
	CO $\geq$ 5 percent
70-71	HC $\geq$ 500 ppm
	CO $\geq$ 4 percent
72-74	HC $\geq$ 350 ppm
	CO $\geq$ 3 percent

The carbon monoxide, hydrocarbons, and carbon dioxide emissions are summarized for each mode in Figures IV-7 through IV-9. Each figure shows for a particular pollutant the arithmetic mean, geometric mean, and 95 percent confidence interval for the six modes. It can be seen that the carbon monoxide and hydrocarbons arithmetic means are higher for the idle modes and lower for the dynamic modes while the reverse is true for the carbon dioxide means. The three idle mode means of carbon monoxide increase from first to third idle while the hydrocarbons idle mode means increase from first to second idle but decrease from second to third idle. Of the three carbon monoxide dynamic mode means, the lowest is at 2500 rpm and the other two, 30 mph and 50 mph, are nearly the same. The means of the hydrocarbons dynamic modes show a decrease from 2500 rpm to 30 mph to 50 mph. Only 3 percent of the vehicles failed the exhaust smoke test.

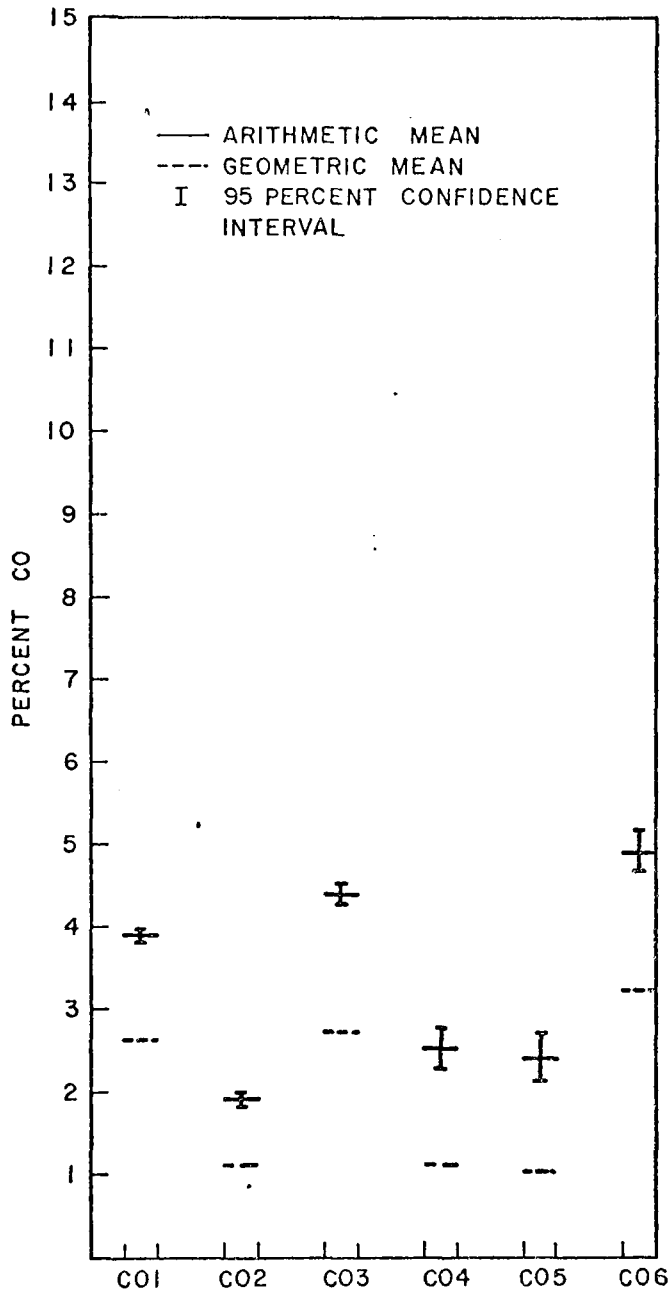

Figure IV-7. Carbon monoxide mean emissions

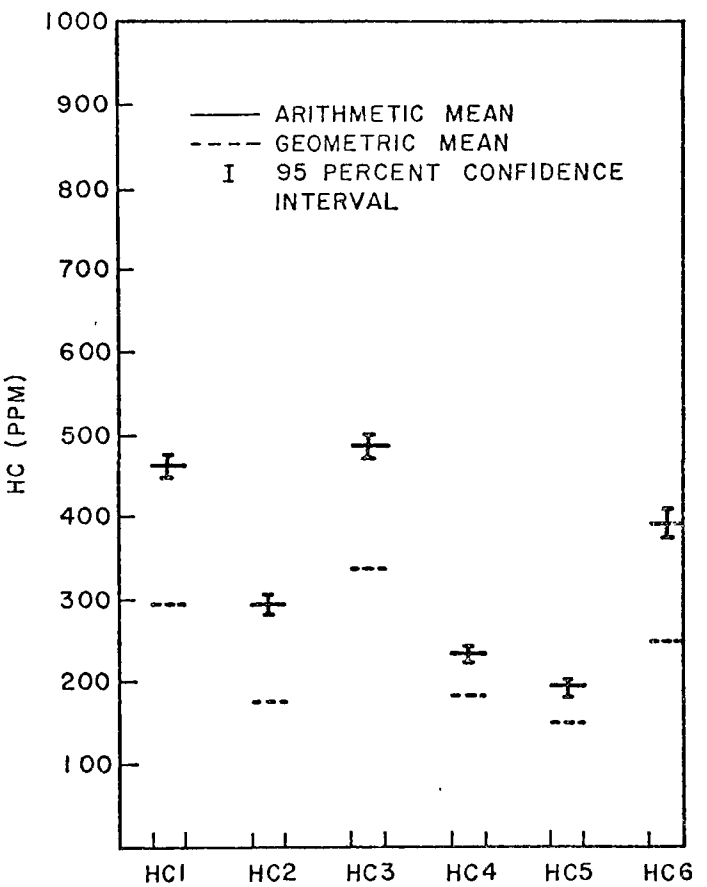

Figure IV-8. Hydrocarbons mean emissions

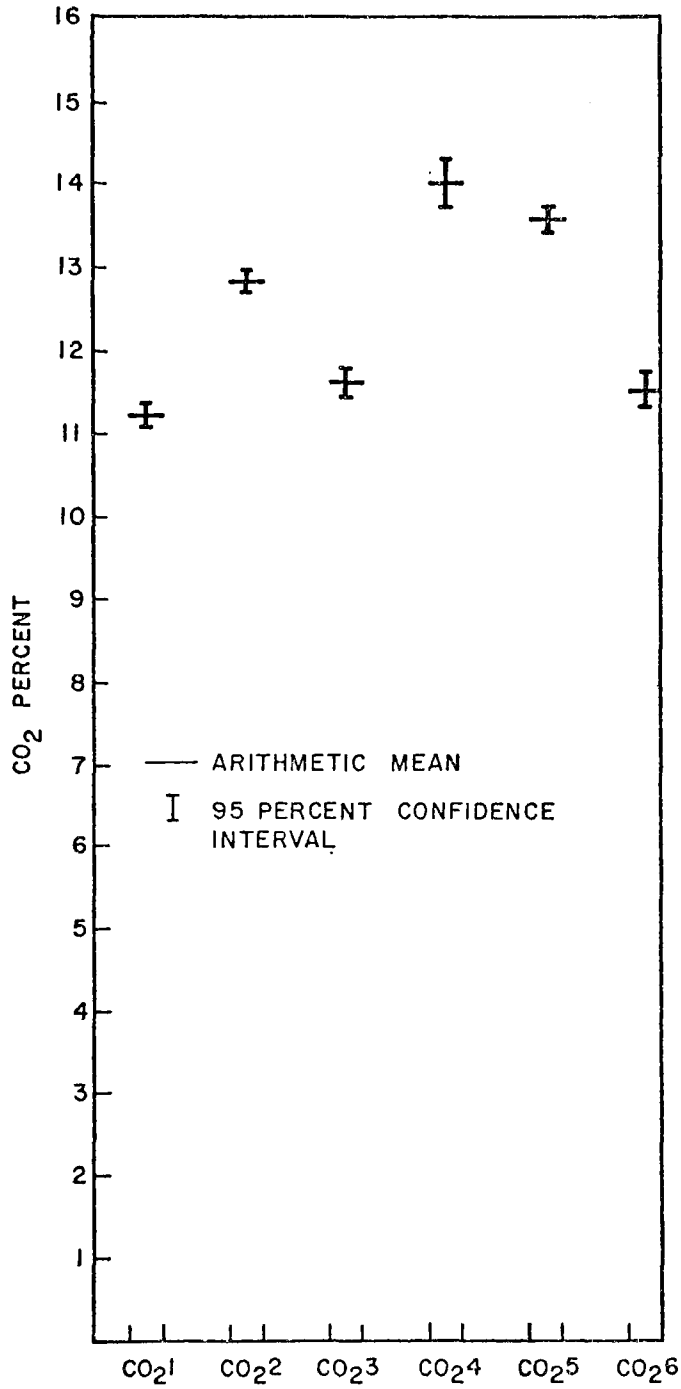

Figure IV-9. Carbon dioxide mean emissions

Only carbon monoxide and hydrocarbons results will be considered further in this discussion since carbon dioxide is not considered a serious vehicle emission. Also, the discussion of results will look primarily at the emissions readings for the third mode (second idle) because this was the mode used for determining failure and because a car that failed was more likely to fail at one of the idle modes due to generally higher emissions for the idle modes. The third hydrocarbons reading will be referred to as HC3 and the third carbon monoxide reading as CO3.

The geometric mean of a distribution is always less than the arithmetic mean. The degree of difference between them is a good indication of the degree of skewness of the data. As can be seen in Figures IV-7 and IV-8 the geometric means are in general much less than the corresponding arithmetic means. This means that a number of outlying readings are tending to increase the arithmetic means so that the arithmetic means as a measure of central tendency are high. This is borne out by the skewness measure which was calculated for each mode for each pollutant.

The 95 percent confidence interval around the sample mean of a pollutant at a particular mode indicates that there is 95 percent confidence that the population mean lies within that interval. In general, the 95 percent confidence intervals are very narrow, especially for the means of the first three modes. This is due mostly to the large sample size - about 6300 vehicles were tested in the first three modes and about one third of these were also tested in the second three modes. A larger sample size decreases the length of the confidence interval around the mean, thus increasing confidence in the mean.

The normality of the emissions data can be studied by the standard deviation, kurtosis, and skewness. The standard deviations for the pollutants measured at the different modes were in general about equal to the mean values. This indicates that there is a large amount of spread to the data. Kurtosis is a measure of the peakedness of a distribution of data. The data distributions of each pollutant at each mode were,

for the most part, more peaked than the normal distribution; i.e., leptokurtosis. A distribution is considered to be skewed when there is a considerably larger number of extreme cases on one side of the distribution curve than on the other. When the skewness measure is positive, the distribution is skewed to the right. In general, skewness indicated that most of the data distributions were markedly skewed to the right. Figures IV-10 and IV-11 are relative frequency graphs of the third hydrocarbons (HC3) mode data and the third carbon monoxide (CO3) mode data, respectively. The hydrocarbons data distribution is very definitely skewed to the right, with 13.2 percent of the data greater than 1000 ppm and 1.6 percent greater than 2000 ppm. The carbon monoxide data distribution is also skewed to the right with 1.2 percent of the data greater than 10 percent CO and, in addition, is bimodal. The bimodality of the carbon monoxide distribution could not be broken down into two separate distributions by control, weight class, cylinders, or engine displacement. The emissions tests data are not normally distributed, which has been found in other studies.

The log normality of the emissions was studied to determine if the log of the data would produce a normal distribution. Figures IV-12 and IV-13 are relative frequency graphs of the log of the data from the third hydrocarbons mode and the third carbon monoxide mode. Both distributions appear more normal and skewness and kurtosis are decreased. But it appears that the log distributions are not sufficiently more normal than the data distributions to warrant using them. In addition, the relatively large sample size reduces the sampling error and increases confidence that the data distributions are representative of the population distribution.

As discussed in DESCRIPTION OF SAMPLE VEHICLE CHARACTERISTICS, the sample is significantly different from the population with respect to age, make, and control by make due to bias. Since emissions also tend to differ significantly between age groups, between make groups, and between control

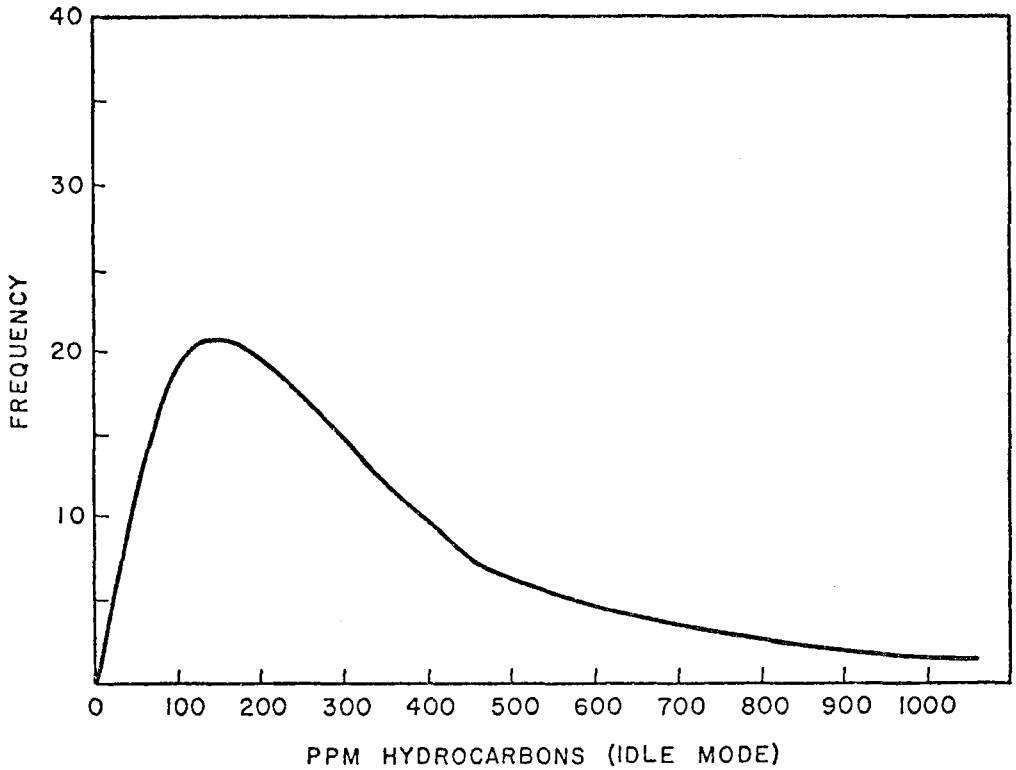

Figure IV-10. Relative frequency of hydrocarbons (idle mode)

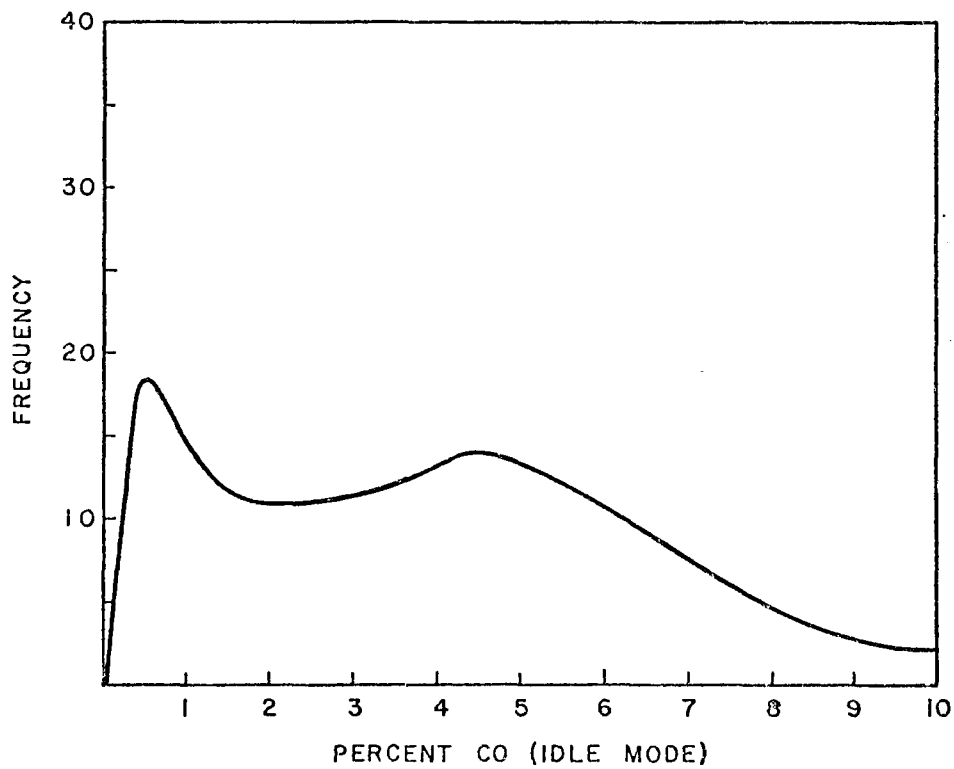

Figure IV-11. Relative frequency of carbon monoxide (idle mode)

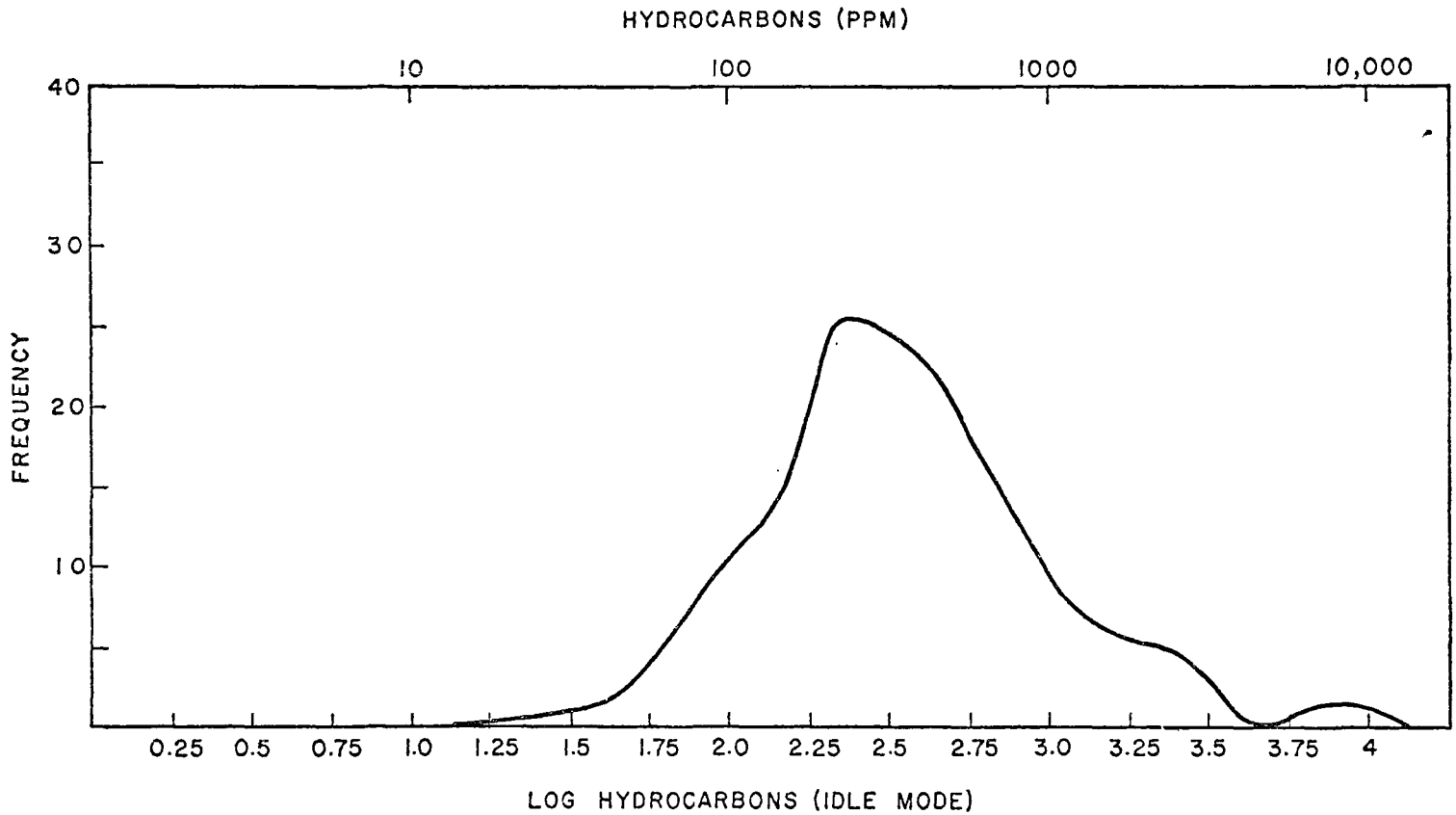

Figure IV-12. Relative frequency of log hydrocarbons (idle mode)

GCA/TECHNOLOGY DIVISION

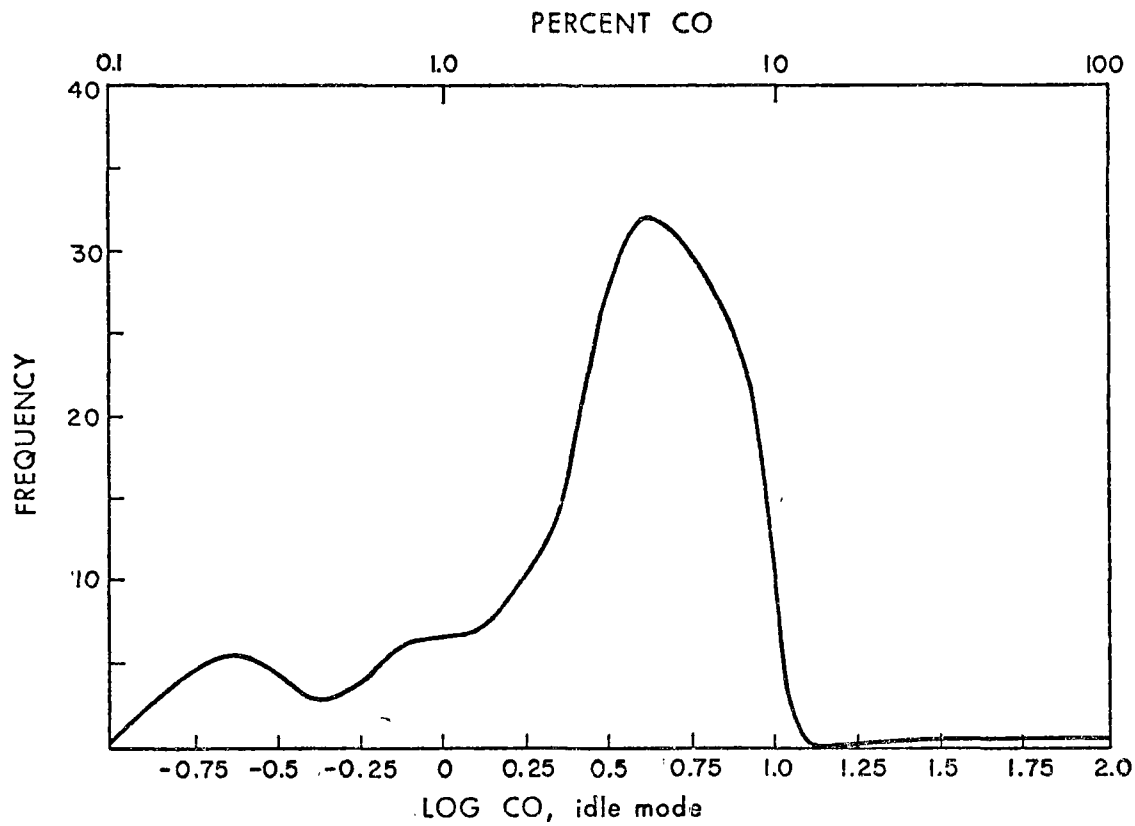

Figure IV-13. Relative frequency of log carbon monoxide (idle mode)

by make groups (see EMISSIONS OF GROUPS), the sample mean emissions may not be representative of the population mean emissions. This is determined by weighting emissions, as shown in Tables IV-13 through IV-15. Table IV-13 shows that age adjusting increases the CO3 mean emissions slightly and the HC3 mean emissions considerably. The over-representation of newer cars in the sample apparently has affected the sample mean, especially for hydrocarbons. Table IV-14 shows that adjusting for the different make composition of the sample does not appreciably affect either CO3 or HC3 mean emissions. It appears that the effects of over-representation of some vehicle makes have been cancelled out by the effects of higher emissions of other vehicle makes. In Table IV-15, there is little effect on CO3 but a considerable effect on HC3 from adjusting for control by make. Apparently, some control by make groups with higher emissions have been underrepresented in the sample.

Table IV-13. WEIGHTING FOR AGE

Age groups	Proportion of population	Proportion of sample	Mean emissions	
			CO3	HC3
1	0.036	0.058	3.1	208.7
2	0.09	0.109	2.8	271.1
3	0.086	0.115	3.5	285.8
4	0.067	0.094	4.2	353.9
5	0.063	0.089	4.3	378.4
6	0.072	0.094	4.6	418.5
7	0.065	0.086	4.6	470.2
8	0.061	0.075	5.5	679.6
9^+	0.46	0.28	5.4	764.4

	Sample mean emissions	Population adjusted mean emissions
CO3	4.4	4.7
HC3	485.3	557.8

Table IV-14. WEIGHTING FOR MAKE

Make groups	Proportion of population	Proportion of sample	Mean emissions	
			CO3	HC3
1	0.39	0.351	4.4	526.8
2	0.278	0.257	4.5	371.7
3	0.126	0.161	4.4	422.1
4	0.073	0.061	3.7	414.1
5	0.045	0.049	4.9	630.4
6	0.041	0.050	4.3	625.8
7	0.032	0.047	4.5	387.2
8	0.01	0.024	4.0	518.7

	Sample mean emissions	Population adjusted mean emissions
CO3	4.4	4.4
HC3	466.4	466.4

Table IV-15. WEIGHTING FOR CONTROL BY MAKE

Control group	Make group	Proportion of population	Proportion of sample	Mean emissions	
				CO3	HC3
0	1	0.206	0.151	5.5	874.7
0	2	0.115	0.081	5.3	557.0
0	3	0.067	0.055	4.6	594.2
0	7	0.026	0.020	5.4	558.5
0	0	0.065	0.047	6.0	933
1	1	0.067	0.062	4.7	471.5
1	2	0.038	0.050	4.9	386.9
1	3	0.027	0.033	4.3	412.8
1	7	0.006	0.010	4.5	317.9
1	0	0.036	0.026	4.2	561
2	1	0.049	0.057	4.4	354.2
2	2	0.041	0.050	4.0	290.5
2	3	0.021	0.026	4.4	368.0
2	7	0.005	0.007	4.6	308.3
2	0	0.048	0.042	4.2	477
3	1	0.065	0.081	2.2	204.5
3	2	0.044	0.076	3.8	277.9
3	3	0.022	0.047	4.1	272.1
3	7	0.006	0.011	2.7	249.1
3	0	0.048	0.068	2.9	314

	Sample mean emissions	Population adjusted mean emissions
CO3	4.4	4.6
HC3	485.5	548.3

EMISSIONS OF GROUPS

The sample can be divided into several different kinds of groups according to certain vehicle and testing characteristics. It is interesting to compare emissions between the groups within each characteristic. Table IV-16 shows the results of a one way analysis of variance performed on HC3 and CO3 results within the following characteristics - age, make, weight class, control, test and cylinders. The groups being compared within each characteristic are shown at the bottom of the table Both HC3 and CO3 showed a significant difference in variance between age groups, control groups, and test groups. HC3 showed a significant difference in variance between make groups while CO3 did not and CO3 showed a significant difference in variance between weight class groups and cylinder groups while HC3 did not. It was expected that there would be significant differences in hydrocarbons and carbon monoxide between the groups of some of these characteristics. It appears that weight class and number of cylinders do not significantly affect hydrocarbons emissions levels; also, that make does not significantly affect carbon monoxide emissions levels.

Figures IV-14 through IV-21 show mean HC3 and CO3 emissions for age groups, make groups, control groups and mileage groups. In general, mean emissions are higher for older cars, for cars with higher mileage, and for cars with no or early emissions controls. CO3, however, is higher for the 1974 cars. HC3 mean emissions were especially high for cars of Volkswagen and other foreign makes, while CO3 mean emissions did not vary significantly between makes.

Table IV-17 shows the results of a t-test performed on HC3 and CO3 results between exhaust groups, between retest groups, and between result groups. There were three exhaust groups - single, dual, left, and dual, right - but only the latter two were compared by the t-test. Neither

Table IV-16. ANALYSIS OF VARIANCE

	AGE	MAKE	WEIGHT CLASS	CONTROL	TEST	CYLIN
HC3	S	S	N	S	S	N
CO3	S	N	S	S	S	S

Note: S - significant
N - not significant

Characteristic	Groups
Age	0, 1, 2, 3, 4, 5, 6, 7, 8, 8+
Make	GM, Ford, Chrysler, Japanese, Other foreign, AMC, VW, Other domestic.
Weight class	Under 2800, 2800-3800, over 3800.
Control	pre-68, 68-69, 70-71, 72-74.
Test	One test only, first of two tests (before retest), second of two tests (retest)
Cylinders	2, 4, 6, 8

Table IV-17. T-TEST

	EXHAUST	RETEST	RESULT
HC3	N	S	S
CO3	N	S	S

Note: S - Significant
N - Not significant

Characteristics	Groups
Exhaust	Dual, left versus dual, right
Retest	Before retest versus retest
Result	Pass versus fail

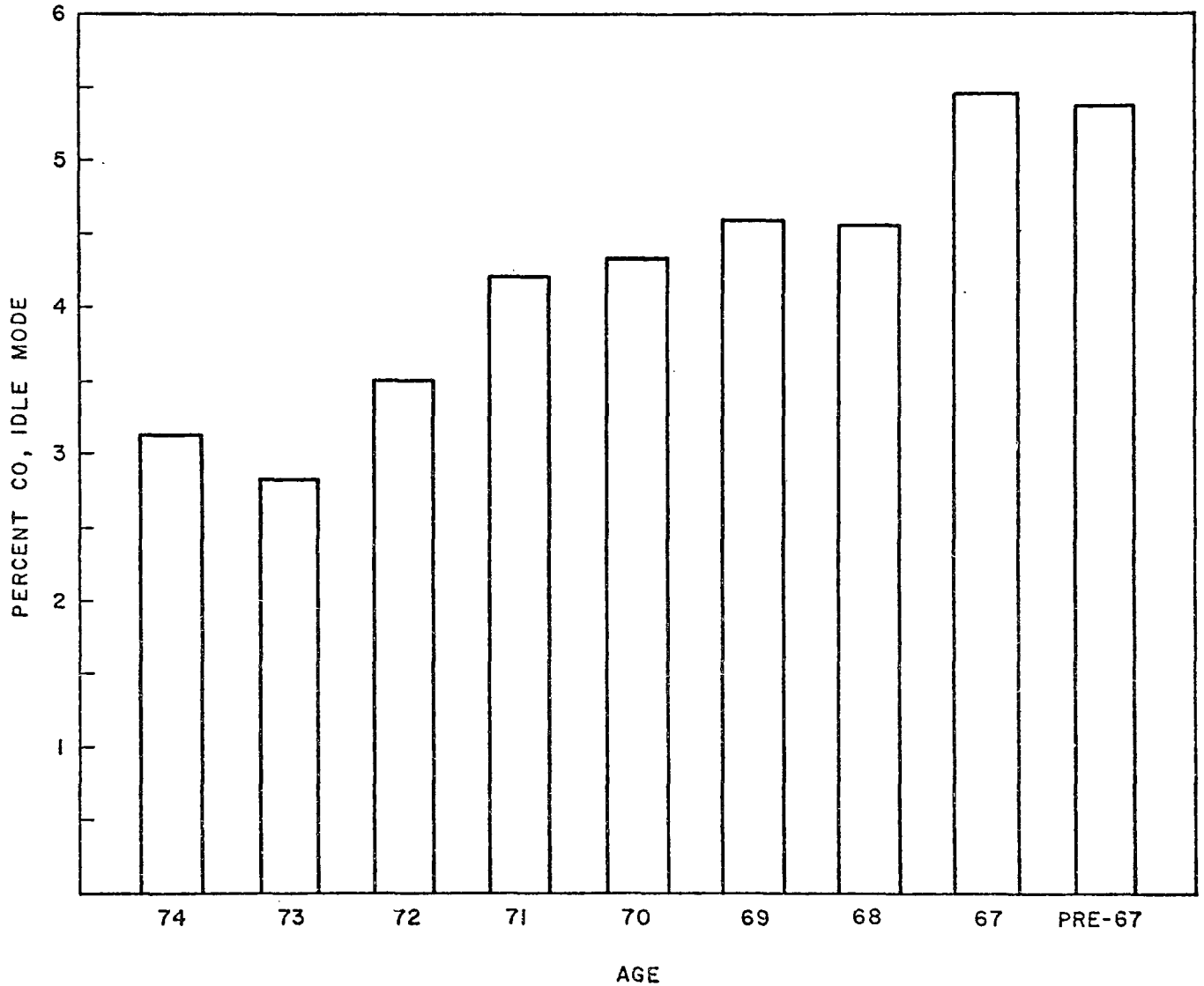

Figure IV-14. Carbon monoxide (idle mode) by age

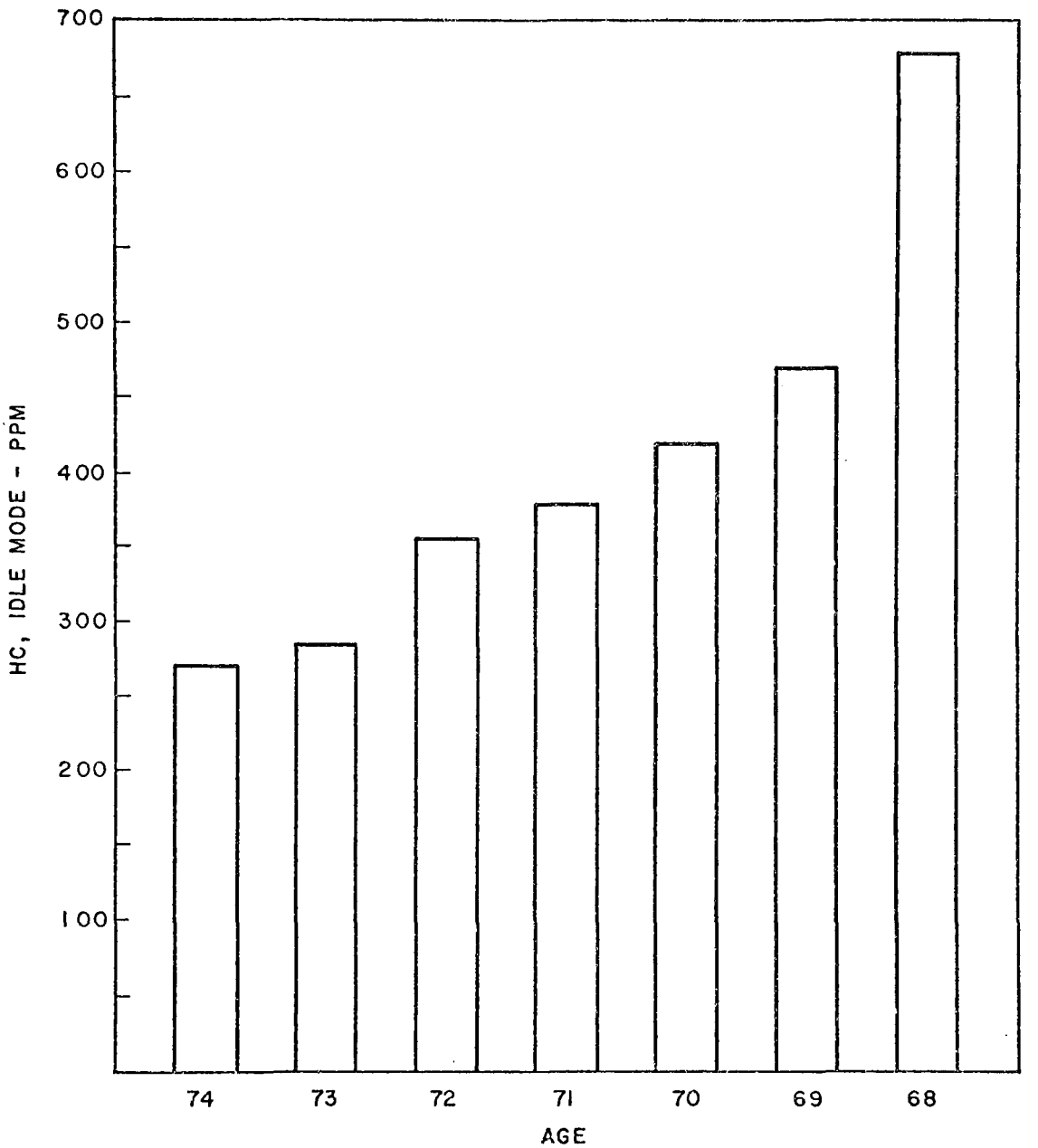

Figure IV-15. Hydrocarbons (idle mode) by age

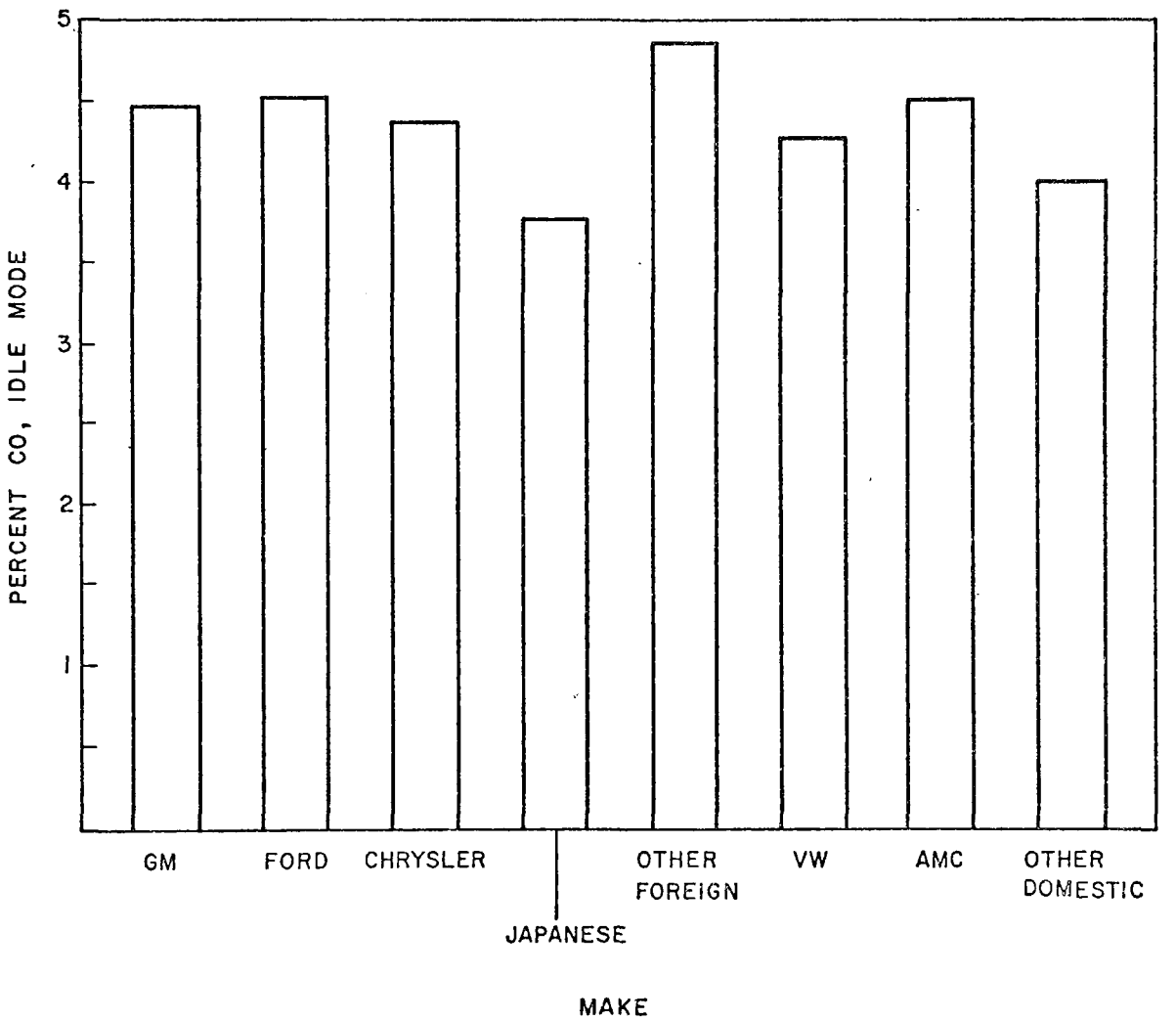

Figure IV-16. Carbon monoxide (idle mode) by make

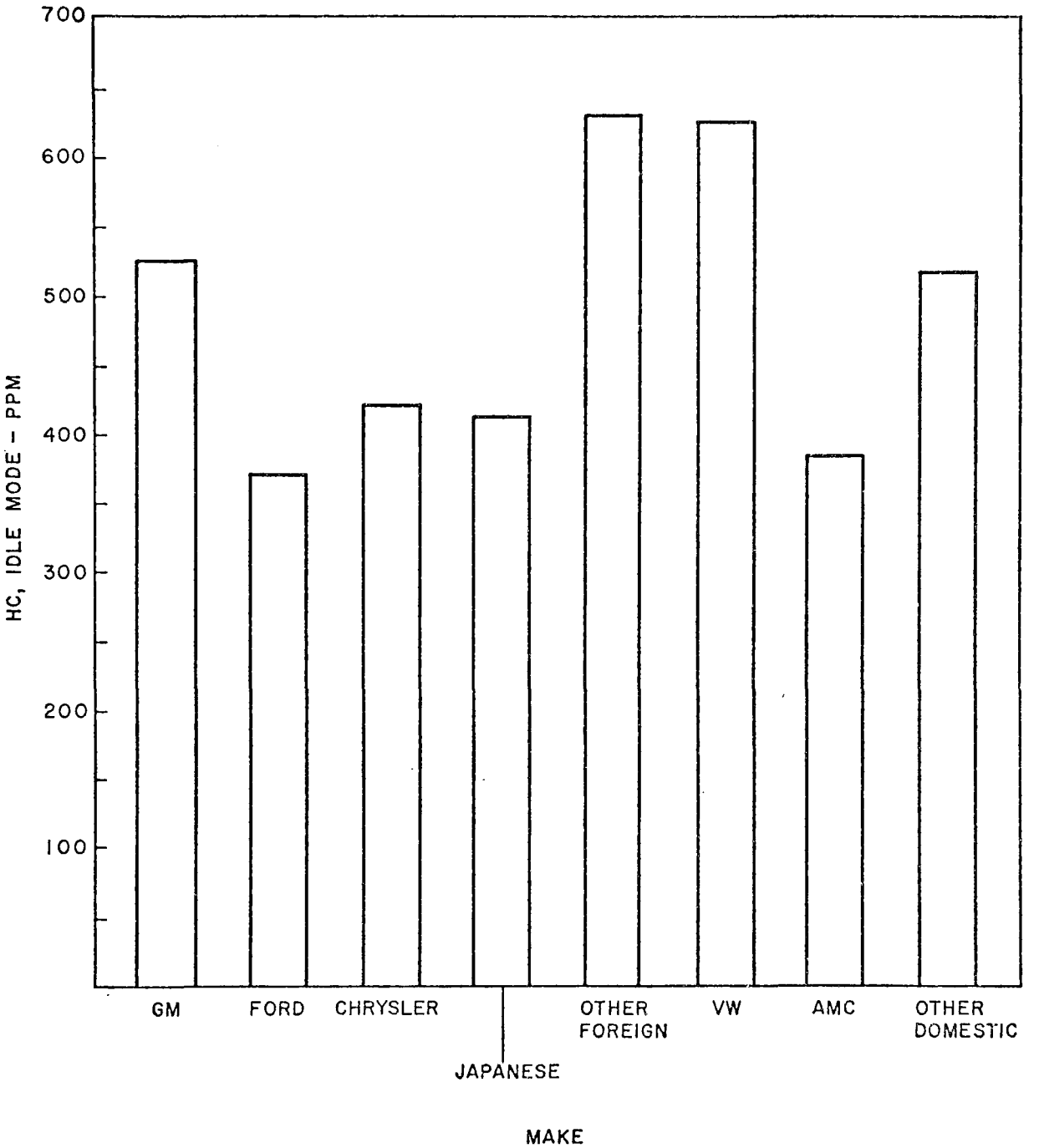

Figure IV-17. Hydrocarbons (idle mode) by make

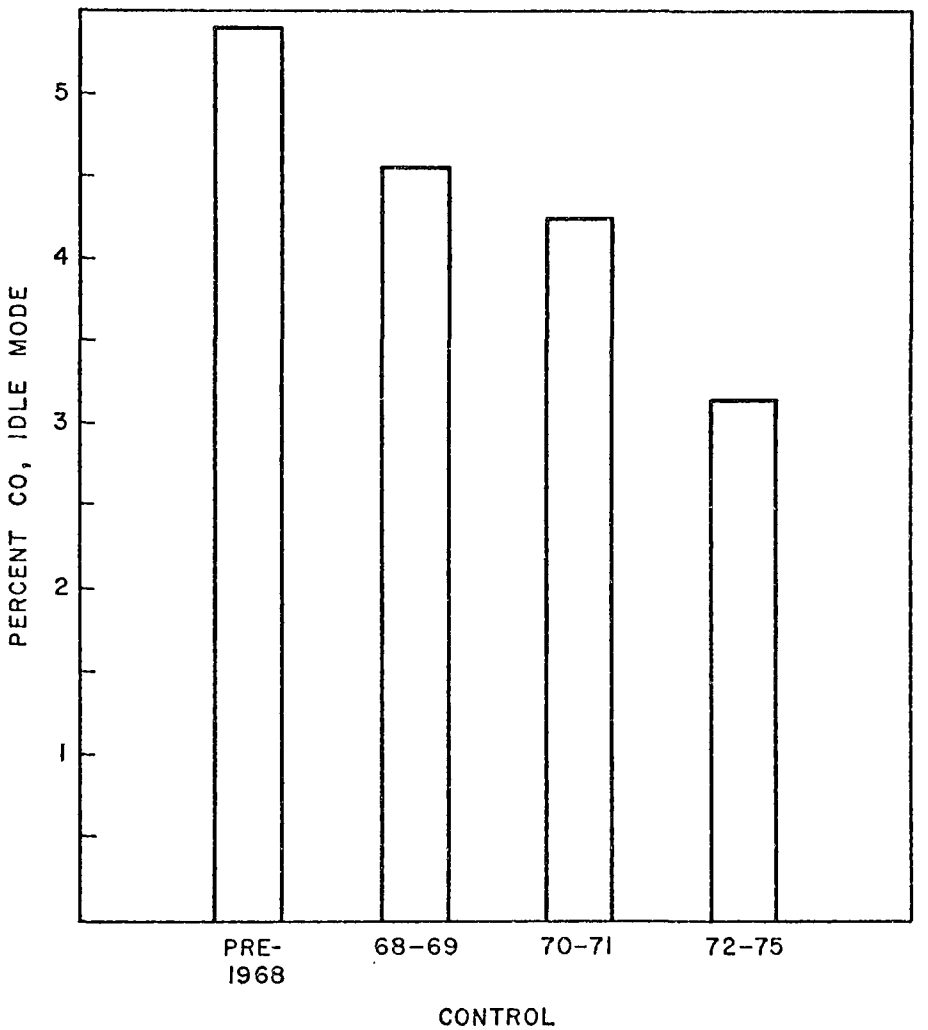

Figure IV-18. Carbon monoxide (idle mode) by control

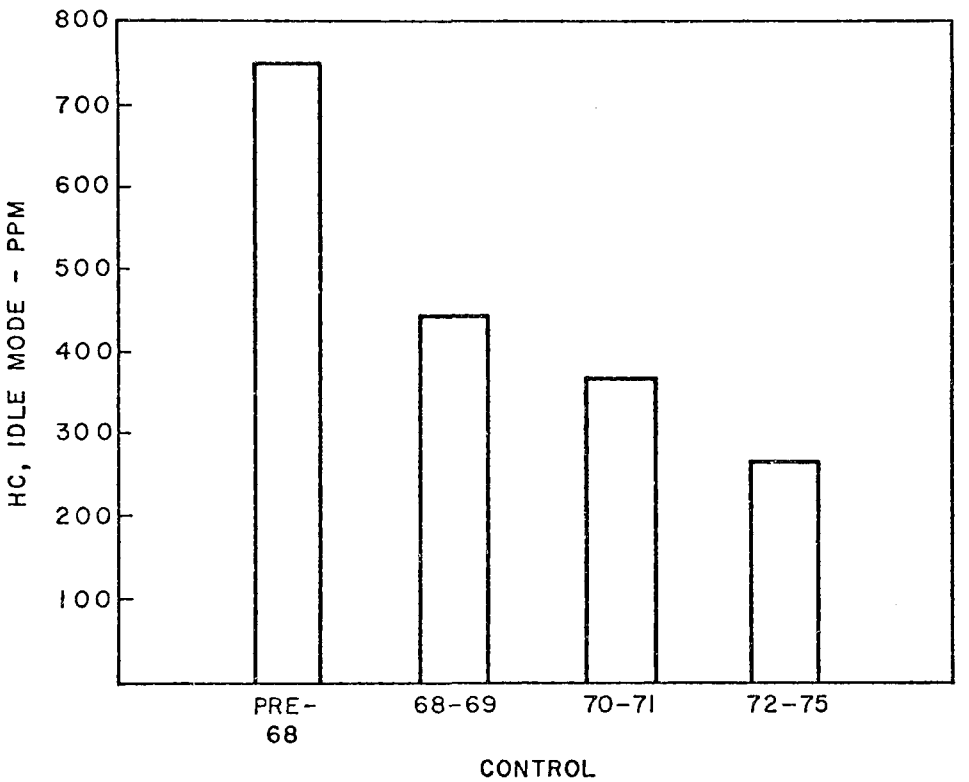

Figure IV-19. Hydrocarbons (idle mode) by control

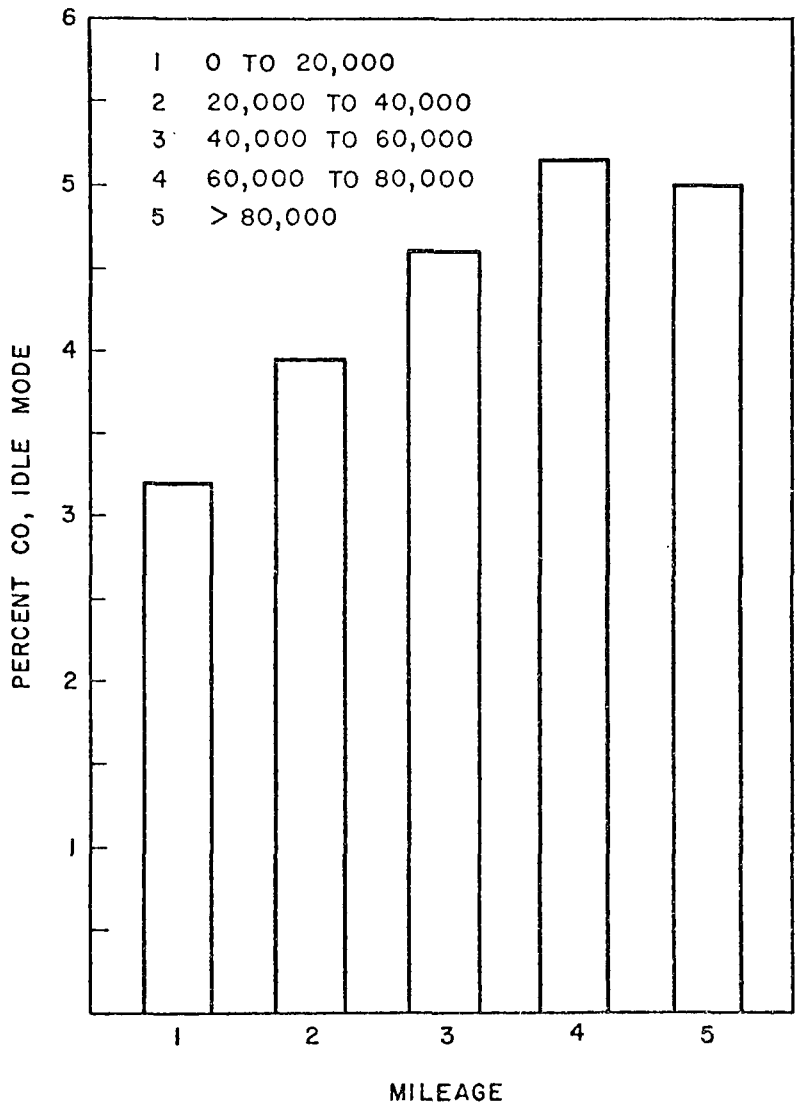

Figure IV-20. Carbon monoxide (idle mode) by mileage

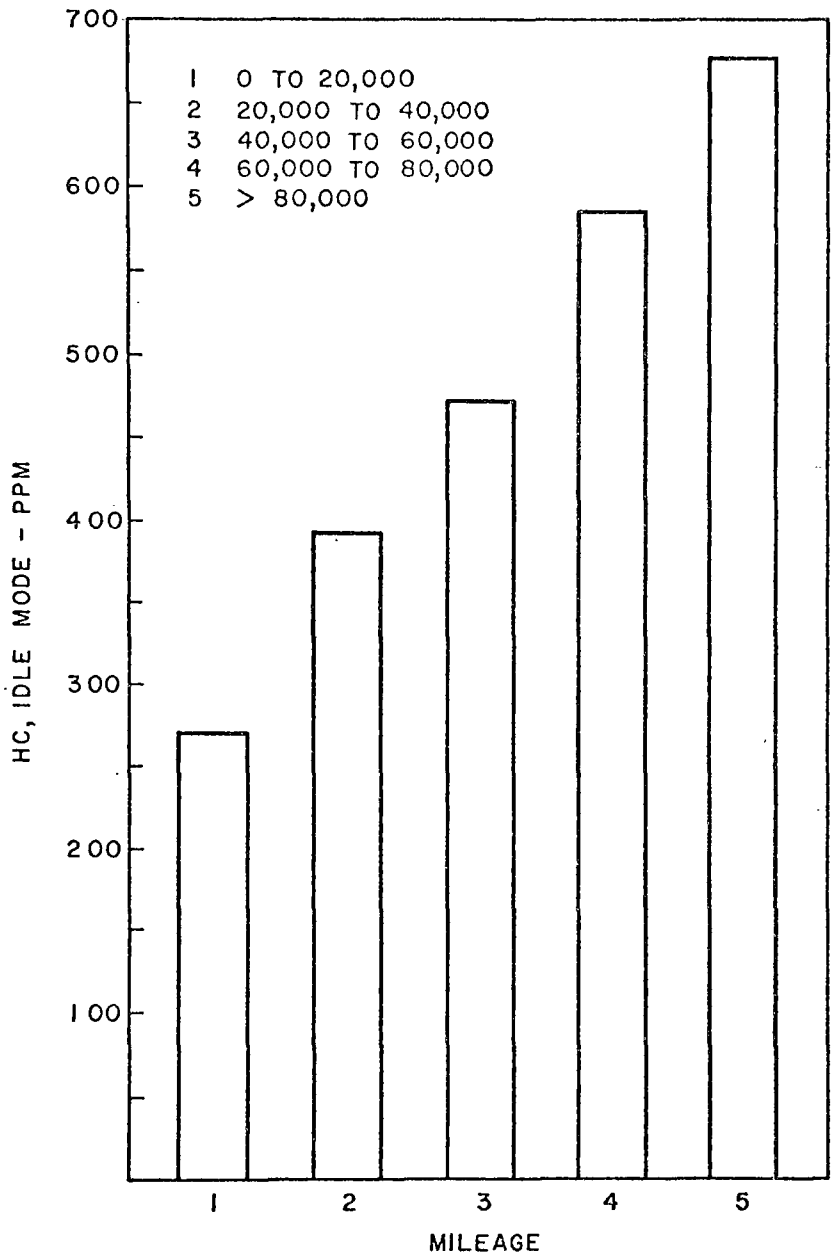

Figure IV-21. Hydrocarbons (idle mode) by mileage

HC3 nor CO3 mean emissions were significantly different between the two dual exhaust groups, indicating that only one side of a dual exhaust need be sampled to determine the emissions of a vehicle. The result t-tests showed that both CO3 and HC3 mean emissions were significantly different between the pass and fail groups, as expected. For only those vehicles coming in for two tests, the retest t-test compared the emissions of the first test with the second test. Both HC3 and CO3 mean emissions were significantly different between these two groups.

Looking at retest again, Figures IV-22 and IV-23 show the mean emissions of the sample, the before retest subsample, and the retest subsample for each mode of hydrocarbons and carbon monoxide. For hydrocarbons at all modes, the mean emissions of the before retest group are higher than for the whole sample. A decrease occurs so that the mean emissions of the retest group are less than the before retest group and on the order of the sample mean. This would be expected if maintenance has occurred between the two tests. For carbon monoxide, except at the first mode, the opposite case occurs - the mean emissions of the retest group are considerably higher than the sample mean and the mean of the before retest group. It is not known how many vehicles of the two test group actually received corrective maintenance between the two tests or how much time elapsed between the two tests. This increase in carbon monoxide mean emissions, unexpected when compared to the decrease in hydrocarbons, could be due to deterioration in low emissions from continued aging rather than reduction from high emissions to low brought about by maintenance, or maintenance could be faulty. The contrast between the carbon monoxide and the hydrocarbons trends makes it difficult to guess what happened between the first and second tests and to draw any conclusions.

Figures IV-24 and IV-25 are similar to Figures IV-22 and IV-23 except that the mean emissions of only those cars in the retest group whose repair cost is greater than zero are compared with the sample mean

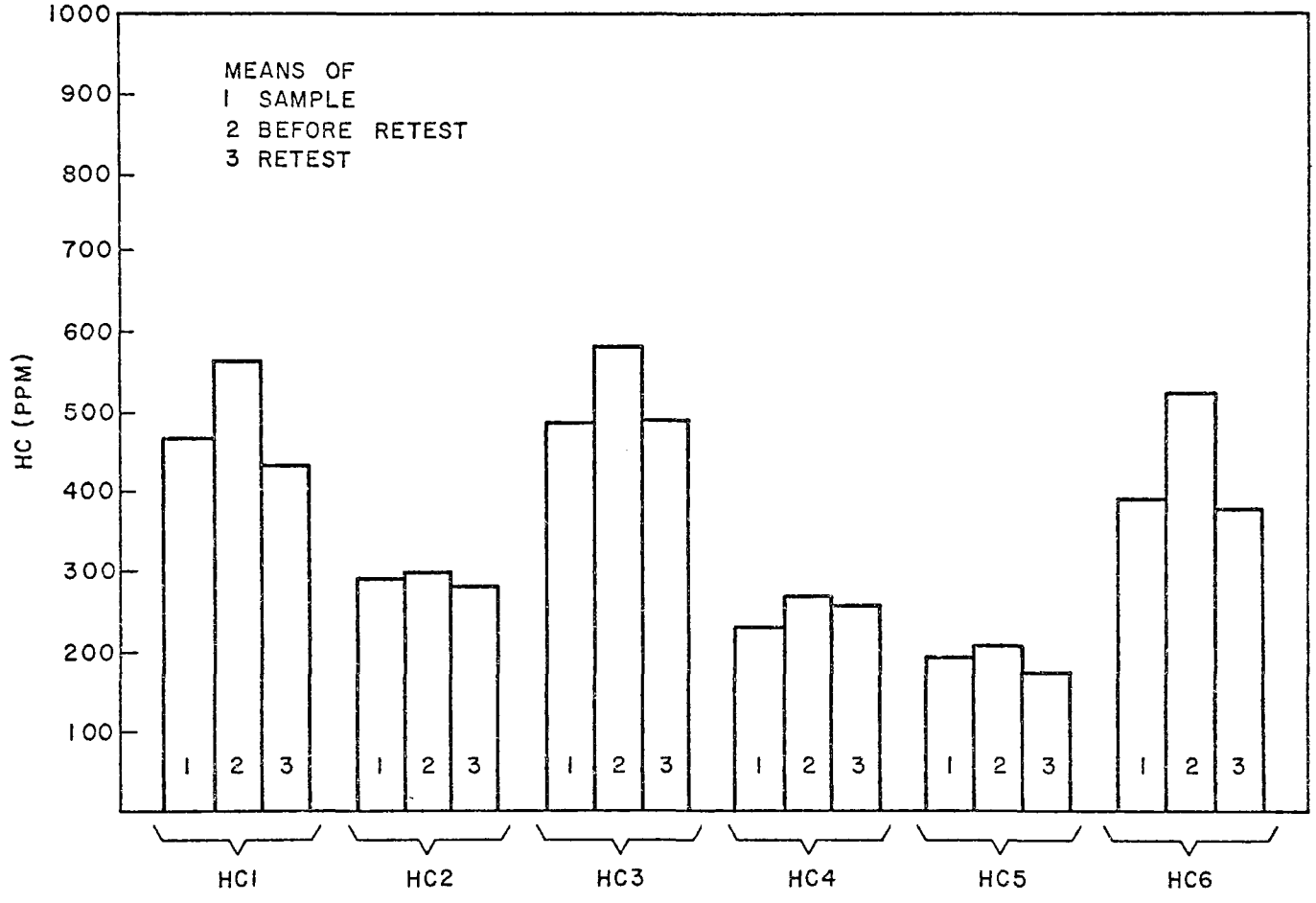

Figure IV-22. Hydrocarbons mean emissions - sample, before retest, retest

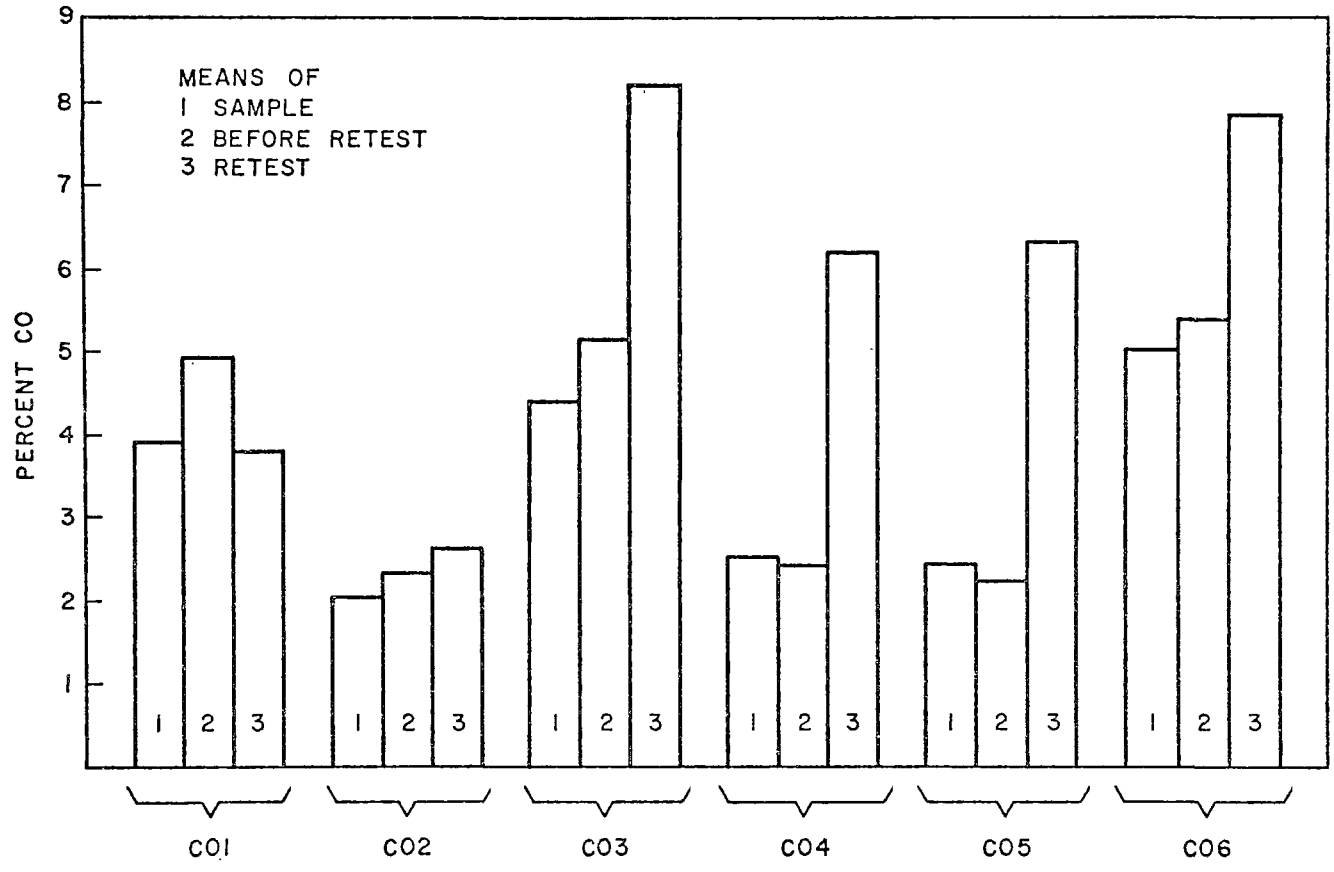

Figure IV-23. Carbon monoxide mean emissions - sample, before retest, retest

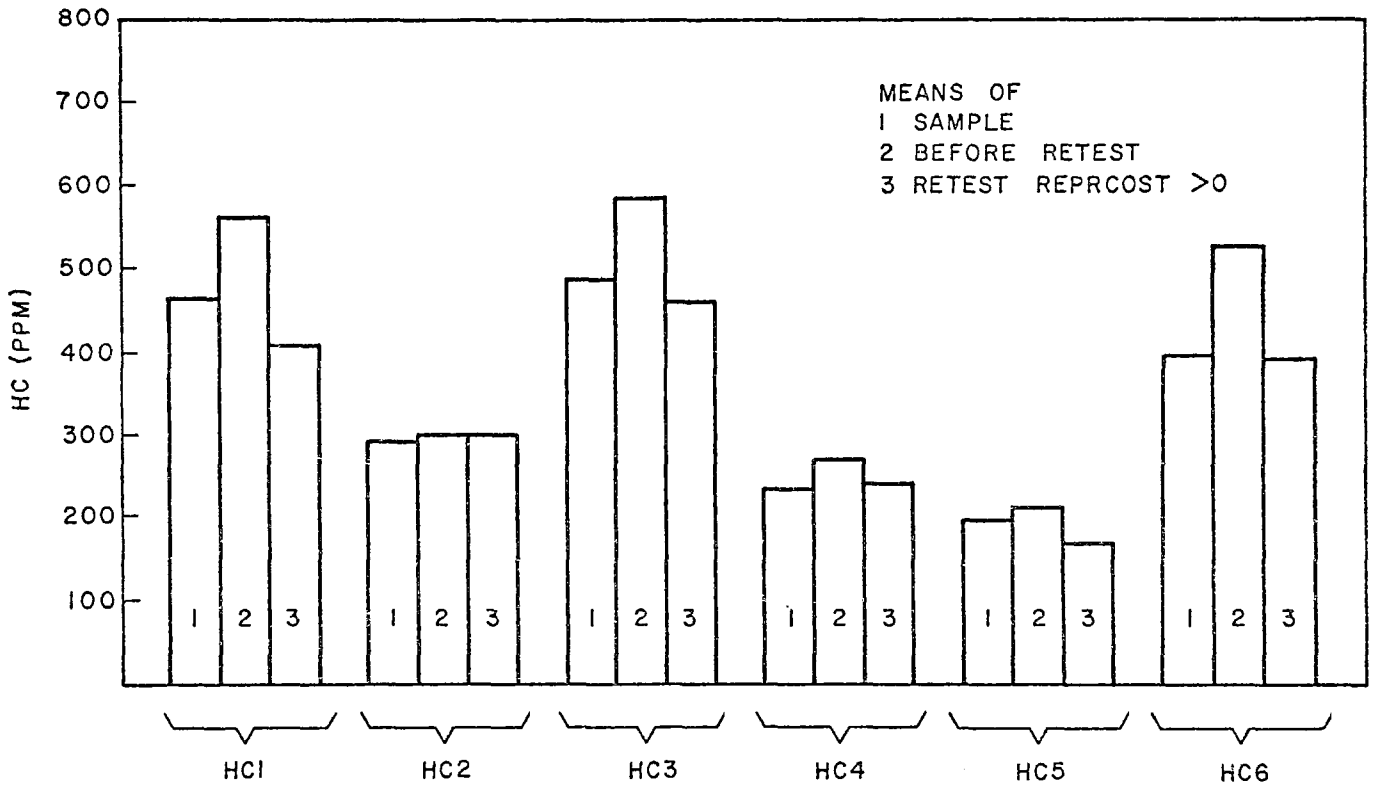

Figure IV-24. Hydrocarbons mean emissions - sample, before retest, retest and repair cost <0

GCA/TECHNOLOGY DIVISION

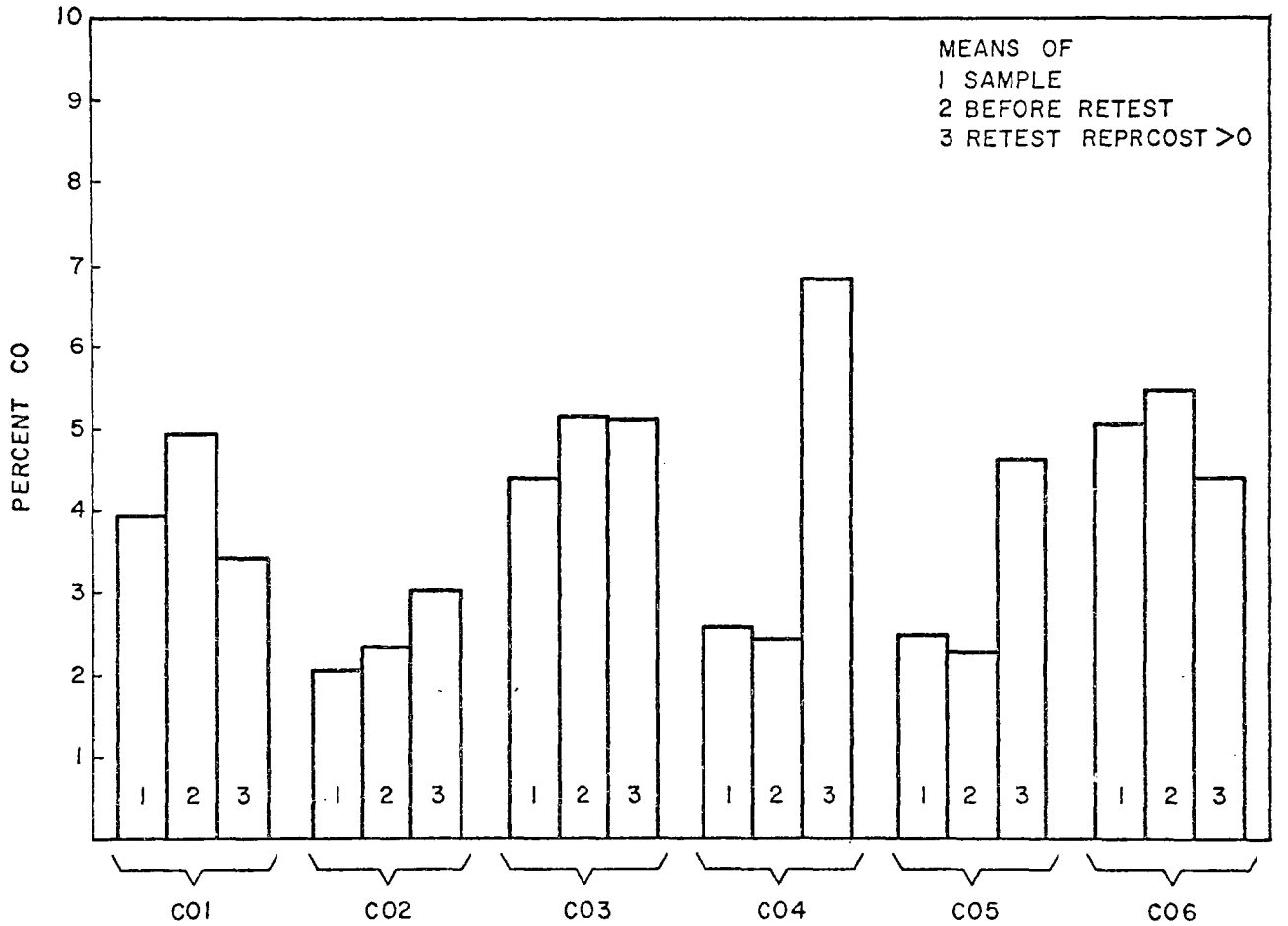

Figure IV-25. Carbon monoxide mean emissions - sample, before retest, retest and repair cost <0

GCA/TECHNOLOGY DIVISION

emissions and the before retest mean emissions. The hydrocarbons mean emissions for this group are comparable to the entire retest group. The carbon monoxide mean emissions, however, are lower. In fact, the pattern noticed in Figure IV-23 of retest mean carbon monoxide emissions being higher than before retest is not as evident among those retest cars with repair cost greater than zero. In Figure IV-25, for the two idle modes, CO3 and CO6, the mean emissions of the retest, repair cost greater than zero group are less than the before retest mean emissions. The three dynamic modes still show mean emissions of the retest, repair-cost greater than zero group to be greater than the before retest mean emissions but for CO5, the difference is less. The changes could be due to the fact that it is more likely that the cars in this subgroup have actually received maintenance.

The cumulative frequency of CO3 for the whole sample is compared with the cumulative frequencies of CO3 of the before retest and retest subsamples in Figure IV-26. The sample curve is the lowest and the before retest curve is the highest, as expected. But the before retest and retest curves cross at the far end, indicating that something is affecting the higher cases. The cumulative frequencies of the sample and the before retest and retest subsamples of HC3 are compared in Figure IV-27. The sample curve is lowest as expected, but the before retest and retest curves are reversed, the retest curve being highest. It appears that HC3 has increased over time.

Figures IV-28 and IV-29 are cumulative frequency curves of CO3 and HC3, respectively, broken down into control groups. The vehicles with no emissions controls (pre-68) are the highest curves. As emissions controls increase (from 68-69 to 70-71 to 72-74), the curves drop but remain parallel. A line has been drawn at the 50 percent cumulative frequency point on both graphs. This can be used to determine emissions levels to be used as fail criteria corresponding to a 50 percent failure rate - see Table IV-18. Similarly, cumulative frequency curves for carbon monoxide and hydrocarbons at the dynamic modes - 2500 rpm, 30 mph, and 50 mph - were drawn (Figures IV-30 through IV-35). But it was found that,

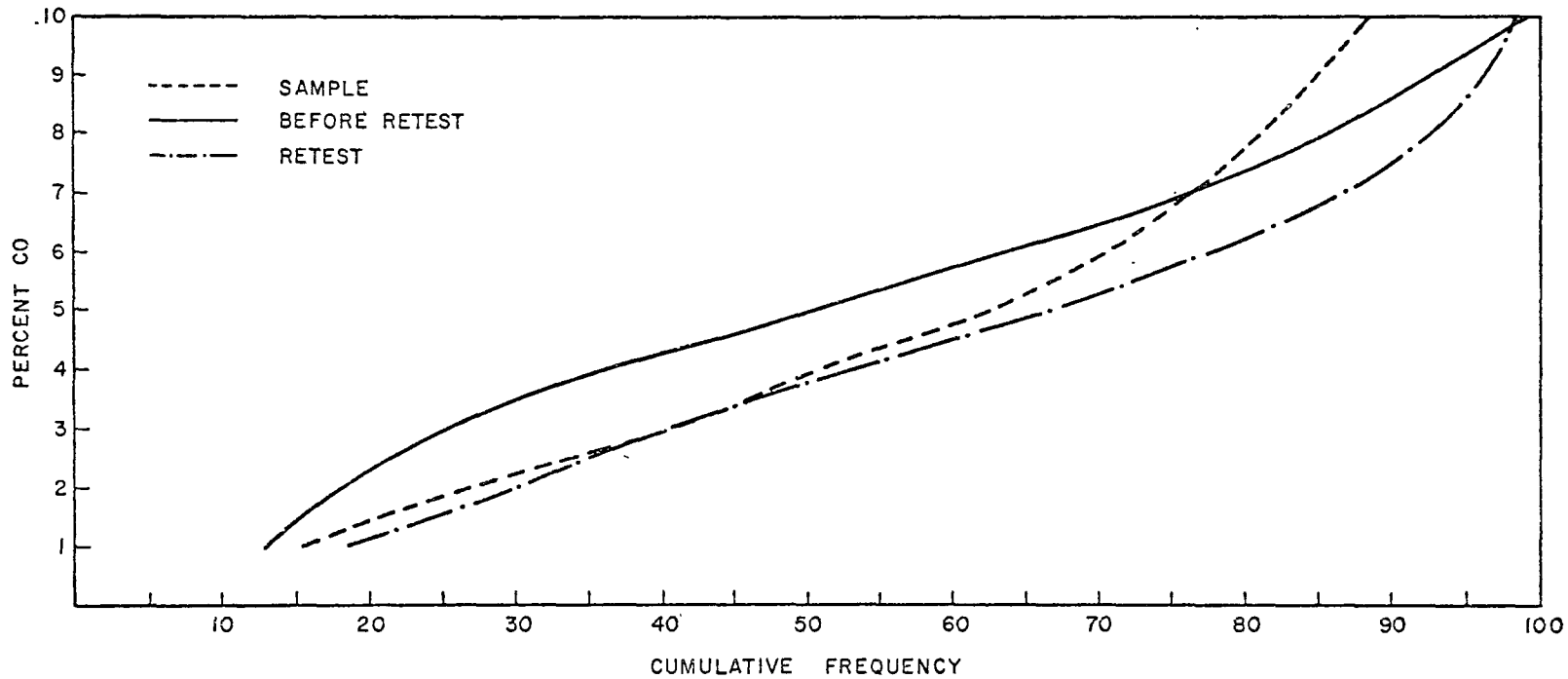

Figure IV-26. Cumulative frequency of carbon monoxide (idle mode) - sample, before retest, retest

GCA/TECHNOLOGY DIVISION GCA

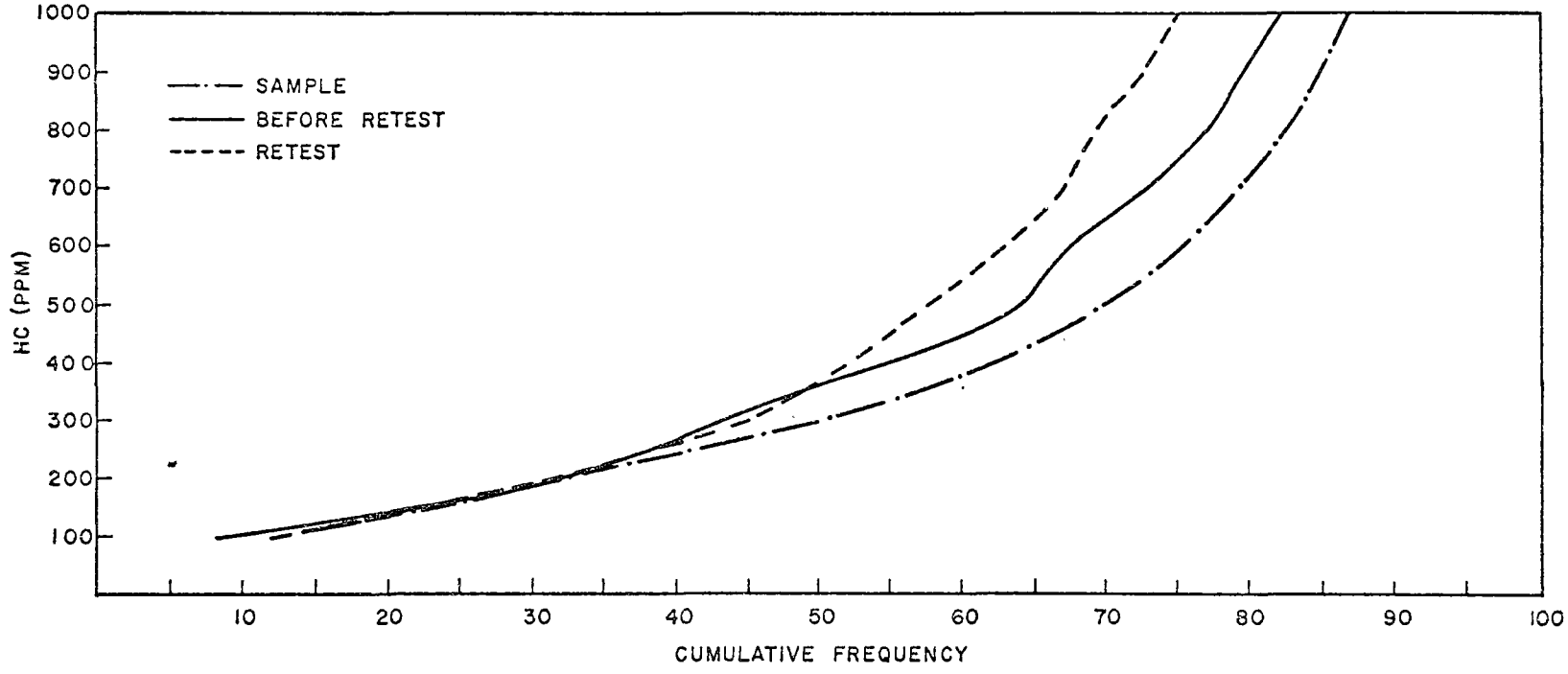

Figure IV-27. Cumulative frequency of hydrocarbons (idle mode) - sample, before retest, retest

GCA/TECHNOLOGY DIVISION

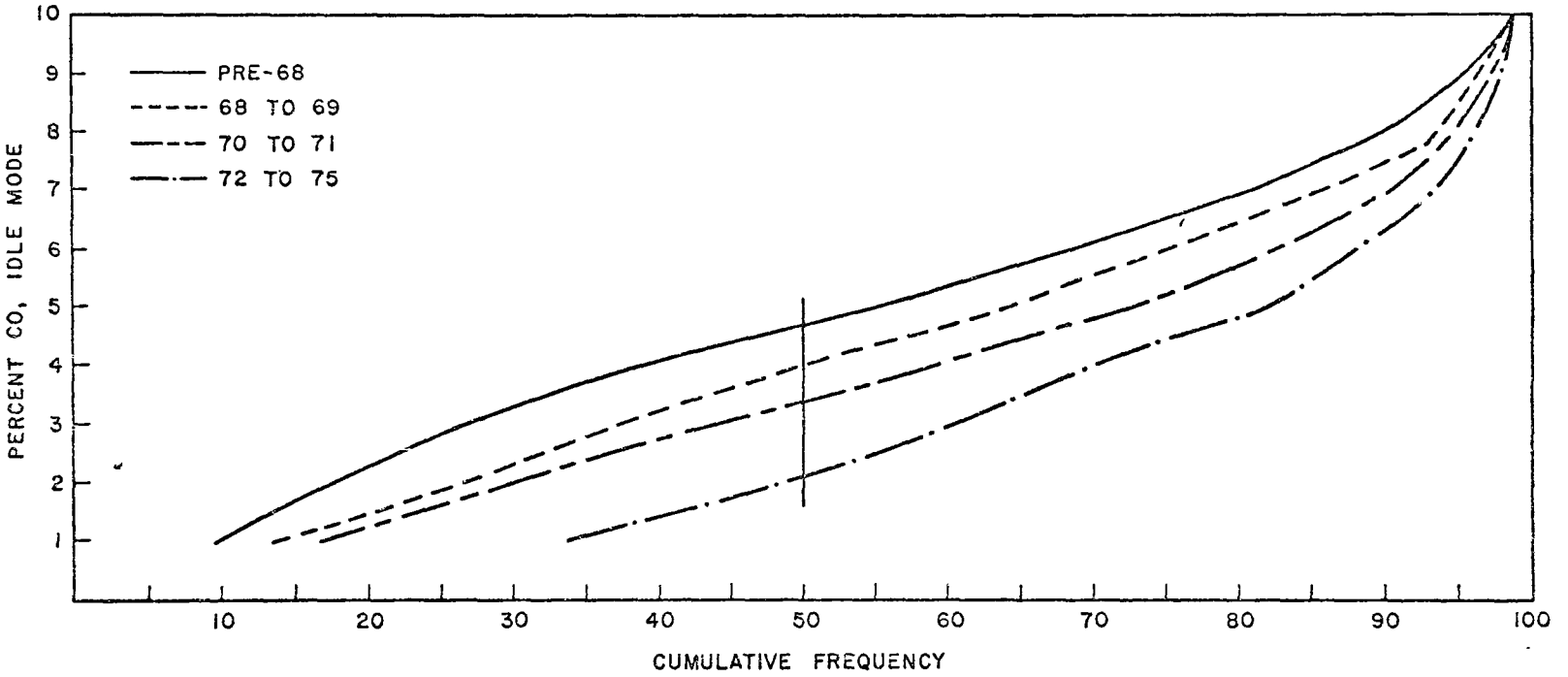

Figure IV-28. Cumulative frequency of carbon monoxide (idle mode) by control

GCA/TECHNOLOGY DIVISION

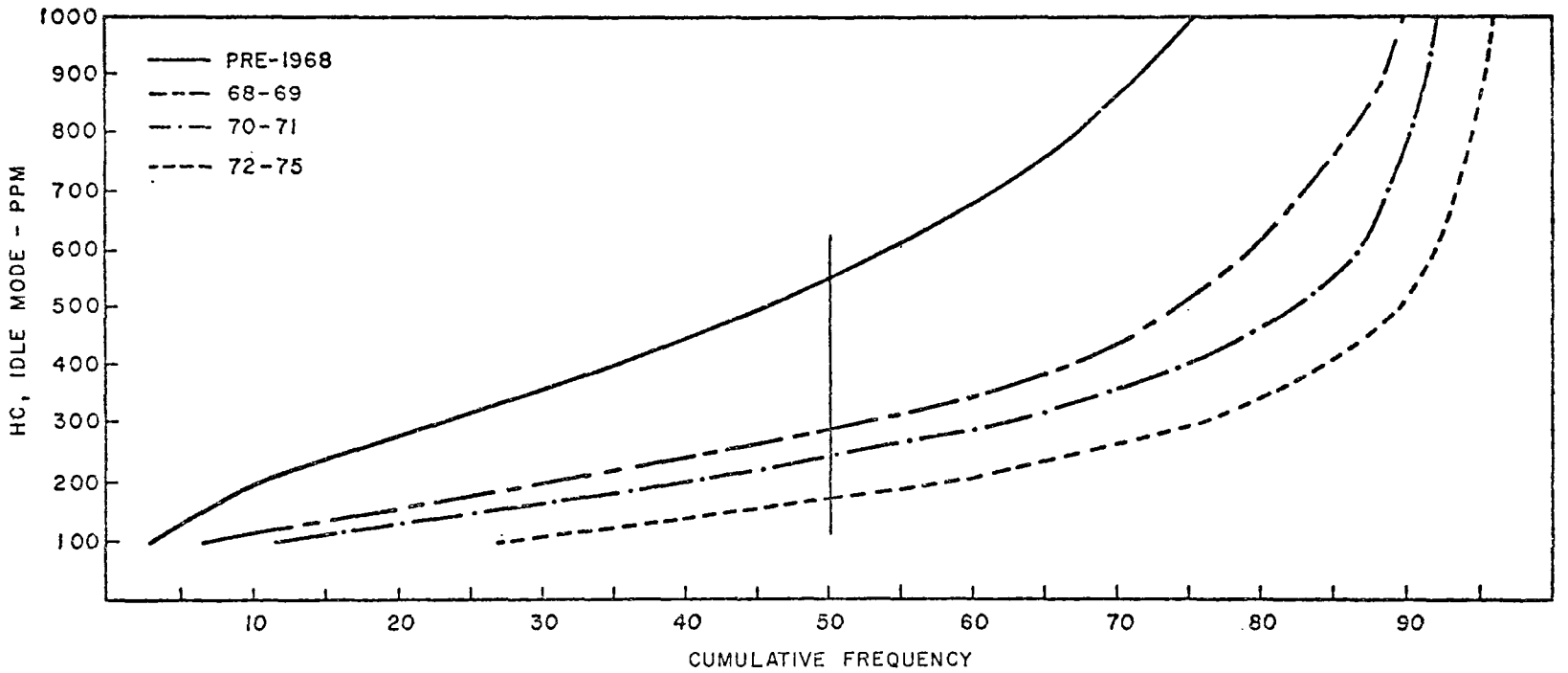

Figure IV-29. Cumulative frequency of hydrocarbons (idle mode) by control

GCA/TECHNOLOGY DIVISION GCA

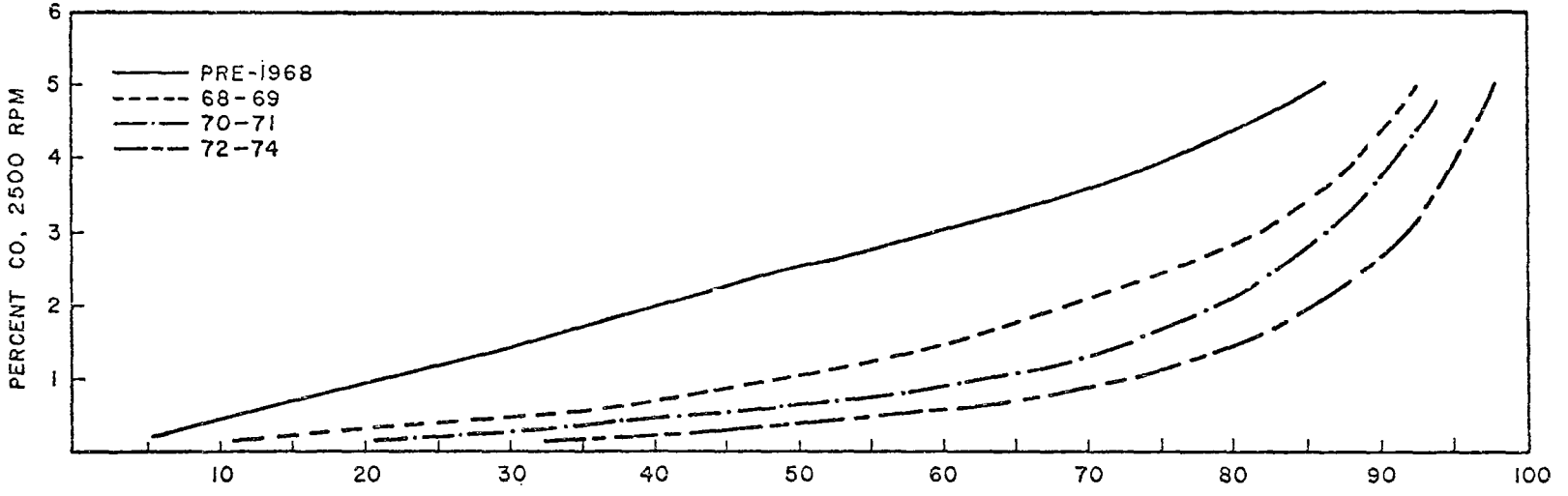

Figure IV-30. Cumulative frequency of carbon monoxide (2500 rpm) by control

GCA/TECHNOLOGY DIVISION

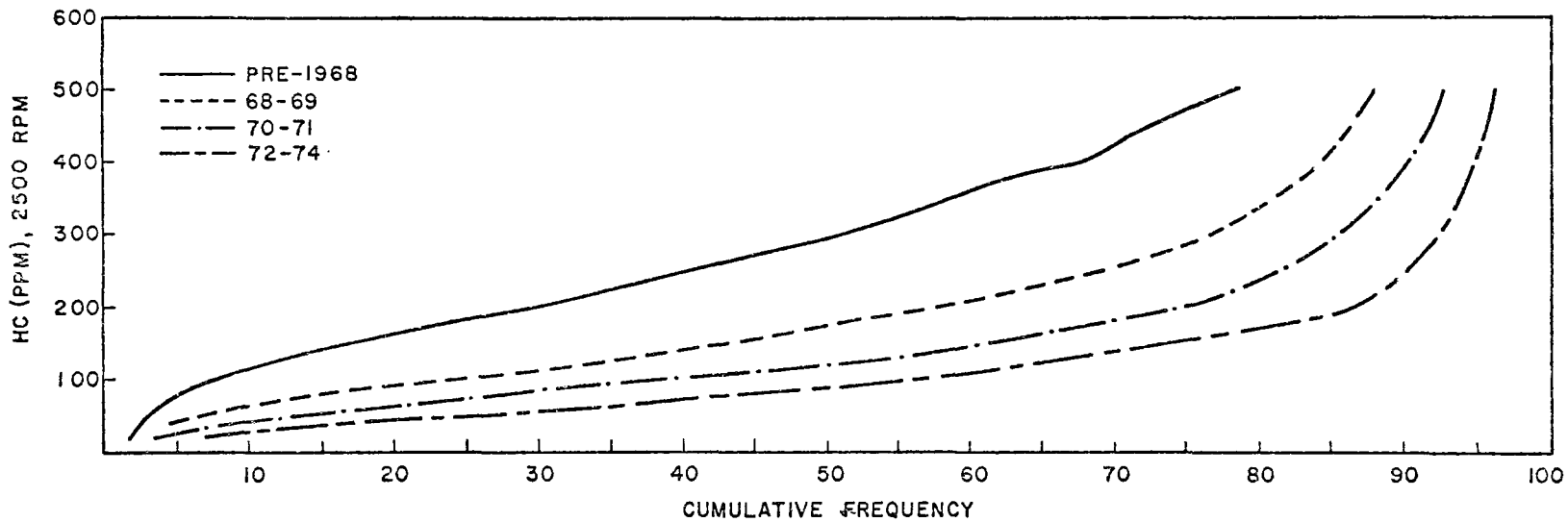

Figure IV-31. Cumulative frequency of hydrocarbons (2500 rpm) by control

GCA/TECHNOLOGY DIVISION

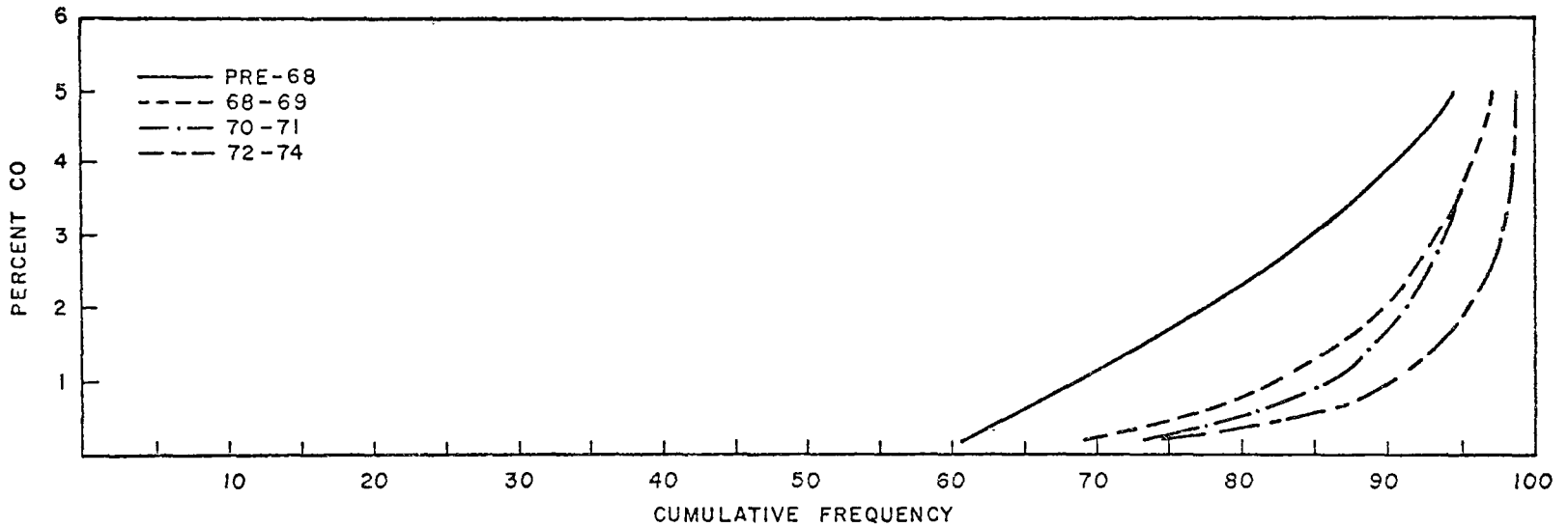

Figure IV-32. Cumulative frequency of carbon monoxide (30 mph) by control

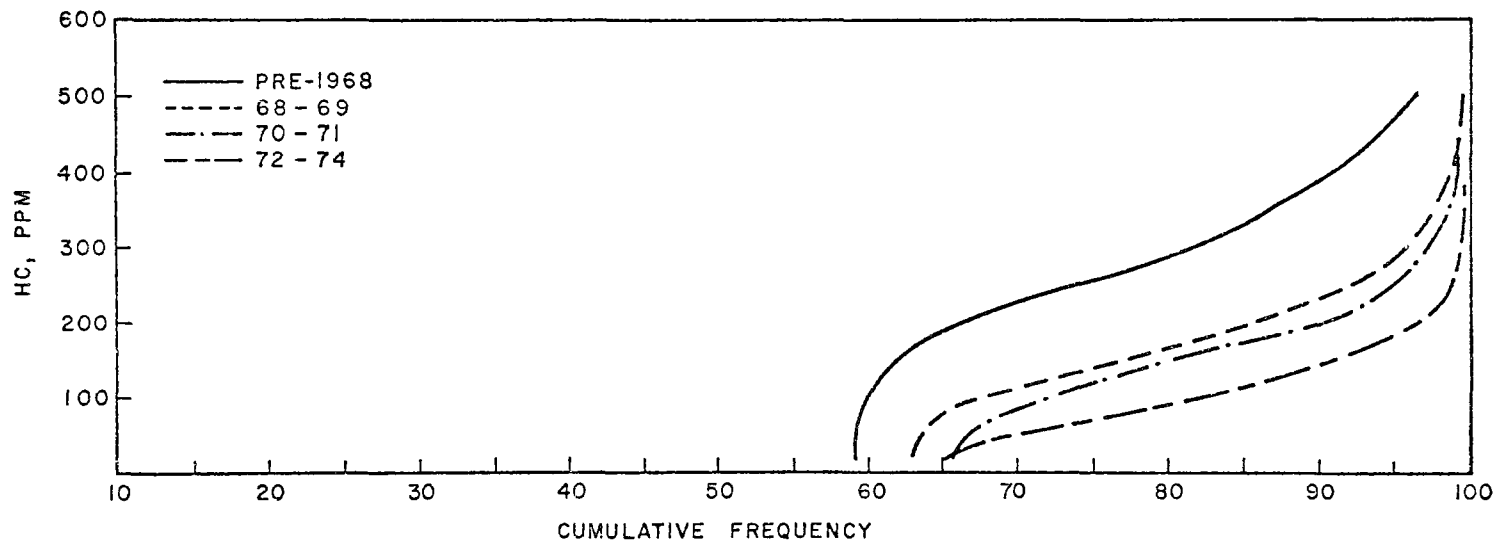

Figure IV-33. Cumulative frequency of hydrocarbons (30 mph) by control

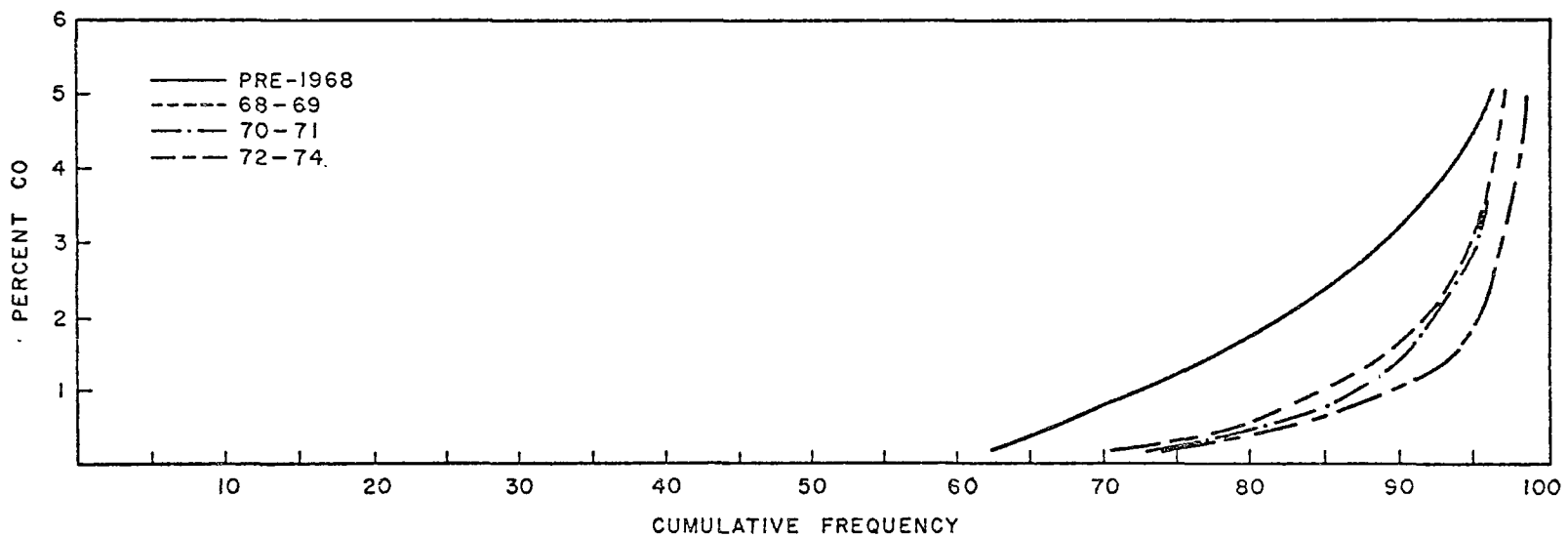

Figure IV-34. Cumulative frequency of carbon monoxide (50 mph) by control

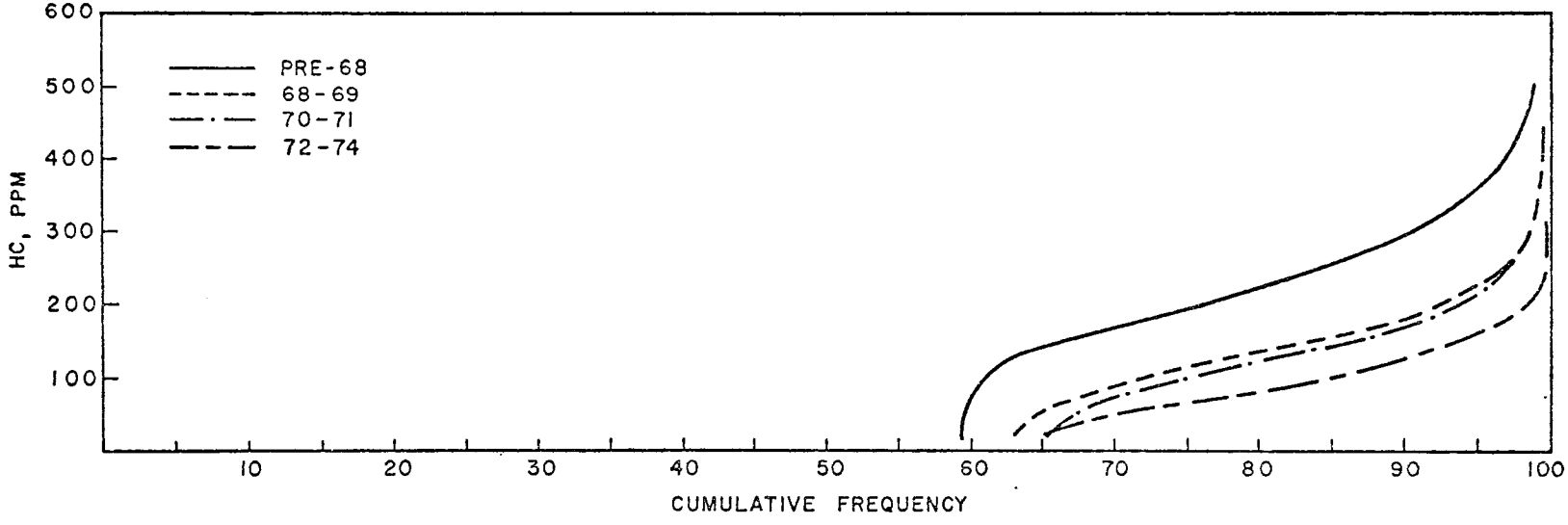

Figure IV-35. Cumulative frequency of hydrocarbons (50 mph) by control

Table IV-18. FAILURE RATE AND FAILURE LEVELS

		Emissions levels for failure rates of		
Pollutant	Control	40 %	50 %	60 %
CO (idle)	pre 68	5.3 %	4.8 %	4.1 %
	68-69	4.8	4.0	3.4
	70-71	4.1	3.5	2.8
	72-74	3.2	2.1	1.4
HC (idle)	pre 68	680 ppm	560 ppm	480 ppm
	68-69	340	290	260
	70-71	290	260	200
	72-74	210	180	180

for emissions at 30 mph and 50 mph, more than half of the vehicles had hydrocarbons emissions less than 20 ppm and more than half had carbon monoxide emissions less than 0.2 percent. The cumulative frequency curves can be used for determining failure levels corresponding to failure rates for the Portland vehicle population. Even though the sample and population differed significantly with respect to control, this variable has been eliminated as an effect by splitting the sample into control groups.

CORRELATION AND REGRESSION

Some of the variables believed to affect emissions were studied using stepwise regression. Eight different dependent variables were chosen for the stepwise regression - HC3 (third mode-second idle), HC4 (fourth mode - 30 mph light load), CO3 (third mode), CO4 (fourth mode), and the log of each of these, LOGHC3, LOGHC4, LOGCO3, and LOGCO4. The independent variables used to predict a dependent variable in a stepwise regression were age, make, mileage, weightclass, and deterioration factors for hydrocarbons (DETERHC) and for carbon monoxide (DETERCO). The deterioration factors, obtained from AP-42, are factors by which the emissions of

a light duty car when new are multiplied to predict emissions after time has elapsed. The deterioration factors depend on the model year and the age of the car.

Table IV-19 shows for each dependent variable the order of the independent variables entered in a stepwise fashion into the regression equation. The parameter r^2, the proportion of the variance in the dependent variable accounted for by the regression equation, is shown in parentheses. For each dependent variable, r^2 increases as new independent variables are entered into the regression equation. An independent variable is entered only if the significance of the resulting regression equation was greater than mere chance. The most important variable in all of the regression equations was AGE, with the deterioration factors and WGTCLASS next in importance. MAKE and MILEAGE were the least important. In general, r^2 values were low, indicating that much of the variance of the dependent variables remained unexplained after the independent variables were entered. But r^2 values were higher for the LOG variables so it appears that the logarithms of emissions values are better predicted by the regression equations.

The correlations between the emissions levels of a pollutant at different modes are shown in Table IV-20 in six correlation matrices - idle mode CO, idle mode HC, dynamic mode CO, dynamic mode HC, idle mode CO by dynamic mode CO, and idle mode HC by dynamic mode HC. In general, correlation is better when the emissions are from like modes - both idle or both dynamic. Correlation of idle and dynamic hydrocarbons is better than for carbon monoxide. More than half of the correlation coefficients are greater than 0.5, more than two thirds are greater than 0.4. Correlation is positive for all pairs, as expected. It appears that, in general, a high reading at one mode indicates high readings at other modes.

Table IV-19. STEPWISE REGRESSION

Dependent variable	Independent variables (r^2)				
	1	2	3	4	5
CO3	AGE (0.098)	DETERCO (0.098)	WGTCLASS (0.098)	MILEAGE (0.099)	
LOGCO3	AGE (0.121)	WGTCLASS (0.123)	DETERCO (0.125)	MILEAGE (0.126)	MAKE (0.126)
CO4	AGE (0.036)	DETERCO (0.039)	MAKE (0.041)	WGTCLASS (0.042)	MILEAGE (0.042)
LOGCO4	AGE (0.214)	DETERCO (0.227)	MAKE (0.232)	WGTCLASS (0.234)	MILEAGE (0.235)
HC3	AGE (0.144)	DETERHC (0.160)	WGTCLASS (0.168)	MAKE (0.169)	MILEAGE (0.169)
LOGHC3	AGE (0.278)	WGTCLASS (0.287)	DETERHC (0.296)	MAKE (0.297)	MILEAGE (0.297)
HC4	AGE (0.168)	DETERHC (0.174)	WGTCLASS (0.176)	MAKE (0.176)	MILEAGE (0.176)
LOGHC4	AGE (0.378)	WGTCLASS (0.388)	MILEAGE (0.389)	MAKE (0.389)	DETERHC (0.389)

Table IV-20. CORRELATION COEFFICIENT MATRICES

Idle mode \ Idle mode	CO3	CO6	Idle mode \ Idle mode	HC3	HC6
CO1	0.403	0.429	HC1	0.935	0.869
CO3	–	0.773	HC3	–	0.895

Dynamic mode \ Dynamic mode	CO4	CO5	Dynamic mode \ Dynamic mode	HC4	HC5
CO2	0.393	0.199	HC2	0.576	0.508
CO4	–	0.706	HC4	–	0.687

Idle mode \ Dynamic mode	CO2	CO4	CO5	Idle mode \ Dynamic mode	HC2	HC4	HC5
CO1	0.375	0.090	0.088	HC1	0.551	0.605	0.546
CO3	0.202	0.498	0.557	HC3	0.577	0.689	0.525
CO6	0.255	0.478	0.506	HC6	0.508	0.632	0.576

The correlations between the emission levels of carbon monoxide and hydrocarbons at the same modes were also determined. Correlation was positive and low - the correlation coefficient r was never greater than 0.5. Thus, a high level of one pollutant does not necessarily indicate a high reading of the other.

TAMPERING DATA

Among the data recorded for each vehicle tested was information concerning the condition of certain under-the-hood and engine parts, that is, whether or not there was tampering. Table IV-21 records the percentages of vehicles for each engine characteristic where there was tampering.

Table IV-21. ENGINE TAMPERING

	Tampering
CARBURETOR	1.9 %
INTAKE MANIFOLD	1.3
EXHAUST	1.3
ADDON	2.2
OTHER	2.4

Table IV-22 shows the percentages of vehicles for each under-the-hood characteristic within the following categories - not present, one present, one present and disconnected, and two present and one disconnected.

RECOMMENDATIONS FOR FUTURE DATA COLLECTION

If data collection is to be continued when the inspection/maintenance program becomes mandatory, certain improvements could be made to increase the usefulness of the data. In order to determine emissions reductions after maintenance and deterioration of emissions reductions

Table IV-22. UNDER HOOD TAMPERING

	Not present	One present	Present and disconnected	One present one disconnected
PCV	10.1 %	88.3 %	1.0 %	0.5 %
AIRPUMP	90.3	8.6	1.0	0.2
EGR	87.2	12.5	0.2	0.1
EVAP	70.6	28.8	0.3	0.3
DISTRIBUTOR	83.2	16.0	0.6	0.2
PREHEAT	42.3	52.3	4.0	1.3
CATALYTIC MUFFLER	98.8	1.1	0.0	0.1

over time, it would be desirable to collect all information on a vehicle into one case, using the license plate number to identify all information on one vehicle and the date to order all the lines of information. Background information could be collected on one card for each vehicle coming in for its first test. A second card would include maintenance information and testing results. Maintenance information might include when and what kind of maintenance was performed, the cost, and whether the maintenance was performed by a service station or by the vehicle owner. The information from each subsequent test - both maintenance information and testing results - could be entered on another card and the cards sorted by license plate number and date. The usefulness of collecting CO_2 emissions data and information on vehicle tampering should be studied to determine if this information should continue to be collected in the future.

There should be specific instructions on filling out the vehicle testing data sheets. All missing values should be filled in with the same code. Where there are several possible responses to a question, they should be clearly defined and coded with numbers. Someone should be made responsible for editing the data sheets before keypunching.

CONCLUSIONS

Comparing the age, make, and control by make distributions of the sample with the population, it was found that the sample was significantly different from the population with respect to all three characteristics. Since emissions also tend to differ significantly between age groups, between make groups, and between control by make groups, the sample mean emissions may not be representative of the population mean emissions. This can be checked by weighting. Population weighting of the sample for age and for control by make increased mean idle hydrocarbons emissions. Weighting for make did not make a difference in idle hydrocarbon mean emissions. Idle carbon monoxide mean emissions were not appreciably affected by weighting for any of the three characteristics.

The sample was also compared with the subsample of vehicles which failed one or more of the tests. The fail subsample differed significantly from the sample with respect to age, make, weight class, and number of cylinders.

When carbon monoxide and hydrocarbons mean emissions are compared between modes, it can be seen that the means are higher for the idle modes and lower for the dynamic modes. The geometric means of each pollutant at each mode are in general considerably less than the corresponding arithmetic means, indicating that a number of outlying readings are tending to increase the arithmetic means. The emissions tests data were shown by measures of standard deviation, kurtosis, and skewness not to be normally distributed. The large sample size decreases the length of the 95 percent confidence interval, reduces sampling error, and increases confidence in the observed data distributions.

Idle carbon monoxide and idle hydrocarbons mean emissions were compared between the groups within age, make, weight class, control, test, cylinder, exhaust, and retest characteristics. Both differed significantly

between age groups, control groups, test groups, and retest groups; idle carbon monoxide mean emissions differed significantly between weight class groups and cylinder groups; idle hydrocarbons mean emissions between make groups. Neither was significantly different between the two dual exhaust groups, indicating that only one side of a dual exhaust need be sampled to determine the emissions of a vehicle.

When hydrocarbons mean emissions at the different modes are compared between the before retest and the retest groups and between the before retest and the retest, repair cost greater than zero groups, the before retest mean emissions are higher at all modes. This would be expected if maintenance had occurred between the two tests. For carbon monoxide, however, the retest group's mean emissions are higher than the before retest group except at the first mode, which would seem to indicate that deterioration in emissions rather than reduction through maintenance had occurred. This may be a result of not being able to identify clearly all cars which had received maintenance between the two tests. That this is possible is indicated by the change in the pattern when comparing carbon monoxide mean emissions between the before retest and the retest, repair cost greater than zero groups - the mean emissions of the three idle modes are less than the corresponding before retest mean emissions, while the mean emissions of the three dynamic modes remain greater than the before retest mean emissions.

Cumulative frequency curves of carbon monoxide and hydrocarbons at idle, 2500 rpm, 30 mph, and 50 mph, broken down into control groups, have been drawn. These curves can be used for the Portland vehicle population, to determine the emissions levels which correspond to different failure rates.

Some of the variables believed to affect emissions were studied by using them in regression equations. Age was the most important variable, with deterioration factors and weight class next in importance. But in general, less than 40 percent of the variance of any dependent variable was explained by entering all of the independent variables.

The correlations between the emissions levels of a pollutant at different modes and between pollutants at the same mode were studied. Correlation was positive for all pairs and higher when the emissions were from like modes. A high reading at one mode appears to indicate high readings at other modes of the same pollutant, but a high reading of one pollutant does not necessarily indicate a high reading of the other pollutant at the same mode.

Of the 6300 tests, only 104 could be identified as possibly occurring after maintenance had been performed - these tests indicated a repair cost greater than zero. Therefore, emissions reductions were not calculated for such a small group.

Data on under hood tampering and engine tampering showed that only a small percentage of the vehicles had been tampered with - in all cases, less than 6 percent and in most cases, less than 2 percent.

APPLICATIONS TO AN INSPECTION/MAINTENANCE PROGRAM

Emissions Testing

Comparing the emissions of the left and right sides of a dual exhaust showed that there was no significant difference between the two sides. It was concluded that, during emissions testing, it would be necessary to test only one side of a dual exhaust to determine the emissions of a vehicle. However, there may be some dual exhaust vehicles where the emissions of one side are considerably higher than the other side. This would result in errors of omission if the high emitting side were not the side tested. It is advisable to determine the rate of errors of omission which would occur if only one side of a dual exhaust were tested. One should decide whether or not the rate of errors of omission is acceptable in view of the savings of time which would result.

In the analysis of the Portland inspection/maintenance program emissions data, emissions levels of the idle modes were higher than for the dynamic modes, so most vehicles which failed, failed due to high emissions in the idle modes. It would appear from this, that tests of idle mode emissions would be sufficient to identify high emitting vehicles. Since the Federal Test Procedure is the standard of measure for defining vehicular emission levels during typical urban driving patterns, an effective inspection test should pass only those vehicles which would pass the FTP.

An analysis of the correlation between the vehicular emission levels measured by the FTP and the emissions measured by several different short test procedures has been performed.[2] In general, the results showed that the best correlation is always achieved for the loaded mode tests which provide a measure of the mass emission rate. (Table IV-23). The idle mode volumetric measurement consistently achieved the lowest degree of correlation with the FTP. The poor correlation between the idle measurements and the FTP should be considered when comparing the idle mode and loaded mode inspections.

One comparison of the effects of an idle mode emission inspection and a dynamic (loaded) mode emission inspection has shown that the tests would be equally effective in a vehicle inspection program.[2] Another study indicated that loaded steady state inspections were more effective than idle inspections in reducing carbon monoxide and hydrocarbons emissions.[3]

Measurements of idle emissions do not provide as much diagnostic information so maintenance may be excessive. Certain kinds of maintenance may be performed which reduce idle mode emissions but which do not effect, or may increase, the true emissions.[2] Therefore, an inspection/maintenance program would probably be most effective if a dynamic mode test procedure were used.

Table IV-23. CORRELATION OF FTP AND SHORT TEST PROCEDURES[2]

Test procedure	Emission measurement	Correlation coefficient HC	CO
Federal short cycle	mass	0.94	0.81
Seven mode cycle	mass	0.91	0.70
Key mode (multiple regression)	mass	0.96	0.81
Steady state modes (multiple regression)	mass	0.06	0.82
Idle mode	mass	0.80	0.62
Seven mode cycle	volumetric	0.57	0.77
Key mode (multiple regression)	volumetric	0.79	0.68
Steady state modes (multiple regression)	volumetric	0.81	0.68
Idle mode	volumetric	0.35	0.50

The Portland inspection/maintenance program measured the concentration of carbon monoxide, hydrocarbons, and carbon dioxide in the exhaust mixture. Another method, Constant Volume Sampling (CVS), provides an integrated measure of the total exhaust flow over the test cycle and the sample which is analyzed provides an integrated measure of the average pollutant concentration during the entire cycle. The mass emission rate as a function of vehicle usage can be directly calculated from this. Table IV-23 shows that the best correlation with the FTP occurs when the mass emission rate, rather than the volumetric concentration, is measured. Therefore, an inspection/maintenance program would probably be more effective if results were measured as mass emission rate.

The cumulative frequency of emissions levels can be used to determine failure levels corresponding to different failure rates. Figures IV-28 and IV-29 and Table IV-18 were determined from the Portland inspection/maintenance program idle emissions data. The curves may be applied to the Portland vehicle population.

Percent reductions in idle emissions may be estimated using the failure levels determined from these cumulative frequency distributions, see Table IV-24. For each control group, the critical level for a 50 percent failure rate and the median emissions level for the failing vehicles are shown; these were determined from Figures IV-28 and IV-29. Calculation of the percent reduction from the median emissions value of the failing vehicles (75 percent on the cumulative frequency curves) assumes that, on the average, the emissions of the failing vehicles will be reduced to at least the critical level. Some vehicles after maintenance will achieve reductions to emissions less than the critical level, but this will probably be balanced by other vehicles which cannot achieve the critical level without excessive cost. The emissions reductions for the failing vehicles in each control group are then adjusted to represent the reductions for all vehicles in that group (for a 50 percent failure rate, multiply by 0.5). The idle emissions reductions for the sample and for the population are determined using the proportions of vehicles in the

Table IV-24. ESTIMATION OF IDLE EMISSIONS REDUCTIONS FOR A 50 PERCENT FAILURE RATE

Pollutant	Control	Critical level for 50% failure rate (idle emissions)	Median level of failing vehicles (idle emissions)	% reduction from fail median to critical level	% reduction for entire sample
CO	pre 68	4.8%	6.5%	26%	13%
	68-69	4.0	5.8	45	22.5
	70-71	3.5	5.0	30	15
	72-74	2.1	4.4	52	26
HC	pre 68	560 ppm	1000 ppm	23%	11.5%
	68-69	290	510	43	21.5
	70-71	260	410	38	19
	72-74	180	290	38	19

	Sample idle emissions reductions	Population weighted idle emissions reductions	40 CFR 51 Appendix N	Portland TCP
CO	17.7%	17.3%	10%	20%
HC	16.8%	15.4%	11%	25%

control groups. The population weighted idle emissions reductions for carbon monoxide and for hydrocarbons are estimated to be 17.3% and 15.4%, respectively. The assumption on which the estimates are based - that, on the average, the emissions of the failing vehicles will be reduced to at least the critical level - should be checked in future data analyses to determine the validity of the estimates. The estimates are intermediate between the emissions reductions presented in 40 CFR 51, Appendix N and those presented in the Portland Transportation Control Plan.[4,5] They suggest that a considerable reduction in the vehicle population's emissions is possible through an inspection/maintenance program.

Data Collection

The recommendations made in Section G would enable emissions reductions and deterioration to be determined.

It is important to know the characteristics of a sample and to compare it with the population. Bias may have been involved in selecting the sample. In that case, weighting of the sample results may be important in forming inferences about the population.

REFERENCES

1. Compilation of Air Pollutant Emission Factors. AP-42. EPA. Office of Air and Water Programs.
2. Control Strategies for In-Use Vehicles. EPA Office of Air and Water Programs. Washington, D.C. (1972).
3. Effectiveness of Short Emission Inspection Tests in Reducing Emissions Through Maintenance. EPA Office of Air and Water Programs, Ann Arbor, Michigan. (1973).
4. 38 Federal Register 15197, June 8, 1973.
5. Portland Transportation Control Plan.