HIGH ALTITUDE VEHICULAR EMISSION CONTROL PROGRAM

VOLUME IV. ANALYSIS OF EXPERIMENTAL RESULTS

FINAL REPORT

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PREPARED FOR:

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DEPARTMENT OF HEALTH
DENVER, COLORADO 80220

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REGION VIII
DENVER, COLORADO 80203

TRW ENVIRONMENTAL SERVICES

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The results and conclusions presented are based on the data developed from the experimental test program (conducted by Automotive Testing Laboratories). The extent to which these data are not representative of the vehicle population in the Denver area, however, could have a significant impact on the resultant conclusions and recommendations.

PREFACE

This report, "High Altitude Vehicular Emission Control Program," consists of seven volumes. Listed in the following are the subtitles given for each volume:

- Volume I - Executive Summary, Final Report, January 1974.
- Volume II - Experimental Characterization of Idle Inspection, Exhaust Control Retrofit and Mandatory Engine Maintenance, Final Report, December 1973.
- Volume III - Impact of Altitude on Vehicular Exhaust Emissions, Final Report, December, 1973.
- Volume IV - Analysis of Experimental Results, Final Report, December 1973.
- Volume V - Development of Techniques, Criteria and Standards to Implement a Vehicle Inspection, Maintenance and Modification Program, Final Report, December 1973.
- Volume VI - The Data Base, Final Report, January 1974.
- Volume VII - Experimental Characterization of Vehicular Emission and Engine Deterioration, Final Report, June 1974.

The first volume summarizes the general objectives, approach and results of the study. The second volume presents a detailed description of the experimental programs conducted to define the data base. Volume III reports the methods and analysis used in developing the basic relationships between mass emissions and altitude. A quantitative analysis of the results from the experimental program is presented in Volume IV. The fifth volume provides an analysis of the techniques and criteria required in establishing a vehicle emission control program for the Denver area. The actual data base developed from the experimental program is given in Volume IV. Lastly, Volume VI reports the results of the six month deterioration program.

The work presented herein is the product of a joint effort by several consulting firms. Automotive Testing Laboratories (ATL) was responsible for the design and implementation of the basic experiments. TRW provided the data management and analysis of the experimental results. Olsen Laboratories evaluated the feasibility of conducting an emission control program for the Denver area.

ACKNOWLEDGEMENTS

TRW would like to acknowledge the efforts extended by the Colorado State Department of Health and Region VIII of the Environmental Protection Agency.

The contribution of Messrs. Don Sorrels and Frank Taylor and Ms. Lindsay Tipton of the Colorado State Department of Health were of particular significance.

Mr. Dale M. Wells of Region VIII served as Project Officer.

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1.0 SUMMARY AND CONCLUSIONS

This document provides a quantitative assessment of the results of the High Altitude Emission Test Program. The primary objectives of this program were twofold. First, to determine the impact of a series of experimental procedures on vehicular exhaust emissions, and second, to identify those specific procedures that could prove cost effective in reducing vehicular emissions for the Denver area. The basic experiments performed during the course of the test program are listed below:

- Idle Inspection and Maintenance
- Mandatory Engine Maintenance
- High Altitude Engine Adjustment
- Sea Level Retrofit
- High Altitude Retrofit
- Engine Deterioration

Embodied within this list are a large number of subexperiments which were conducted as part of the overall research design. The analysis presented herein focuses attention on those emission reduction procedures that tend to be most cost-effective. The resultant control measures are then evaluated in light of the proposed Colorado Transportation Control Plan.

The significant conclusions and recommendations that have emerged from the study are given in the following:

<u>Idle Inspection and Maintenance</u>

- The vehicle survey showed that idle CO, timing, air cleaner and ignition misfire are most in need of repair. The inspection and repair of these engine parameters should be included as part of the inspection/maintenance program.

- An annual idle inspection and maintenance program, consisting of the measurement of idle HC and idle CO followed, as necessary, by corrective maintenance, appears marginally attractive as a control measure (6.6% reduction for HC, 4.6% reduction for CO and 0% for NO_x). These estimates include the effects of engine deterioration per the EPA schedule. On a semi-annual basis the estimated emission reduction effectiveness is 9.9% for HC, 6.9% for CO and 0% for NO_x.

- An annual program of inspection and maintenance appears to be most cost effective. The final determination on the frequency of inspection should be based on the results from the deterioration program.

- The costs associated with the idle program ($4.05 for the inspection and $10.35 for maintenance) are well within an acceptable range as revealed by a recent survey of the motoring public.

- The two areas of greatest uncertainty in the program involve the accuracy of the inspection process and the effectiveness of engine repair. An increase in service organization effectiveness could lead to significant improvements in emission reductions.

- Results from the experimental program indicate that a state owned and operated inspection system may be more effective than the corresponding licensed garage approach.

- A minimum inspection program could form the basis for insuring the operatability of advanced emission control systems on post 1975 vehicles.

- An independent emissions surveillance system should be developed as part of the inspection program. This system would provide a feedback mechanism for measuring the actual performance of the inspection and maintenance program. The sample selected for this program should be representative of the inuse vehicle population.

Mandatory Engine Maintenance

- A mandatory engine maintenance program does not appear very cost-effective particularly in view of the high cost of engine tune-ups (average cost of $49.10) and the relatively low emission reduction performance (9.6% for HC, 4.9% for CO, and 3.5% for NO_x).

High Altitude Engine Adjustments

- The adjustment of idle CO and timing were found to have the largest influence on CO emission levels. (Statistically significant at the 99% confidence level).

- The adjustment of vacuum choke kick was found to have a modest impact on CO emissions (statistically significant at 90% confidence). The adjustment of rpm had little effect on CO emissions (less than a 50% level of confidence).

- None of the four adjustment parameters were found to have a significant impact on either HC or NO_x emissions (less than a 60% level of confidence in all cases).

- A program designed to adjust idle CO and timing for all older vehicles in the population could yield significant emission reductions at reasonable costs.

Sea Level Retrofit

- A combination of air bleed (AIR) and exhaust gas recirculation (EGR) retrofit systems for pre-control vehicles yielded the greastest balanced emission reductions for HC and CO (22% and 21%, respectively). Similarly, a combination of vacuum spark advance disconnect and air bleed produced the greatest NO_x emission reductions (47%).

- An AIR/EGR system for pre-controlled vehicles would yield a population weighted reduction of 3.3% for HC and 6.1% for CO by 1977.

- The average installation cost for the AIR/EGR system was approximately $37.00. It was found to have a negilible effect on gasoline mileage.

- An oxidizing catalytic retrofit system for controlled vehicles provided the largest emission reductions for HC and CO (72% and 84%, respectively). The AIR/EGR system yielded average emission reductions of 17% for HC and 48% for CO. The impact of these systems on gasoline mileage was insignificant.

- The high costs associated with the catalytic system tends to preclude its application for the general vehicle population. Consideration should be given, however, to a catalytic retrofit program for fleet vehicles.

- The AIR/EGR system appears more cost effective and should be considered as a benchmark for comparing other retrofit systems for controlled vehicles. Additional experimental testing of the AIR/EGR is necessary, however, because of the very small sample sizes used in the present test plan (the average number of vehicles tested was five (5)).

High Altitude Retrofit

- The results from the high altitude retrofit experiments revealed no statistically significant emission reductions for either HC or CO. The one exception involved a subset of cars belonging to the Chrysler family (Dodges). In this one case the emission reductions for HC and CO (26% and 54%, respectively) were statistically significant.

- The installation of these systems had an adverse effect of NO_x emissions, ranging from an increase of 16% for Fords to an increase of 84% for Chryslers.

- A high altitude retrofit program does not appear as a viable alternative because of the lower emission reduction potential for HC and CO and relative high costs of installation.

Engine Deterioration

- Engine deterioration could have a significant impact on the overall performance of each of the control strategies studied (especially the idle inspection program). The results from the ongoing deterioration program should be considered before finalizing the vehicular emission control plan for Denver.

Transportation Control Plan

- The estimates used in the Colorado Transportation Control Plan appear somewhat more optimistic than those developed from the experimental test program (particularly for the high altitude retrofit program).

- The application of the experimental data to the existing Transportation Control Plan indicates a 10% to 20% reduction in effectiveness for HC and CO control, respectively.

- It appears, based on these findings, that additional transportation controls may be necessary to meet the minimum air quality standards. Additional emission reductions for the vehicle population could be achieved from one or more of the alternatives outlined above.

- The use of an AIR/EGR system instead of the high altitude kit for 1968-1974 controlled vehicles could help achieve the reductions required to meet the national standards in the Denver AQCR.

- It is recommended that the existing Colorado Transportation Control Plan be reviewed and updated in light of the evidence gained from the experimental test program.

2.0 INTRODUCTION

This report presents a detailed analysis on the results from the experimental test program. The primary objective of this program was to characterize the effectiveness and costs of several vehicular emission control alternatives. The data and information derived from these experiments is intended to help shape the final form of the Colorado Transportation Control Plan. Particular program objectives were the following:

- Develop an emissions inventory baseline for vehicles operating within the Denver AQCR
- Identify the most promising control alternatives for additional testing and evaluation
- Evaluate the impact of the measured results on the proposed transportation control plan.

The original transportation control plan, submitted by the State to the EPA on May 1973, called for a three phase approach for controlling emissions from light-duty vehicles. The data used in estimating the effectiveness of the proposed plan was based on extrapolated performance estimates developed at sea level. Recent evidence has indicated that vehicles operating at high altitude (above 4000 feet) have substantially different emission characteristics than vehicles operating at lower altitudes. The EPA has acknowledged this fact and has proposed rules for developing certification procedures of new vehicles intended for initial sale at high altitude.* This emphasis on the impact of altitude on vehicular emissions has helped identify the need for a

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* Federal Register, Vol. 38, No. 197 (October 12, 1973).

high altitude vehicular emissions data base.

The specific experiments performed as part of the current program were designed to accomplish the following:

Engine and Emission States Survey

A survey was performed to ascertain the extent and frequency of engine malfunctions and maladjustments occurring in the vehicle population. The survey also included the measurement of key mode and CVS emission levels. This data served as a baseline for contrasting the effectiveness of the various control alternatives, e.g. sea level retrofit. The survey consisted of 300 vehicles which are representative of the vehicle population distribution within the AQCR. Results from the survey helped identify those particular engine parameters that are cost-effective to repair.

Idle Inspection and Maintenance Program

This experimental program was designed to evaluate the costs and effectiveness of a service garage administered idle inspection and maintenance program. The program consisted of inspecting the emission levels (HC and CO) at idle and performing specific engine adjustments (air fuel, rpm, timing) on those vehicles failing the inspection. Additional engine repair was undertaken, as necessary, to achieve the pre-established emission criterion. Again, a fleet of 300 vehicles was used in measuring the effectiveness of this program. Cost data were recorded on the various phases of the inspection and maintenance process.

Mandatory Engine Maintenance Program

A program of mandatory engine maintenance involves the periodic repair or replacement of specific emission oriented engine components, e.g. air cleaner. Such an approach avoids many of the problems associated with inspection by concentrating exclusively on effective engine repair. A mandatory program was simulated experimentally by tuning up approximately 150 vehicles. Mass emission measurements were performed both prior and after maintenance. The costs associated with mandatory repair were also collected and have been included in the analysis.

Idle Engine Adjustment Program

An experimentally designed program was undertaken to determine the influence of selected engine adjustments on exhaust emissions. Four specific engine adjustments were evaluated -- air/fuel ratio, rpm, basic timing and vacuum choke kick. These four adjustments were identified as being inexpensive and easy to modify. The experiments were performed using 25 cars which were chosen to represent the vehicle population.

Sea Level and High Altitude Retrofit Program

A series of tests were undertaken to measure the relative effectiveness of a number of leading retrofit systems. The systems were partitioned in three categories: 1) sea level systems for pre-1968 vehicles, 2) sea level systems for 1968-1974 vehicles, and 3) high altitude kits for 1968-1974 vehicles. Specific devices tested included air bleed, exhaust gas recirculation, vacuum spark advance disconnect, catalytic converter and various combinations of the above. Additionally, the four major automobile manufacturers provided high altitude kits. The sample size for these experiments range from 3 to 48. Cost data for each system was also collected and evaluated.

The data developed from each of these experiments was processed using TRW's Data Management System. The process results have been merged into a single internally consistent data base. An analysis of these results indicates that the assumed performance values used in the proposed Transportation Control Plan are optimistic and; therefore, additional vehicular control may be necessary. These results underscore the impact of altitude on vehicular emissions.

The preceeding section (Section 1.0) has provided a summary of the conclusions and recommendations synthesized from the study. This section (Section 2.0) focuses on the background of the test program and presents a summary of the basic experimental programs. Section 3.0 discusses the methods of analysis used in the evaluation including an overview on TRW's Data Management System and statistical regression methodologies. Section 4.0 summarizes the results from the vehicle engine and emission survey. These results include frequency histogram plots of the major variables that were measured. A detailed analysis of the idle inspection program is provided in Section 5.0. This analysis examines the implications of inspection accuracy and maintenance effectiveness on the viability of this control approach.

Section 6.0 presents an evaluation of the cost effectiveness of mandatory engine maintenance. In Section 7.0, the effects of idle engine adjustments on exhaust emissions are studied and a set of response influence coefficients are developed. Section 8.0 discusses the effectiveness of both sea level and high altitude retrofit systems as a means for reducing exhaust emissions from the inuse vehicle fleet. Finally, in Section 9.0 the impact of the experimental test results are evaluated with respect to the proposed transportation control plan. Specific analyses are presented on the actual effectiveness of retrofitting the pre-controlled segment of the vehicle population.

3.0 METHODS OF ANALYSIS

The principal reason for utilizing computer technology in this effort was the need to process very large amounts of data and to perform complex operations on this data.

With the use of computerized processing methods the data generated by the numerous testing activities of this program could be accessed and sorted, and concise and illuminating results prepared rapidly and accurately.

Presented in this section are the data management and statistical analysis techniques used in handling and developing trends from the data base.

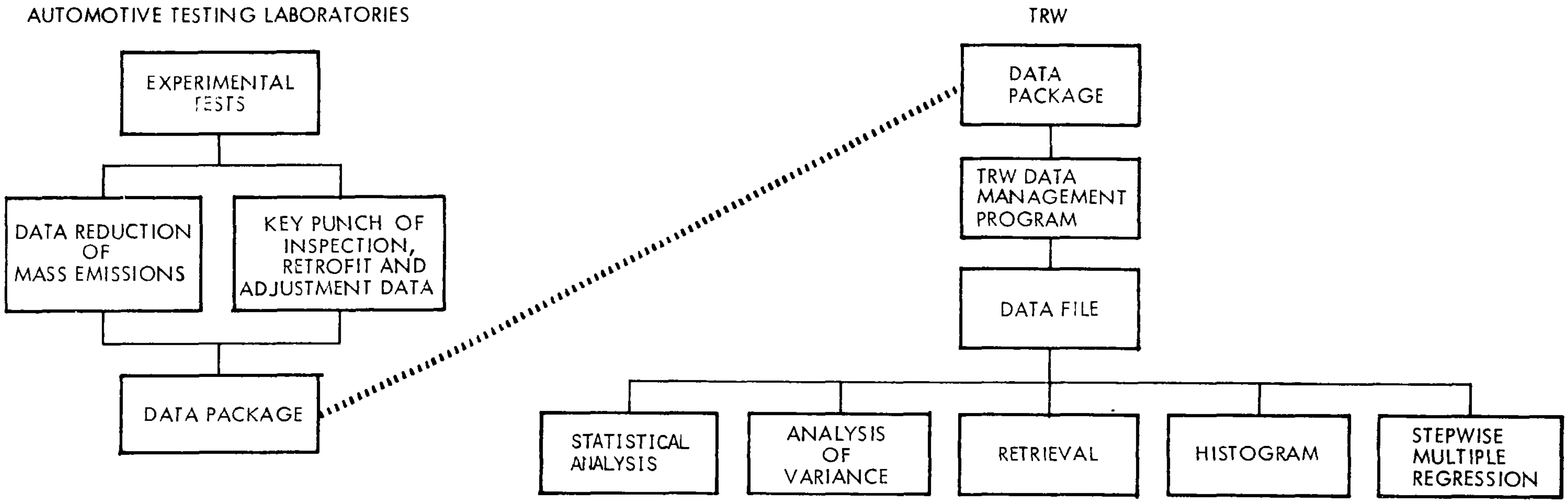
3.1 DATA MANAGEMENT

The nature and extent of the experimental test program required the application of a total data management system. This section presents a detailed description of the system utilized in support of the program. The data management system, developed as part of the Coordinating Research Council CAPE-13 Project, provides comprehensive capability for evaluating multidimensional emission test programs.

Figure 3-1 presents a schematic overview of the TRW Data Management System as related to the current emission test program. This schematic shows the division of work between TRW and ATL with respect to the development and analysis of the basic data. ATL was responsible for reducing the CVS mass emission data and preparing the raw data files for the inspection, maintenance, and retrofit and adjustment experiments. TRW performed the following basic data management activities:

Table 3-1

Data Management Approach



- edit test data
- store test data
- retrieve test data
- compute basic statistics
- sort test data
- develop graphic presentations
- statistical analysis

These activities are also depicted in Figure 3-1. A brief description of of each of these data management functions is presented in the subsequent paragraphs.

Data Editing

A multi-purpose editing program (EDIT) was utilized to reduce potential transportation and procedural errors between the test site (Denver) and TRW's computing facilities (Space Park). Data listings obtained from from the raw keypunch cards were analyzed and corrected using the remote TRW timeshare system. This procedures allows review by both the testing engineers and data management specialists. The program EDIT was utilized not only in examining specific data point entries , but also in updating parameter values on the file record. This latter capability was important as refinements to the raw data were implemented.

Data Storage

The total data has been stored on a permanent magnetic tape. This approach serves two purposes: 1) provide a back-up for all of the data developed during the experimental testing, and 2) permit a more cost effective method of handling the data during the collection and editing phase. A copy of the magnetic tape will be made available to the State of Colorado and the EPA upon request. A working file will also be maintained on the CDC 6500 disk pack for future analysis.

Graphic Presentation

A major part of the data analysis activity is to summarize information in the form of histograms. Two programs are used to perform the retrieval and plotting functions. CETP is used to retrieve data records for the requested plots, sort the data and write a data input file for the plotting routine. HISTM provides histogram frequency plots of the data. The plots are drawn by a Cal Comp plotter from a tape written by HISTM.

Retrieving and Sorting Test Data

The principle data handling program in the data management system (CETP-- Colorado Emission Test Program) serves as the basic interface between the data base and the other software. This program retrieves the selected data from disk storage and sorts it by a number of classification systems. The data can be culled in the following ways:

- the total population
- sort by manufacturer
- sort by make within a particular manufacturer
- sort by engine size group
- sort by weight group
- sort by age group
- sort by PASS/FAIL at idle inspection

Additionally the data can also be sorted by:

- CVS
- key modes
- engine parameters
- costs
- vehicle characteristics , e.g. vehicle weight.

Basic Statistics

The program CETP also computes certain simple but essential properties of the data including: standard deviations, t-values, and degrees of freedom. This information provides a quick look capability for analyzing the raw data in addition to the more involved techniques discussed in the next section.

3.2 STATISTICAL ANALYSIS

Several independent statistical packages were used in processing the data relevant to this study.

A major computer program, one developed specifically for the Idle Adjustment Program, is designated ANOV. It performs an analysis of variance for an experimental design. In order to test the effects on emissions produced by adjusting the settings of four engine parameters and their interactions it was necessary to make several simplifying assumptions. These are:

- Choke kick has no second-order interactions with idle CO, RPM and timing.
- Third and fourth order interactions are negligible.
- Parameter settings and emission levels are distributed normally in the general population.

From these assumptions, a one-half fractional factorial experiment involving only eight (8) tests per vehicle could be designed. Each vehicle is subjected to all eight settings in random order and the emissions at each setting are measured.

The ANOV program using this data, estimates two basic factors. First, the variance of the emission levels between settings indicates how much effect the different settings have on emission levels and, second, the variance between vehicles within each setting provides a standard of normalization for determining the net real effect. The ratio of these two factors is compared to a critical "F-value". If the "F-score" exceeds the F-value the effect is said to be statistically significant, i.e. the effect produced by changing that setting is significant.

Another kind of analysis of variance was also used. This one (called Wilson's ANOVA) is a TRW system routine. It computes a confidence level and probability that indicates whether or not a population divided into several groups yields statistically different emissions.That is, the resultant partition provides a measure of potential differences. This program was used in determining the merit of separating the vehicle population into sub-divisions for key mode emission analysis. The results of this analysis are given in section 5.0.

The third major statistical package was a program designed to perform three main types of regression analysis; ordinary least squares, two-stage least squares, and limited information single equation analysis. Regression equations were derived with this program for the high altitude experimental program (see Volume III).

The major data handling program CLTP also computes such minor statistics as means, standard deviations and t-scores. The t-scores in turn are used to determine the significance of the given means and standard deviations.

4.0 SURVEY OF ENGINE AND EMISSION STATES

This section presents a survey on the existing state of engine repair and emission levels for vehicles operating in the Denver area. The survey provides detailed diagnostic information on the extent of the engine maladjustment and malfunction and on the corresponding emission levels for HC, CO and NO_x. This information is of crucial importance in establishing a benchmark for comparing the relative effectiveness of alternative vehicular control strategies. Specifically, the survey included the engine and emission parameters shown in Table 4-1.

4.1 ENGINE PARAMETER SURVEY

The surveyed engine parameters have been classified into three sets to reflect differences in engine maladjustments and malfunctions:

1) Idle adjustments (idle fuel to air ratio, idle speed, basic timing, and dwell).

2) Ignition components affecting misfire or spark advance (NO_x control).

3) Induction system components affecting fuel to air ratio.

Table 4-2 shows the results of the survey partitioned by vehicle control type. The engine parameters are separated into two basic categories -- distributed and nondistributed. Distributed parameters are those of a continuous nature whereas nondistributed parameters are either operating or failed. For example, the survey found 88 percent of all PCV values operating in the total population.

One interesting observation from this data is the relatively high degree of incipient misfire found in the population. On the average 14 percent of the vehicles surveyed were found misfiring which is

Table 4-1

SUMMARY OF ENGINE PARAMETERS AND EMISSION SPECIES SURVEYED

Engine Parameters

Idle Subsystem	Ignition Subsystem	Induction Subsystem
• Idle Fuel/Air Ratio	• Misfire	• PCV Valve
• Idle RPM	• NO_x Control	• Air Cleaner
• Basic Timing		• Air Pump
• Dwell		• Choke

Emission Species

Key Mode	CVS-1975
Idle HC	HC Mass
Idle CO	CO Mass
Idle NO_x	NO_x Mass
HC @ 2500 RPM	
CO @ 2500 RPM	
HC @ Low Cruise	
CO @ Low Cruise	
NO_x @ Low Cruise	
HC @ High Cruise	
CO @ High Cruise	
NO_x @ High Cruise	

approximately four times larger than detected at sea level.* Since misfire has a large effect on hydrocarbons, the incorporation of an ignition tune-up as part of the inspection program may yield effective results.

The results for basic timing are among the more interesting of the distributed parameters in that the mean recorded value is near manufacture specification and yet there is a large variance around the mean value. This would tend to indicate that the adjustment of timing to specification for a segment of the population could produce significant emission reduction results.

Tables 4-3 through 4-6 shows similar results with the data partitioned by vehicle manufacturer, engine displacement and vehicle weight, respectively. The variability in engine states revealed by these different classification schemes indicates that these factors must be taken into consideration as part of any inspection and maintenance program.

Another perspective on the variability of engine states can be gained from reviewing the histograms for the continuous parameters shown in Figures 4-1 through 4-8. Figure 4-1 shows the relative distribution of idle CO for pre-controlled vehicles, i.e., pre 1968. These results show a rather flat response between 2.4% and 9.6% with a rapid drop off beyond this limit. The slight increase at 12% reflects an accumulation for these recorded values beyond that point. A similar trend is also shown for the control vehicles, i.e., post 1967.

* TRW, Inc., A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions, Vol. 4., July 1973.

Table 4-2
SURVEY OF ENGINE STATES BY MODEL YEAR

DISTRIBUTED PARAMETERS

PARAMETER	(<1968) MEAN	(<1968) SD	(1968+) MEAN	(1968+) SD	AVERAGE MEAN	AVERAGE SD
IDLE CO (% Vol)	5.530	2.752	4.325	2.639	4.767	2.737
IDLE RPM (RPM)	35.391	132.027	-11.195	130.463	5.887	132.737
TIMING (DEG)	-.300	8.009	.984	4.979	0.513	6.230
DWELL	-.791	4.330	-.047	4.393	-0.320	4.082
SAMPLE SIZE:	(110)		(190)		(300)	

NONDISTRIBUTED PARAMETERS (PERCENT)

PARAMETER	(<1968) YES	(<1968) NO	(1968+) YES	(1968+) NO	AVERAGE YES	AVERAGE NO
PCV	87	13	89	11	88	12
SAMPLE SIZE:		(91)		(168)		(259)
AIR CLNR	54	46	63	37	59	41
SAMPLE SIZE:		(110)		(190)		(300)
CHOKE	93	7	100	0	97	3
SAMPLE SIZE:		(108)		(189)		(297)
AIR PUMP	100	0	100	0	100	0
SAMPLE SIZE:		(1)		(14)		(15)
MISFIRE	18	82	19	81	19	81
SAMPLE SIZE:		(110)		(190)		(300)
NOX	0	0	80	20	80	20
SAMPLE SIZE:		(0)		(30)		(30)

Table 4-3

SURVEY OF ENGINE STATES BY VEHICLE MANUFACTURER

DISTRIBUTED PARAMETERS

PARAMETER	(GM) MEAN	(GM) SD	(FORD) MEAN	(FORD) SD	(CHRY.) MEAN	(CHRY.) SD	(AMC) MEAN	(AMC) SD	(FOREIGN) MEAN	(FOREIGN) SD
IDLE CO (% Vol)	4.789	2.844	4.514	2.736	5.313	2.464	5.033	3.330	4.376	2.557
IDLE RPM (RPM)	.630	114.058	-.278	119.448	41.420	147.874	-32.000	99.532	-1.515	108.165
TIMING (DEG)	-.289	6.652	.063	6.321	2.700	4.315	-.100	4.557	1.576	6.591
DWELL	-.148	3.708	.177	3.699	-.640	4.246	-.200	3.521	-1.727	5.811
SAMPLE SIZE:	(128)		(79)		(50)		(10)		(33)	

NONDISTRIBUTED PARAMETERS
(PERCENT)

	(GM) YES	(GM) NO	(FORD) YES	(FORD) NO	(CHRY.) YES	(CHRY.) NO	(AMC) YES	(AMC) NO	(FOREIGN) YES	(FOREIGN) NO
PCV	88	13	87	13	96	4	78	22	83	17
SAMPLE SIZE:	(120)		(75)		(49)		(9)		(6)	
AIR CLNR	53	47	62	38	50	50	80	20	85	15
SAMPLE SIZE:	(128)		(79)		(50)		(10)		(33)	
CHOKE	97	3	99	1	94	6	100	0	100	0
SAMPLE SIZE:	(128)		(78)		(49)		(10)		(32)	
AIR PUMP	100	0	100	0	100	0	0	0	0	0
SAMPLE SIZE:	(10)		(2)		(3)		(0)		(0)	
MISFIRE	17	83	20	80	16	84	30	70	24	76
SAMPLE SIZE:	(128)		(79)		(50)		(10)		(33)	
NOX	69	31	88	13	100	0	100	0	50	50
SAMPLE SIZE:	(13)		(8)		(6)		(1)		(2)	

Table 4-4

SURVEY OF ENGINE STATES BY ENGINE DISPLACEMENT

DISTRIBUTED PARAMETERS

MODE	(<100) MEAN	(<100) SD	(100-199) MEAN	(100-199) SD	(200-299) MEAN	(200-299) SD	(300-399) MEAN	(300-399) SD	(400+) MEAN	(400+) SD
IDLE CO (% Vol)	5.347	2.717	4.523	3.175	5.232	2.582	4.680	2.674	4.170	2.867
IDLE RPM (RPM)	5.208	182.997	-21.800	172.009	21.392	134.854	9.358	116.244	-11.957	122.911
TIMING (DEG)	1.458	6.884	.680	5.121	-.147	6.967	.863	5.494	-.152	4.237
DWELL	-1.542	6.420	-1.240	3.479	-.706	3.641	-.212	3.780	1.065	4.131
SAMPLE SIZE:	(24)		(25)		(68)		(137)		(46)	

NONDISTRIBUTED PARAMETERS
(PERCENT)

	(<100) YES	(<100) NO	(100-199) YES	(100-199) NO	(200-299) YES	(200-299) NO	(300-399) YES	(300-399) NO	(400+) YES	(400+) NO
PCV	67	33	100	0	84	16	89	11	91	9
SAMPLE SIZE:	(3)		(16)		(61)		(133)		(46)	
AIR CLNR	88	13	48	52	51	49	59	41	63	37
SAMPLE SIZE:	(24)		(25)		(68)		(137)		(46)	
CHOKE	100	0	100	0	94	6	97	3	100	0
SAMPLE SIZE:	(23)		(25)		(66)		(137)		(46)	
AIR PUMP	0	0	0	0	100	0	100	0	100	0
SAMPLE SIZE:	(0)		(0)		(4)		(8)		(3)	
MISFIRE	17	83	16	84	22	78	18	82	20	80
SAMPLE SIZE:	(24)		(25)		(68)		(137)		(46)	
NOX	0	100	100	0	100	0	81	19	67	33
SAMPLE SIZE:	(1)		(3)		(4)		(15)		(6)	

Table 4-5

SURVEY OF ENGINE STATES BY VEHICLE WEIGHT

DISTRIBUTED PARAMETERS

PARAMETER	1800-2799 MEAN	1800-2799 SD	2800-3799 MEAN	2800-3799 SD	3800-4799 MEAN	3800-4799 SD	4800-5799 MEAN	4800-5799 SD
IDLE CO (% Vol)	4.856	2.793	4.778	2.631	4.867	2.961	3.647	2.546
IDLE RPM (RPM)	-3.478	176.779	3.354	132.389	16.036	109.339	-34.667	141.503
TIMING (DEG)	.674	5.918	.394	5.675	.464	7.243	1.400	3.066
DWELL	-1.348	5.156	-.787	3.522	.464	3.836	.033	5.203
SAMPLE SIZE:	(46)		(127)		(112)		(15)	

NONDISTRIBUTED PARAMETERS (PERCENT)

PARAMETER	1800-2799 YES	1800-2799 NO	2800-3799 YES	2800-3799 NO	3800-4799 YES	3800-4799 NO	4800-5799 YES	4800-5799 NO
PCV	94	6	85	15	92	8	87	13
SAMPLE SIZE:	(18)		(119)		(107)		(15)	
AIR CLNR	72	28	57	43	57	43	60	40
SAMPLE SIZE:	(46)		(127)		(112)		(15)	
CHOKE	100	0	96	4	97	3	100	0
SAMPLE SIZE:	(44)		(126)		(112)		(15)	
AIR PUMP	0	0	100	0	100	0	100	0
SAMPLE SIZE:	(0)		(6)		(7)		(2)	
MISFIRE	17	83	20	80	20	80	13	87
SAMPLE SIZE:	(46)		(127)		(112)		(15)	
NOX	80	20	80	20	75	25	100	0
SAMPLE SIZE:	(5)		(15)		(8)		(2)	

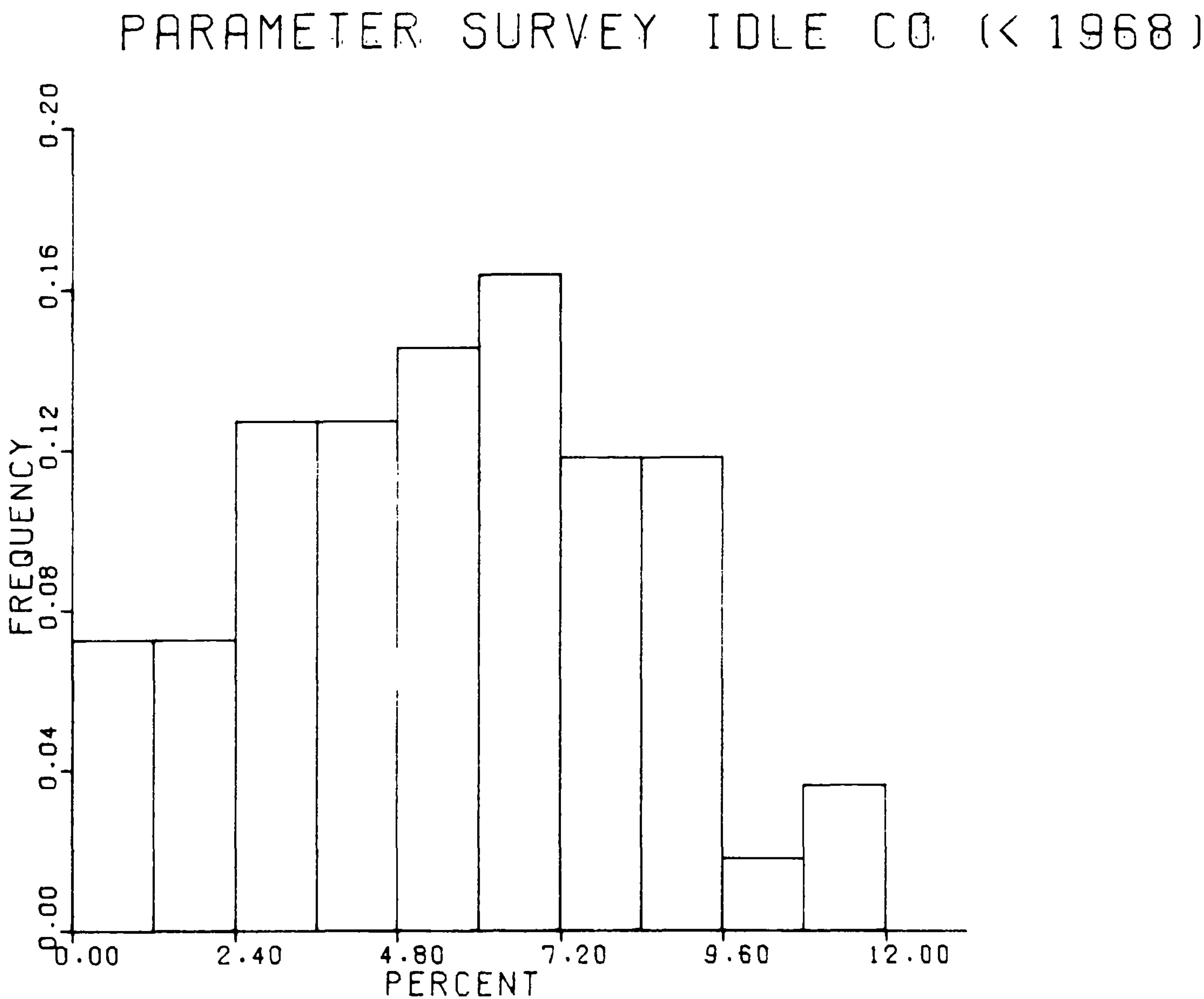


Figure 4-1 Air/Fuel Ratio Frequency Distribution for Pre-Controlled Vehicles

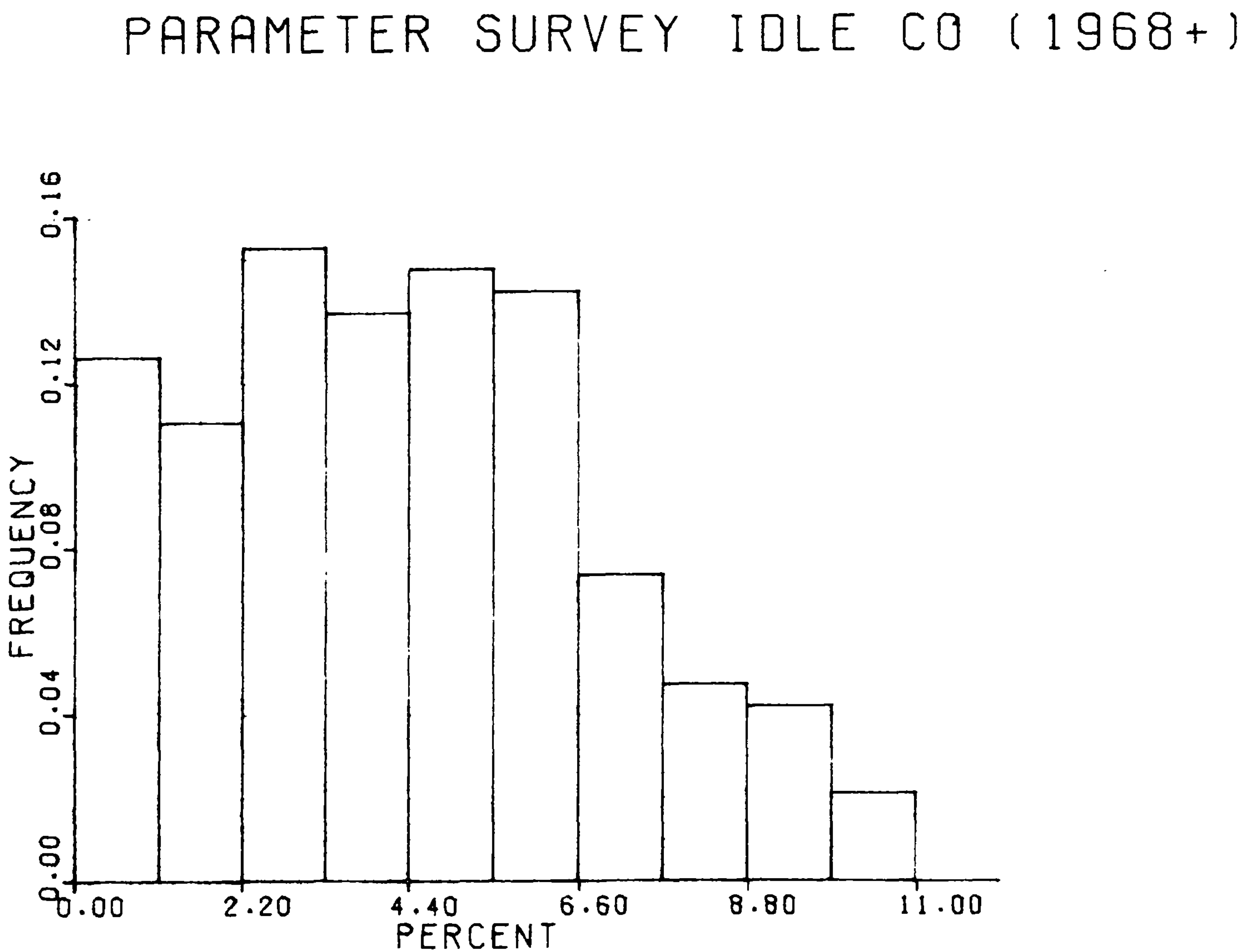


Figure 4-2 Air/Fuel Ratio Frequency Distribution for Controlled Vehicles

The results for idle speed (Figures 4-3 and 4-4), basic timing (Figures 4-5 and 4-6) and dwell (Figures 4-7 and 4-8), show somewhat different results. For the most part, each of these parameters are distributed around specification each exhibiting a rather large variability. The plots for these variables tend to resemble a Gaussian or normal distribution which has been found typical in other studies.*

4.2 KEY MODE EMISSION SURVEY

A similar series of analyses were performed for the key mode data collected in the survey. Tables 4-6 through 4-9 show means and standard deviations for the recorded key modes by model year, vehicle manufacture, engine displacement and vehicle weight, respectively. This data was recorded using the laboratory measuring equipment and can serve as a baseline for evaluating the data recorded at the maintenance garages. The abbreviations HC 2500 and CO 2500 represent HC and CO measurements taken at 2500 rpm. The histogram plots were developed herein using data taken from the Sun laboratory equipment.

Section 5.4 will provide a more definitive analysis on the need for developing individual idle emission standards based on partitioning the population. In summary, the analysis shows that individual standards should be established for idle HC and idle CO by vehicle age i.e., pre 1968 vehicles, 1968-1970 vehicles, and post 1970 vehicles. The analysis produced inconclusive results with respect to the other classification schemes, e.g., engine cubic displacment.

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* TRW, Inc., A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions, Vol. 4., July 1973.

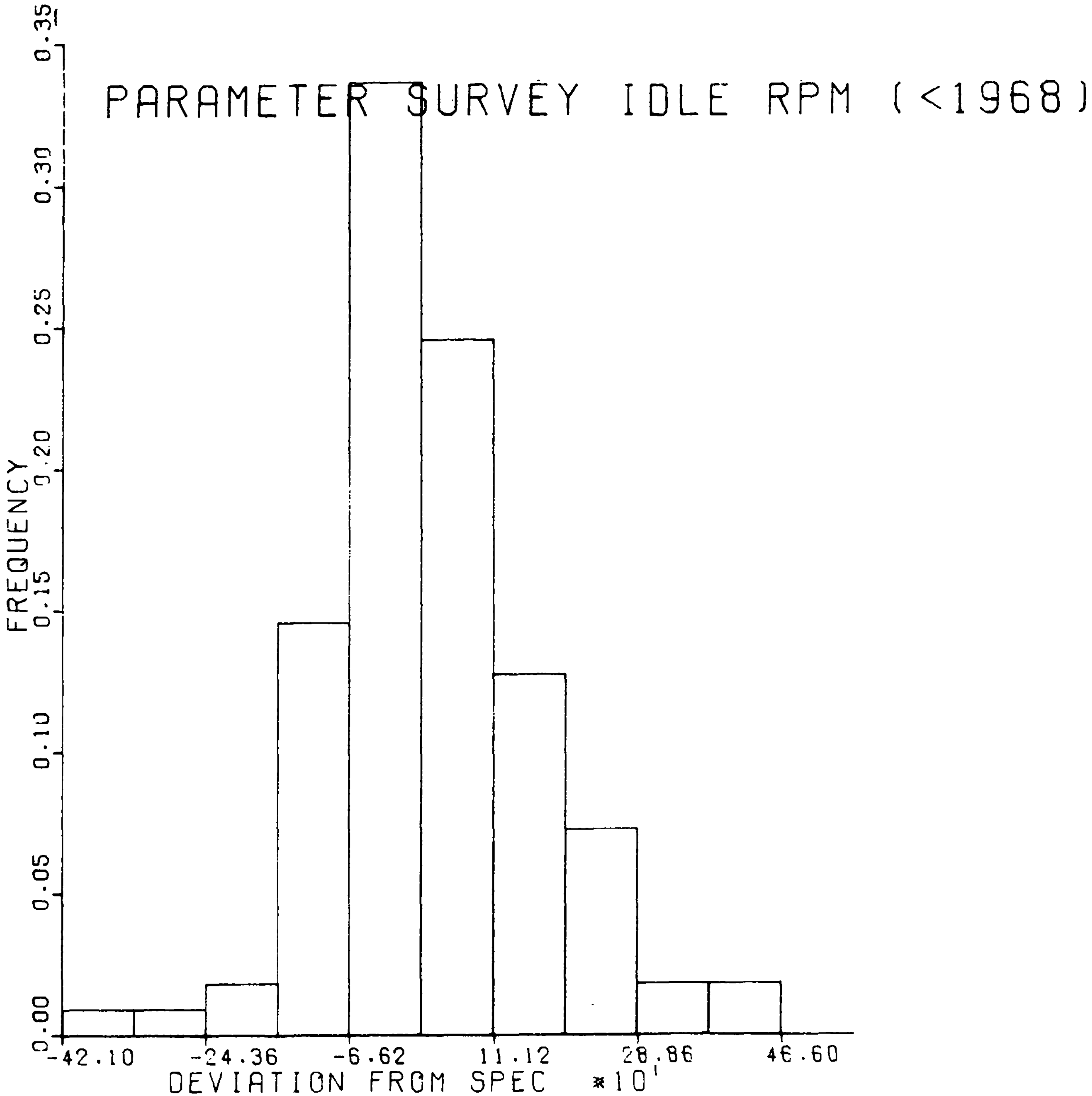

Figure 4-3 Frequency Plot of RPM for Pre-Controlled Vehicles

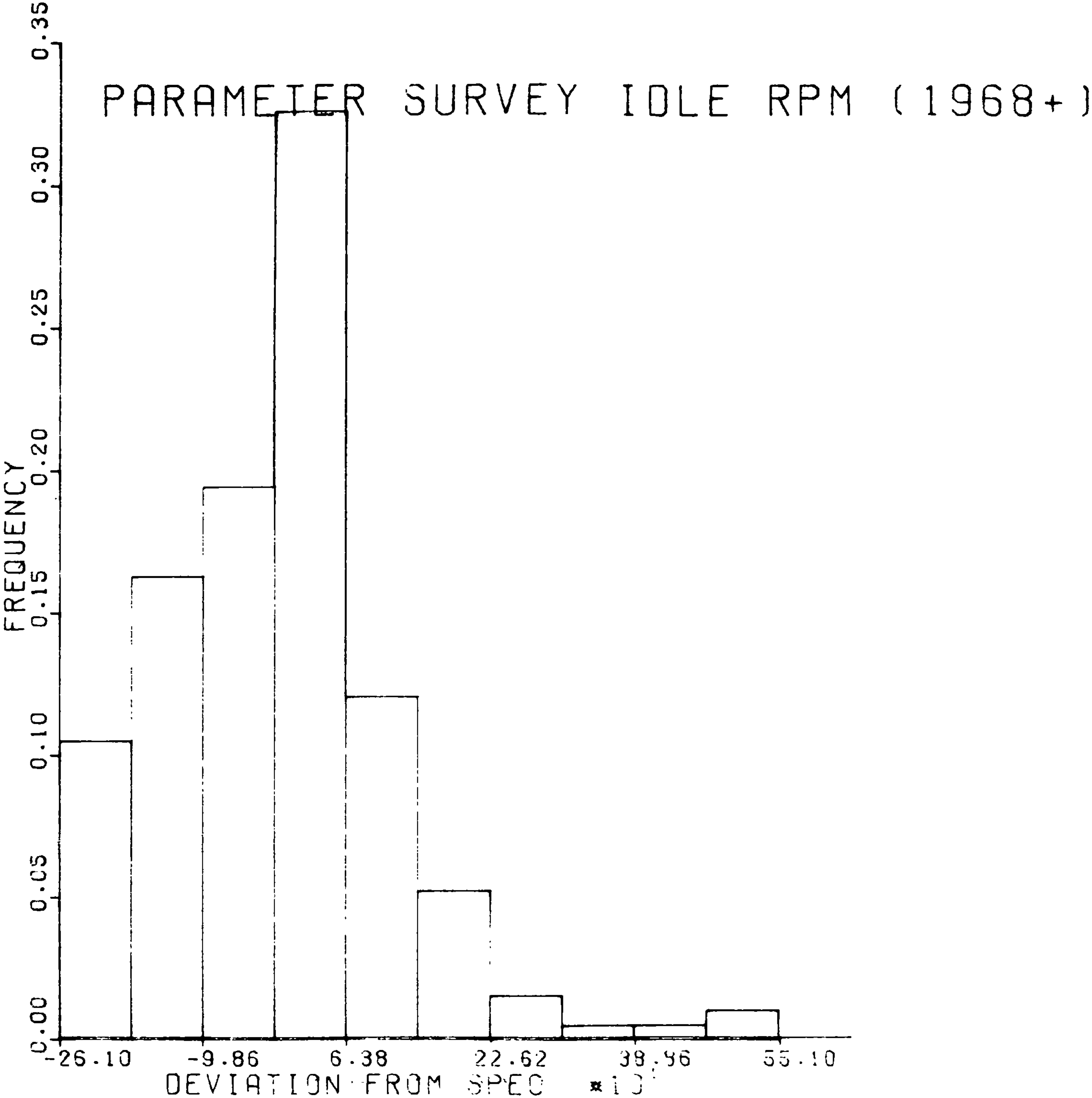

Figure 4-4 Frequency Plot of RPM for Controlled Vehicles

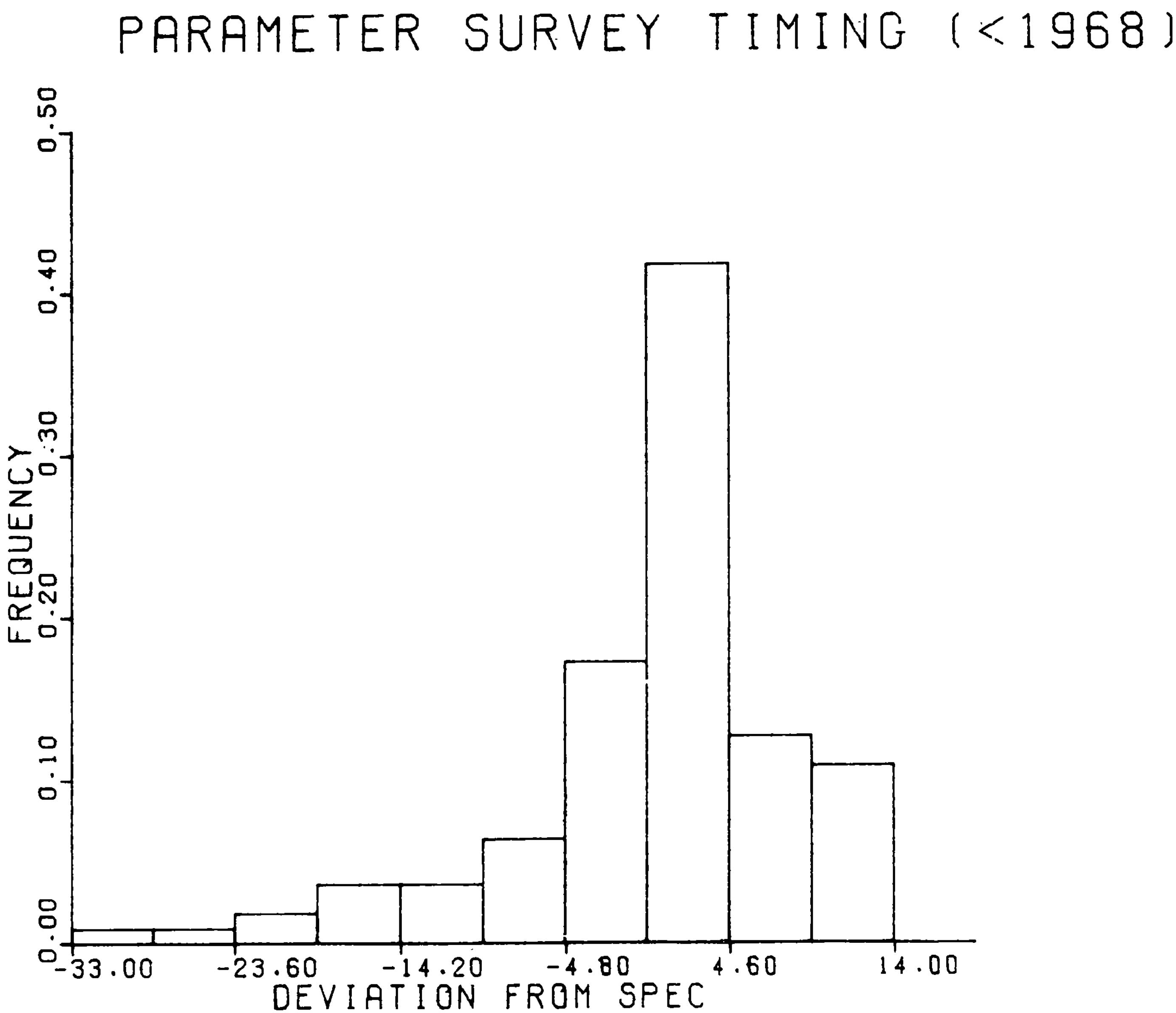

Figure 4-5 Frequency Plot of Timing for Pre-Controlled Vehicles

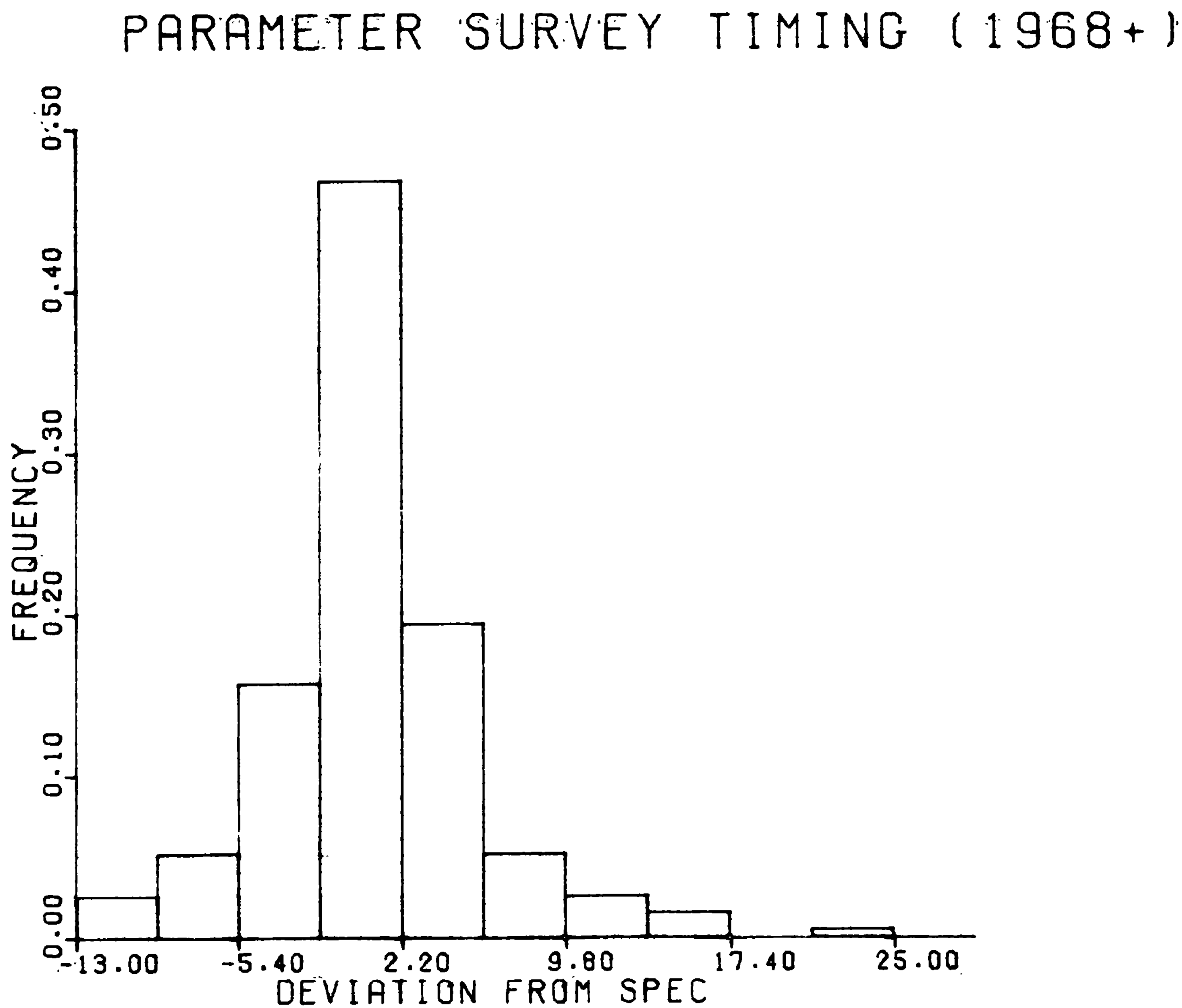

Figure 4-6 Frequency Plot of Timing for Controlled Vehicles

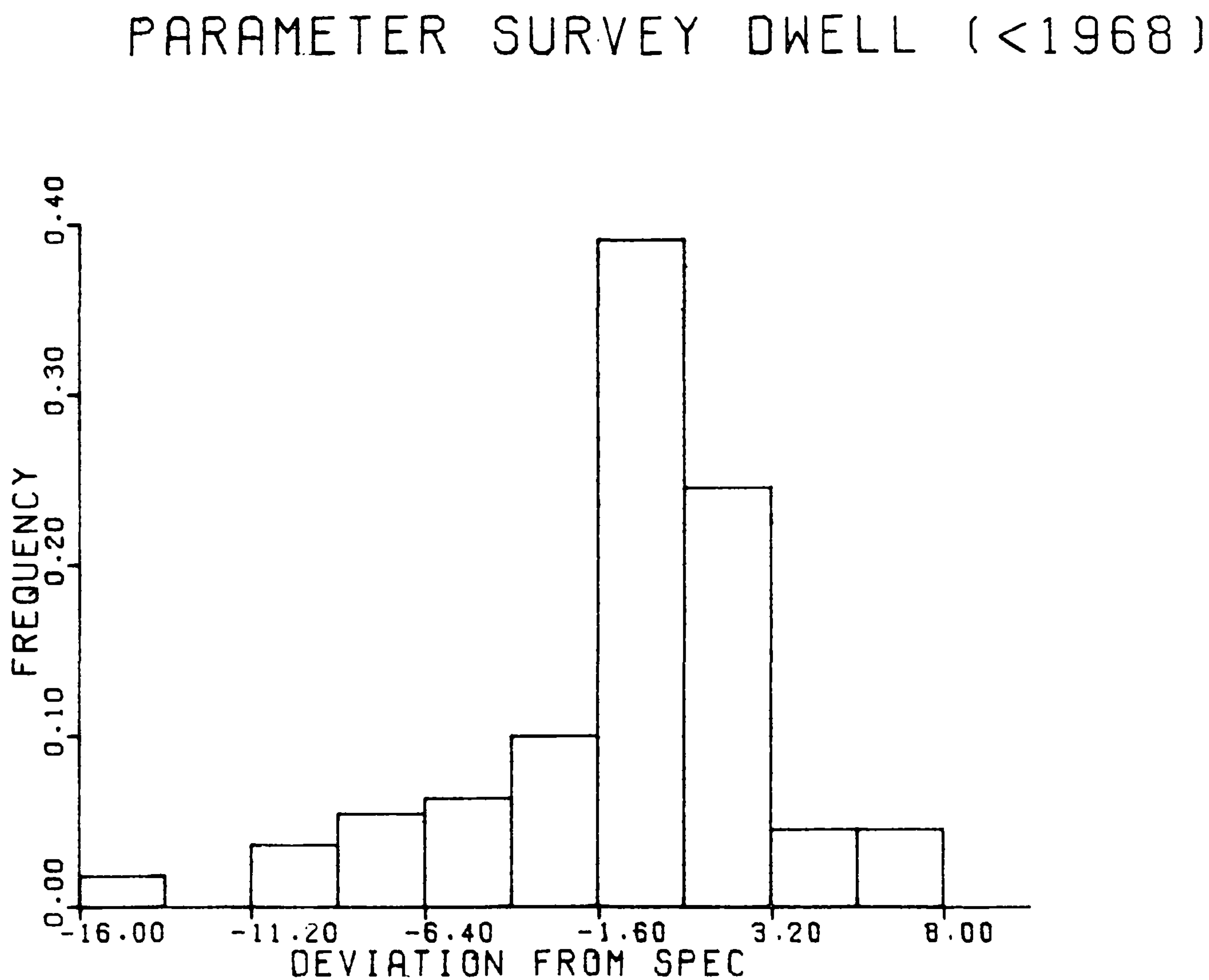

Figure 4-7 Frequency Plot of Dwell for Pre-Controlled Vehicles

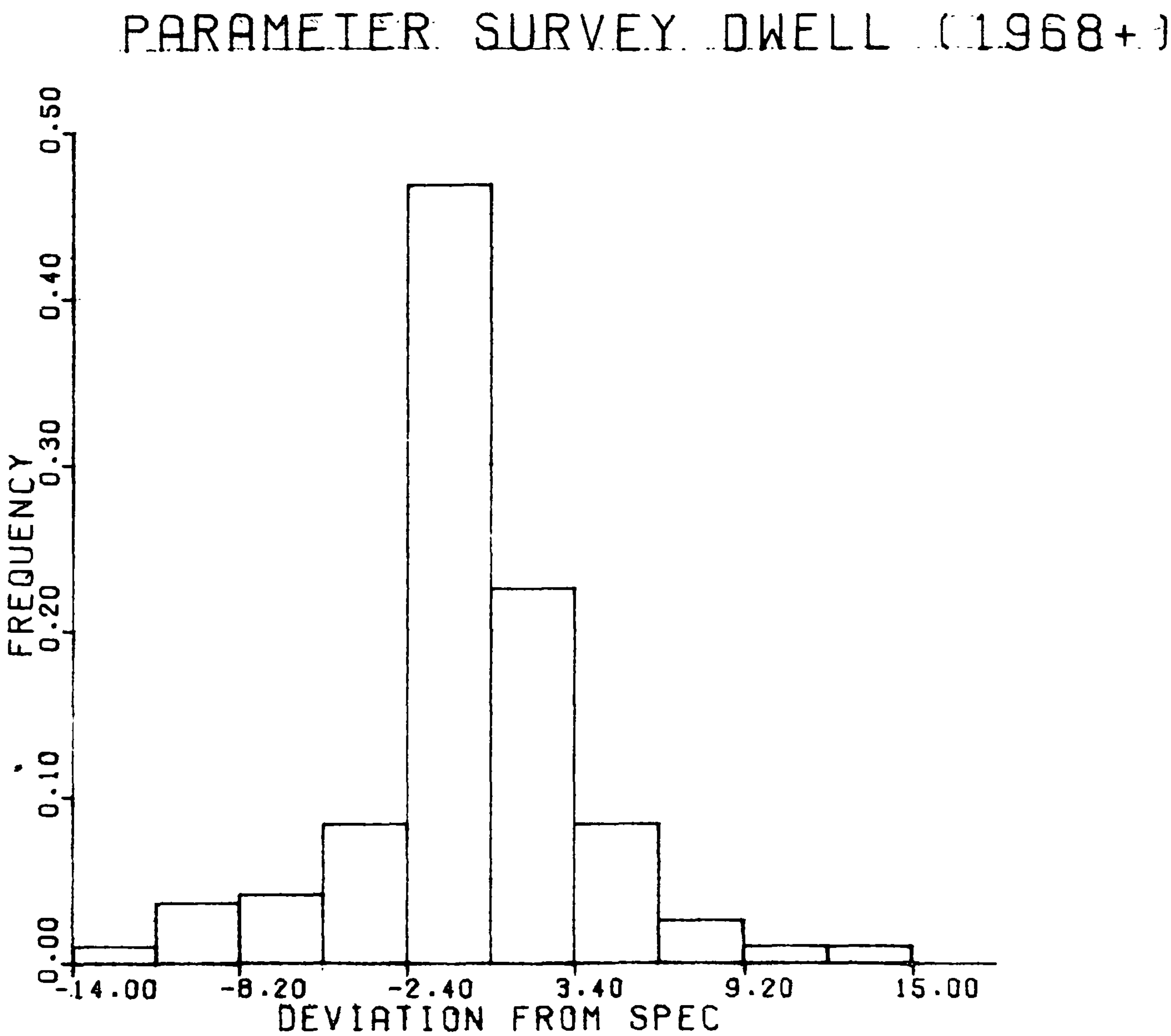

Figure 4-8 Frequency Plot of Dwell for Controlled Vehicles

Table 4-6

SURVEY OF KEY MODE EMISSIONS BY MODEL YEAR

	Pre 1968		Post 1968		Average	
Mode	Mean	SD	Mean	SD	Mean	SD
HC Idle (ppm)	925.818	506.133	612.979	451.036	727.687	494.754
HC 2500 (ppm)	556.596	572.596	318.189	491.139	405.453	534.037
HC Low Cruise (ppm)	667.809	354.670	512.611	266.441	569.517	310.391
HC High Cruise (ppm)	621.445	360.146	491.826	292.372	539.353	324.395
CO Idle (%)	6.287	2.934	4.815	2.902	5.355	2.995
CO 2500 (%)	5.071	2.558	2.524	3.021	3.458	3.109
CO Low Cruise (%)	4.430	2.561	2.171	1.972	2.999	2.458
CO High Cruise (%)	5.525	3.006	2.967	2.412	3.904	2.915
NO_x Idle (ppm)	65.736	56.649	97.705	191.558	85.983	156.852
NO_x Low Cruise (ppm)	1145.736	773.669	1542.837	838.791	1396.500	836.689
NO_x High Cruise (ppm)	1192.591	916.762	1870.237	1095.910	1621.767	1082.845
Sample Size	110		190		300	

Table 4-7

SURVEY OF KEY MODE EMISSIONS BY VEHICLE MANUFACTURER

Mode	GM Mean	GM SD	FORD Mean	FORD SD	CHRYSLER Mean	CHRYSLER SD	AMC Mean	AMC SD	FOREIGN Mean	FOREIGN SD
HC Idle (ppm)	741.812	483.621	698.076	454.836	665.980	454.268	680.700	299.684	851.575	698.577
HC 2500 (ppm)	420.742	573.634	436.532	579.924	378.800	518.615	426.500	426.413	305.758	247.570
HC Low Cruise (ppm)	598.648	391.254	592.468	287.475	530.780	167.424	498.300	181.002	481.848	150.093
HC High Cruise (ppm)	569.359	395.171	544.899	268.691	515.140	309.730	527.300	217.608	450.030	120.187
CO Idle (%)	5.397	3.063	4.953	2.915	5.889	2.782	6.169	4.147	5.097	2.833
CO 2500 (%)	3.490	2.780	3.135	2.830	3.457	3.241	3.085	2.750	4.222	4.585
CO Low Cruise (%)	3.295	2.671	2.395	2.000	3.293	2.551	1.981	1.334	3.164	2.483
CO High Cruise (%)	4.319	3.258	3.028	2.395	4.680	2.322	5.208	3.942	2.825	2.327
NO_x Idle (ppm)	77.641	67.369	85.797	57.961	125.260	359.857	77.500	66.130	61.848	29.073
NO_x Low Cruise (ppm)	1192.953	726.212	1665.251	949.525	1525.740	929.850	1601.900	661.439	1284.606	638.099
NO_x High Cruise (ppm)	392.141	965.330	1861.139	1081.560	1241.200	811.354	1302.500	1302.186	2612.758	1139.335
Sample Size	128		79		50		10		33	

Table 4-8

SURVEY OF KEY MODE EMISSIONS BY ENGINE DISPLACEMENT

	<100		100-199		200-299		300-399		400+	
Mode	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
HC Idle (ppm)	1043.292	767.756	680.880	405.494	723.015	484.342	745.752	473.734	541.565	345.191
HC 2500 (ppm)	356.875	242.051	300.400	233.871	491.618	535.231	419.387	601.791	319.022	536.641
HC Low Cruise (ppm)	508.208	153.038	514.160	187.199	607.485	305.610	607.453	372.934	462.478	167.679
HC High Cruise (ppm)	460.583	135.881	522.800	170.840	583.971	293.519	573.409	404.470	422.065	165.670
CO Idle (%)	5.941	2.889	5.167	3.287	5.893	2.968	5.228	2.895	4.733	3.167
CO 2500 (%)	5.358	4.971	3.833	3.926	4.191	3.154	2.879	2.162	2.903	3.210
CO Low Cruise (%)	3.457	2.085	3.254	2.640	3.702	2.824	2.752	2.414	2.321	1.778
CO High Cruise (%)	2.827	1.703	5.153	3.592	5.342	3.045	3.534	2.798	2.767	2.070
NO_x Idle (ppm)	54.417	22.587	164.640	507.042	73.603	54.207	82.949	63.731	87.093	72.216
NO_x Low Cruise (ppm)	1203.458	537.070	1287.080	749.247	1339.103	876.337	1493.599	910.878	1352.348	701.041
NO_x High Cruise (ppm)	2537.792	1005.319	1546.600	1392.380	1133.574	923.666	1664.372	1035.819	1779.478	941.161
Sample Size	24		25		68		137		46	

Table 4-9

SURVEY OF KEY MODE EMISSIONS BY VEHICLE WEIGHT

Mode	1800-2799 Mean	1800-2799 SD	2800-3799 Mean	2800-3799 SD	3800-4799 Mean	3800-4799 SD	4800-5799 Mean	4800-5799 SD
HC Idle (ppm)	846.478	651.434	686.331	420.566	764.411	506.208	439.333	280.167
HC 2500 (ppm)	368.587	393.992	365.551	455.696	495.277	671.217	185.667	125.668
HC Low Cruise (ppm)	513.739	165.022	562.654	255.461	615.304	407.217	456.800	164.105
HC High Cruise (ppm)	473.326	140.136	532.354	233.590	592.536	450.614	404.000	162.189
CO Idle (%)	5.478	2.963	5.332	2.858	5.506	3.156	4.039	2.685
CO 2500 (%)	4.435	4.568	3.139	2.700	3.548	2.858	2.489	1.987
CO Low Cruise (%)	3.313	2.468	2.860	2.465	3.032	2.565	2.978	1.440
CO High Cruise (%)	3.171	2.374	4.057	3.067	4.057	2.965	3.717	2.610
NO_x Idle (ppm)	60.043	28.749	97.724	229.559	82.920	72.061	89.000	61.586
NO_x Low Cruise (ppm)	1241.630	772.581	1478.835	874.562	1389.116	831.471	1229.467	704.826
NO_x High Cruise (ppm)	2219.152	1190.991	1501.008	1013.391	1542.643	1070.079	1403.000	869.143
Sample Size	46		127		112		15	

Figures 4-9 through 4-30 show frequency distributions for the key mode data for precontrolled and controlled vehicles. This information is extremely important in developing effective exhaust emission standards. With the exception of idle CO, these distributions tend to resemble the standard log normal function (a distribution that is shoved to the left with an extended tail to the right). Of particular significance is the data recorded for cruise hydrocarbons (Figures 4-15, 4-16, 4-21 and 4-22). The bimodal distribution reveals the presence of extremely high emitters which is normally caused by incipient misfire. In fact, the percentage of vehicles exhibiting high hydrocarbon emission corresponds reasonably well with that measured for vehicles with misfire. One interesting note is that HC 2500 also tended to indicate the presence of misfire. This ability to potentially detect misfire of 2500 rpm clearly should be considered in the formulation of the idle inspection program.

4.3 1975 CVS MASS EMISSIONS SURVEY

The measurement of CVS mass emissions for HC, CO and NO_x represented the last major element of the survey program. Establishing the level of mass emissions for the vehicle population is of critical importance for determining actual atmospheric loadings. Tables 4-10 through 4-13 present recorded mass emissions data by model year, vehicle manufacturer, engine cubic displacement and vehicle weight, respectively.

Estimates of CO_2 emission levels are also given along with the normal emission species (HC, CO and NO_x). The substantial difference in recorded values between precontrolled and controlled vehicles for

HC and CO mass is significant and, therefore, the two subpopulations should be treated separately.*

A set of HC, CO and NO_x mass emission frequency distributions for the total population are given in Figures 31 through 33, respectively. The distributions show a similar trend to those recorded for the key mode emissions. These plots also tend to confirm the relatively small number of high emitting vehicles. Repair of these vehicles on the other hand will yield disproportionately larger emission reductions due basically to their larger values. An effective program of vehicle inspection/maintenance should be designed towards detecting and repairing these high emitters.

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* A more detailed analysis on the statistical properties of these measurements is given in Section 5.4.

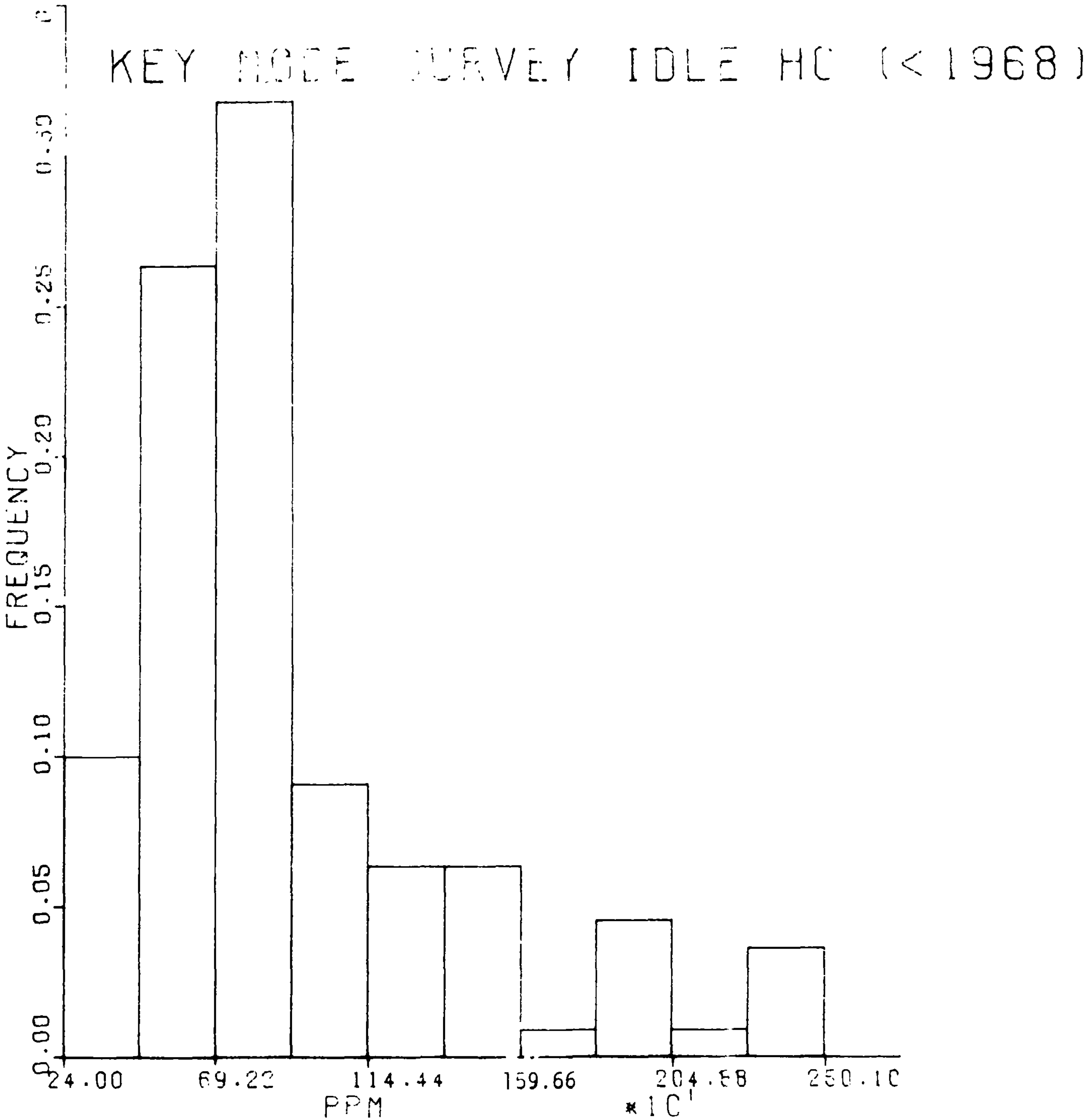

Figure 4-9 Idle HC Frequency Distribution for Pre-Controlled Vehicles

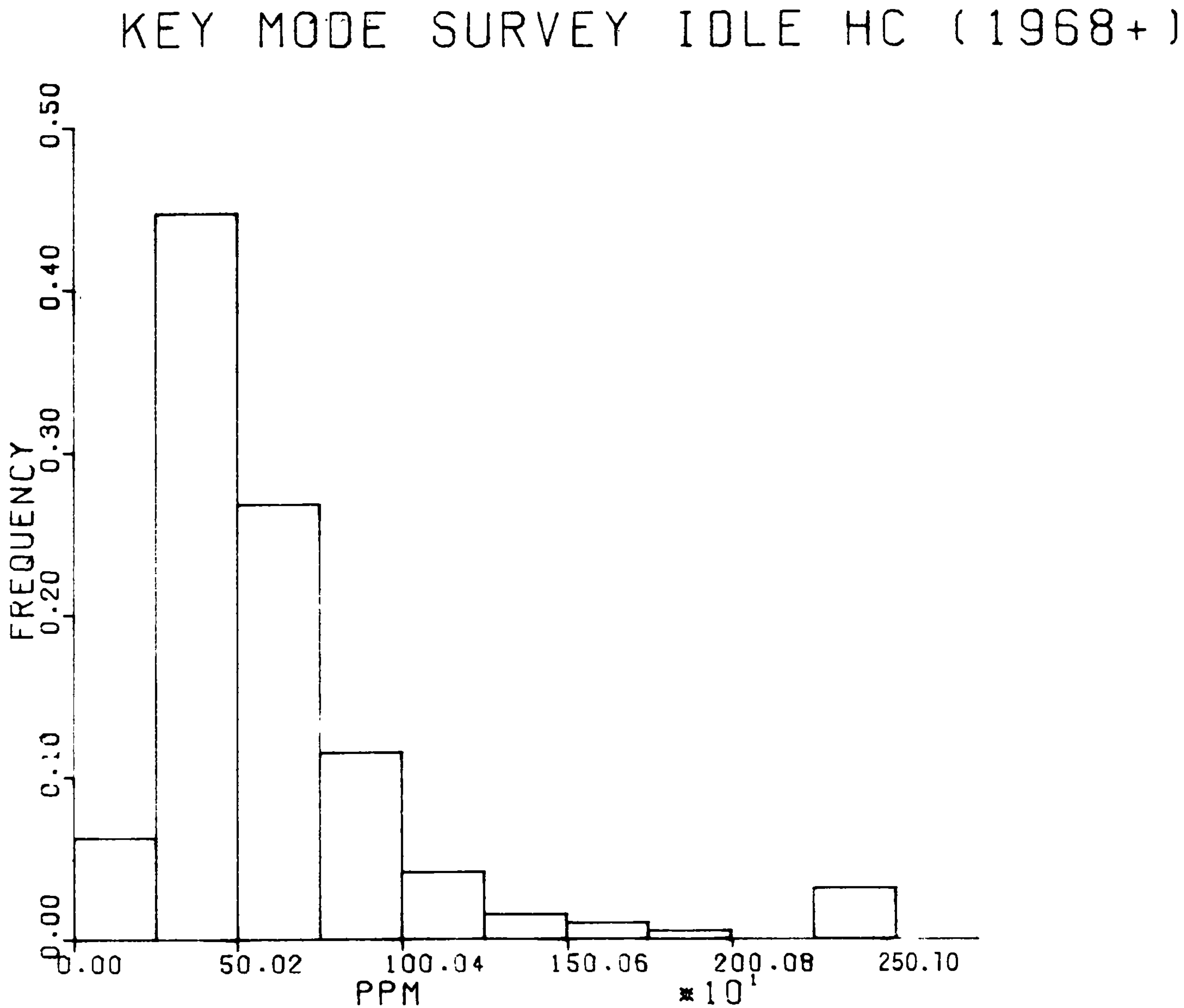

Figure 4-10 Idle HC Frequency Distribution for Controlled Vehicles

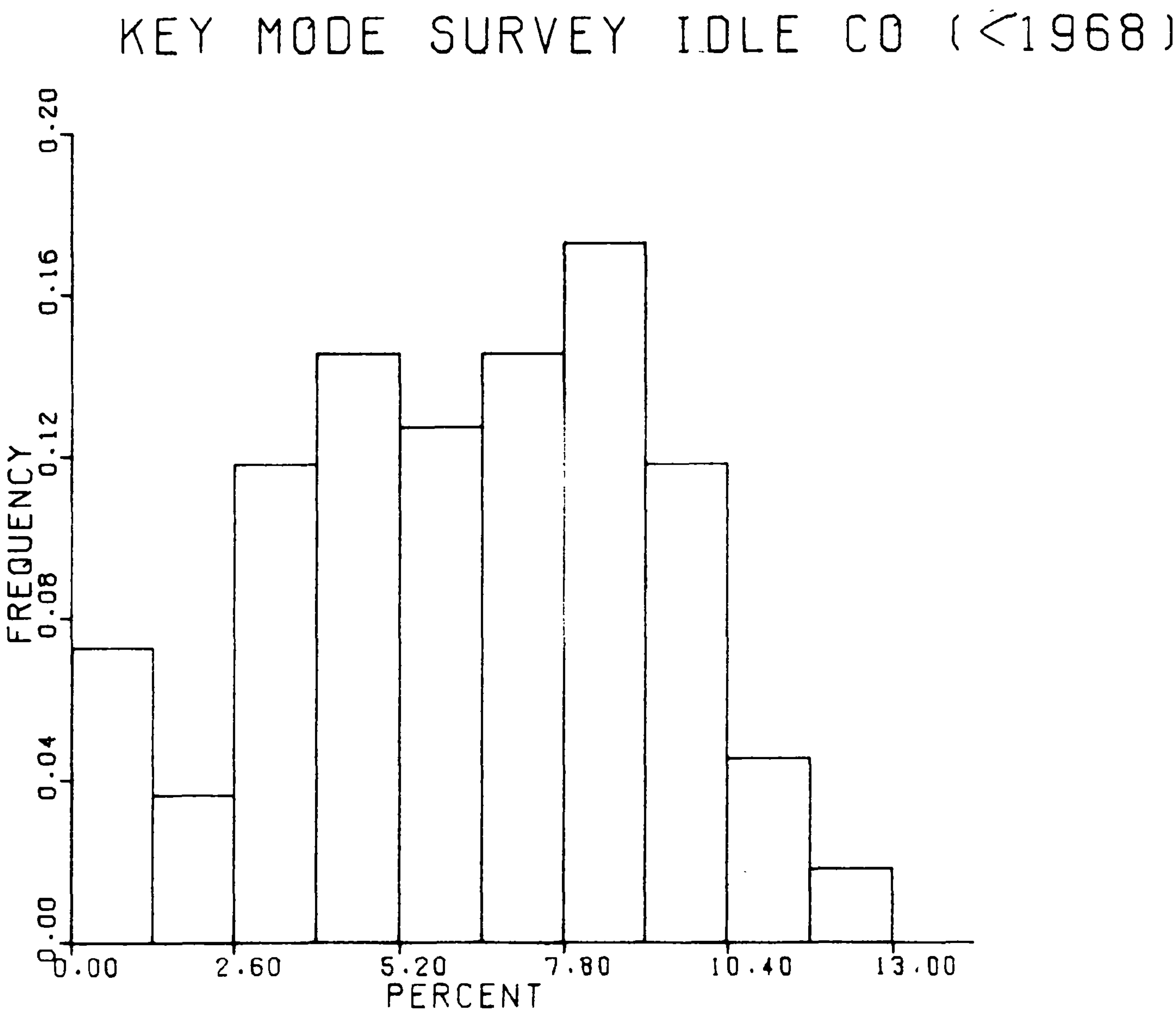

Figure 4-11 Idle CO Frequency Distribution for Pre-Controlled Vehicles

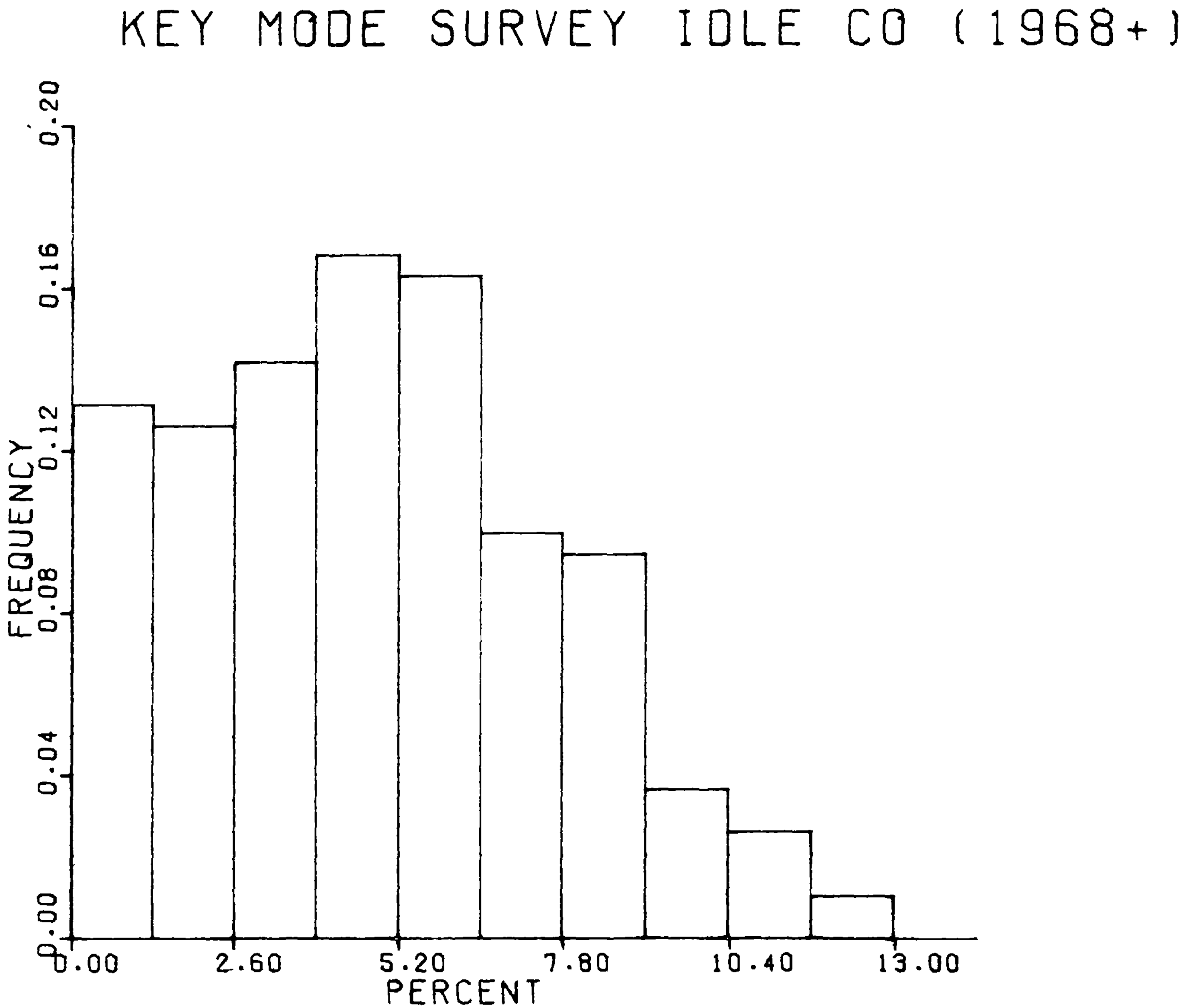

Figure 4-12 Idle CO Frequency Distribution for Controlled Vehicles

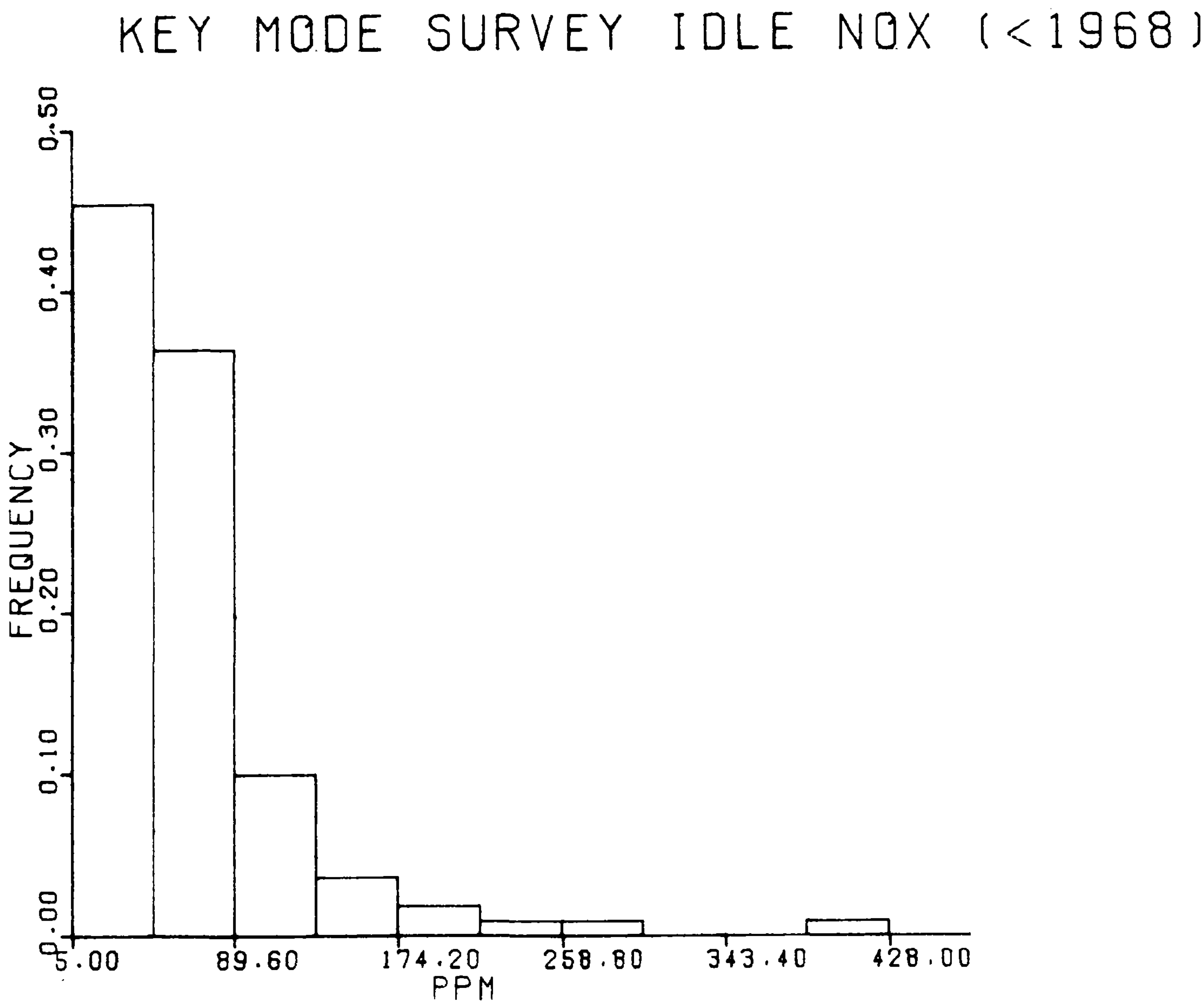

Figure 4-13 Idle NO_x Frequency Distribution for Pre-Controlled Vehicles

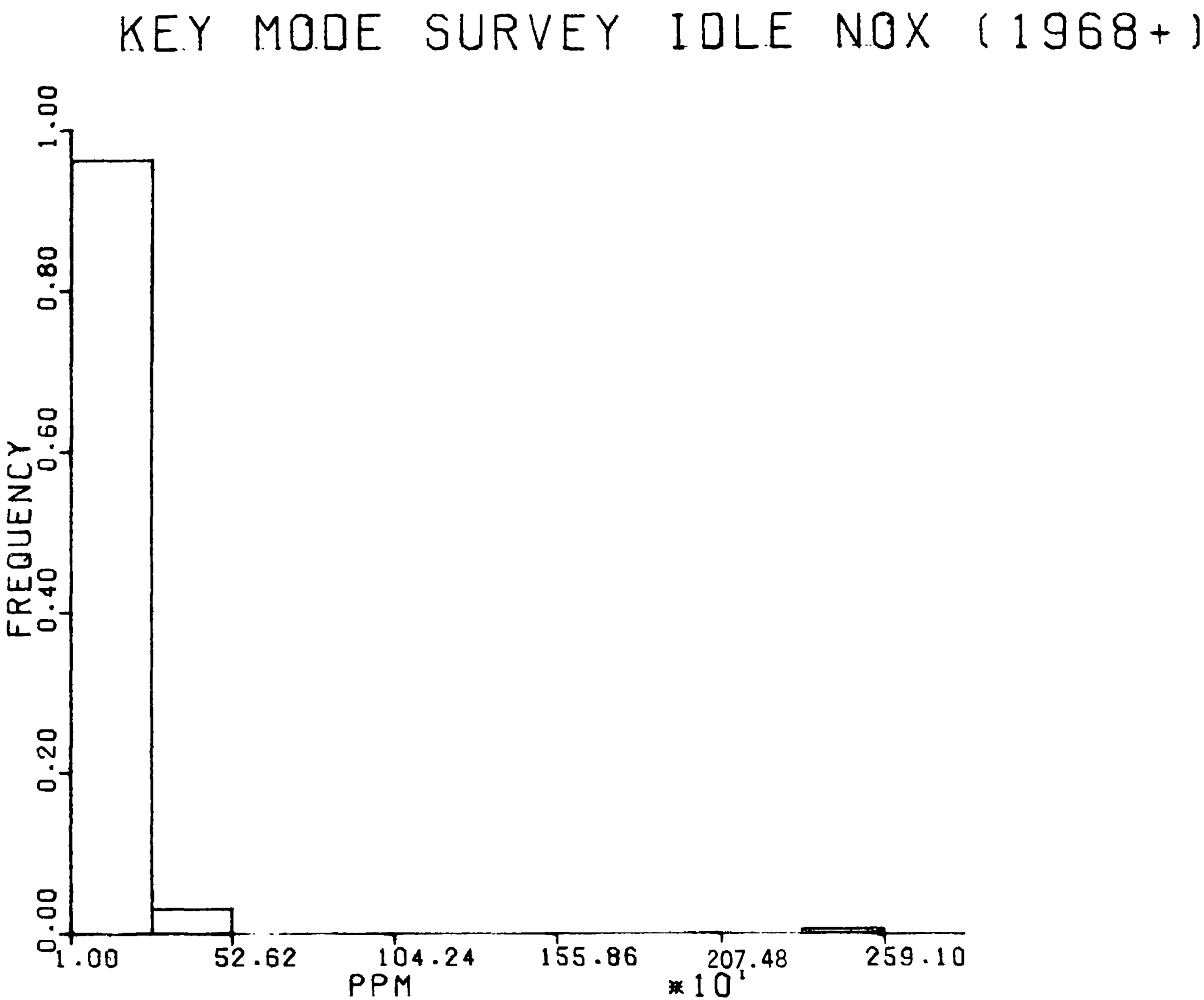

Figure 4-14 Idle NO_x Frequency Distribution for Controlled Vehicles

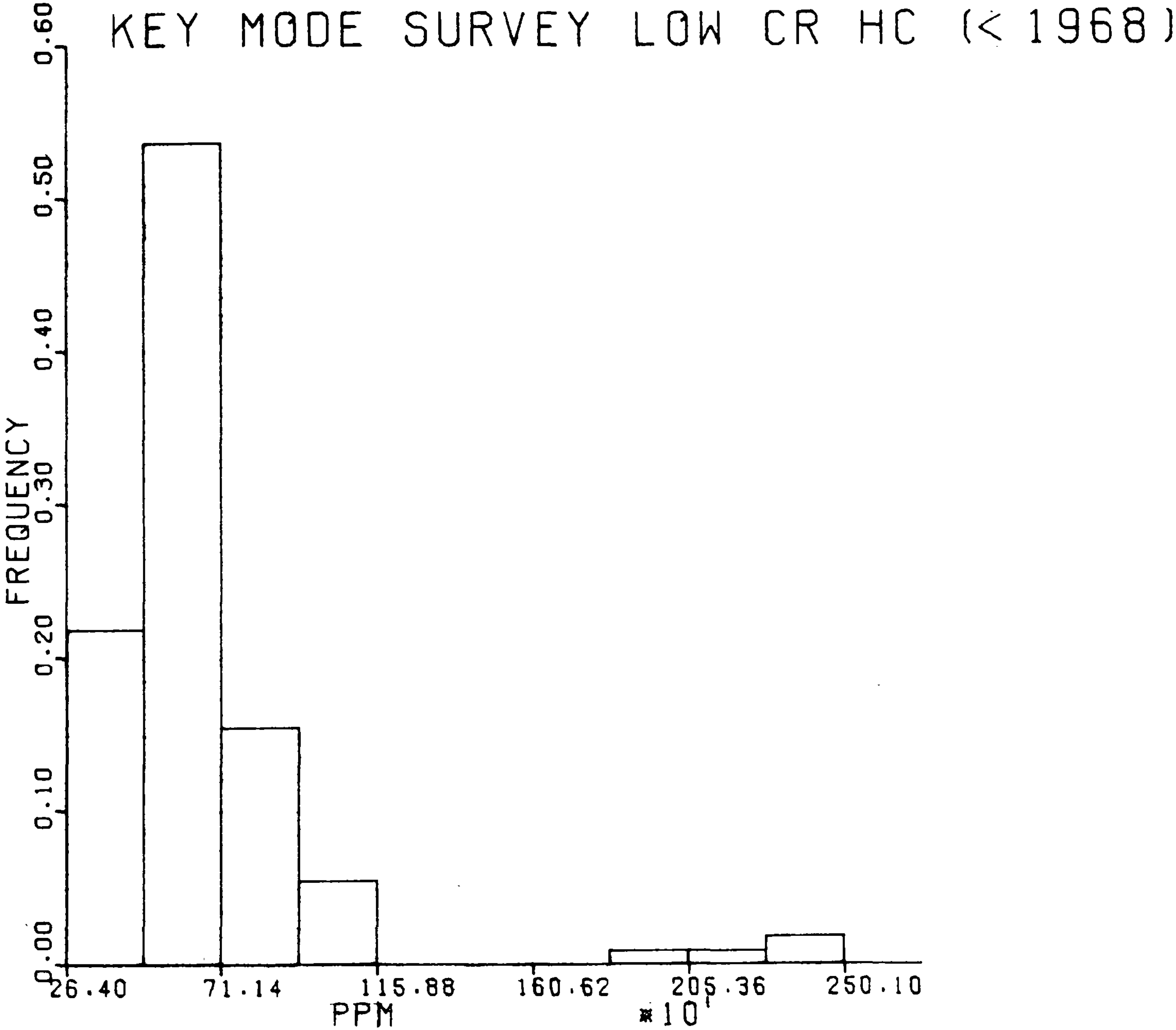

Figure 4-15 Low Cruise HC Frequency Distribution for Pre-Controlled Vehicles

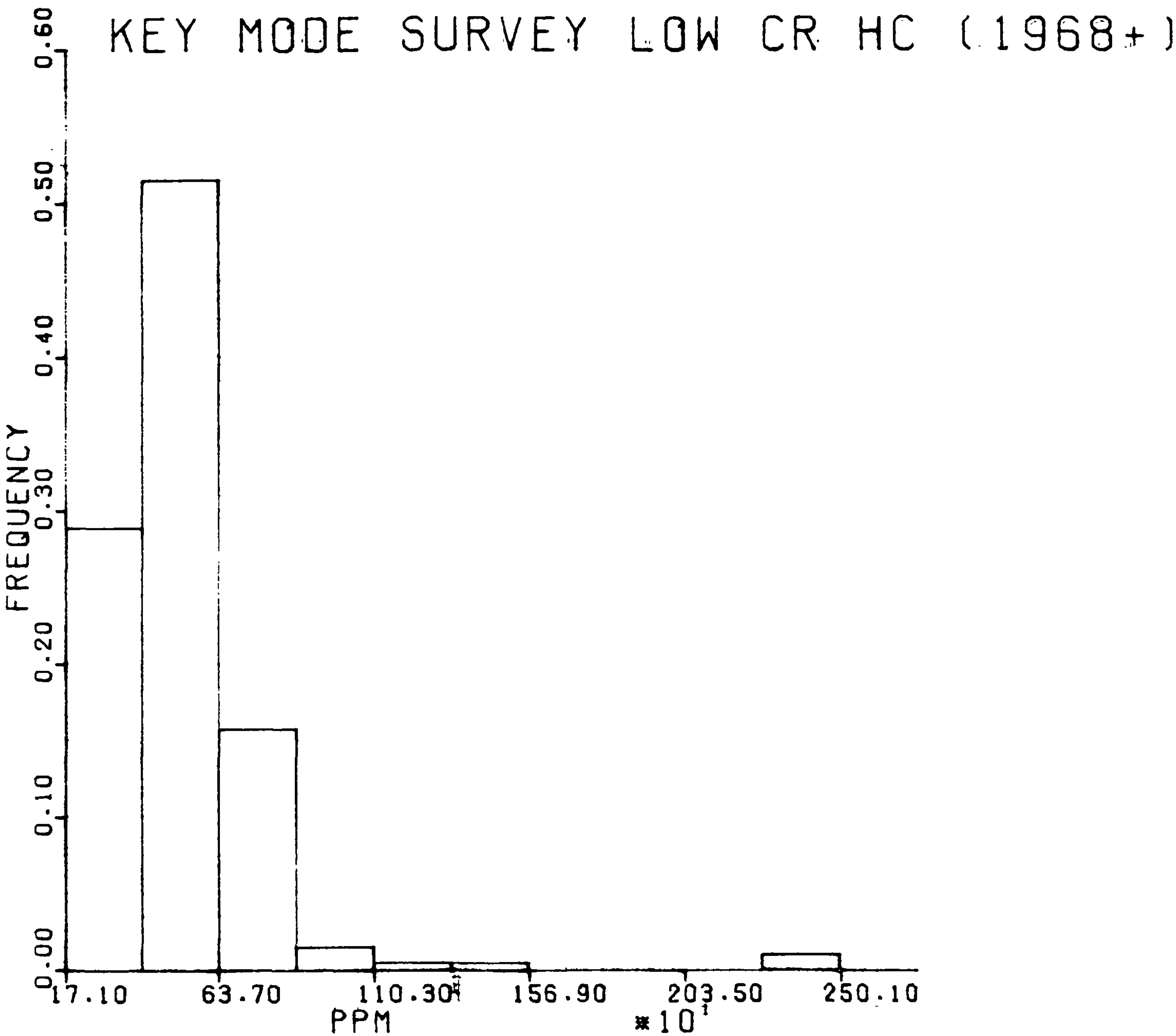

Figure 4-16 Low Cruise HC Frequency Distribution for Controlled Vehicles

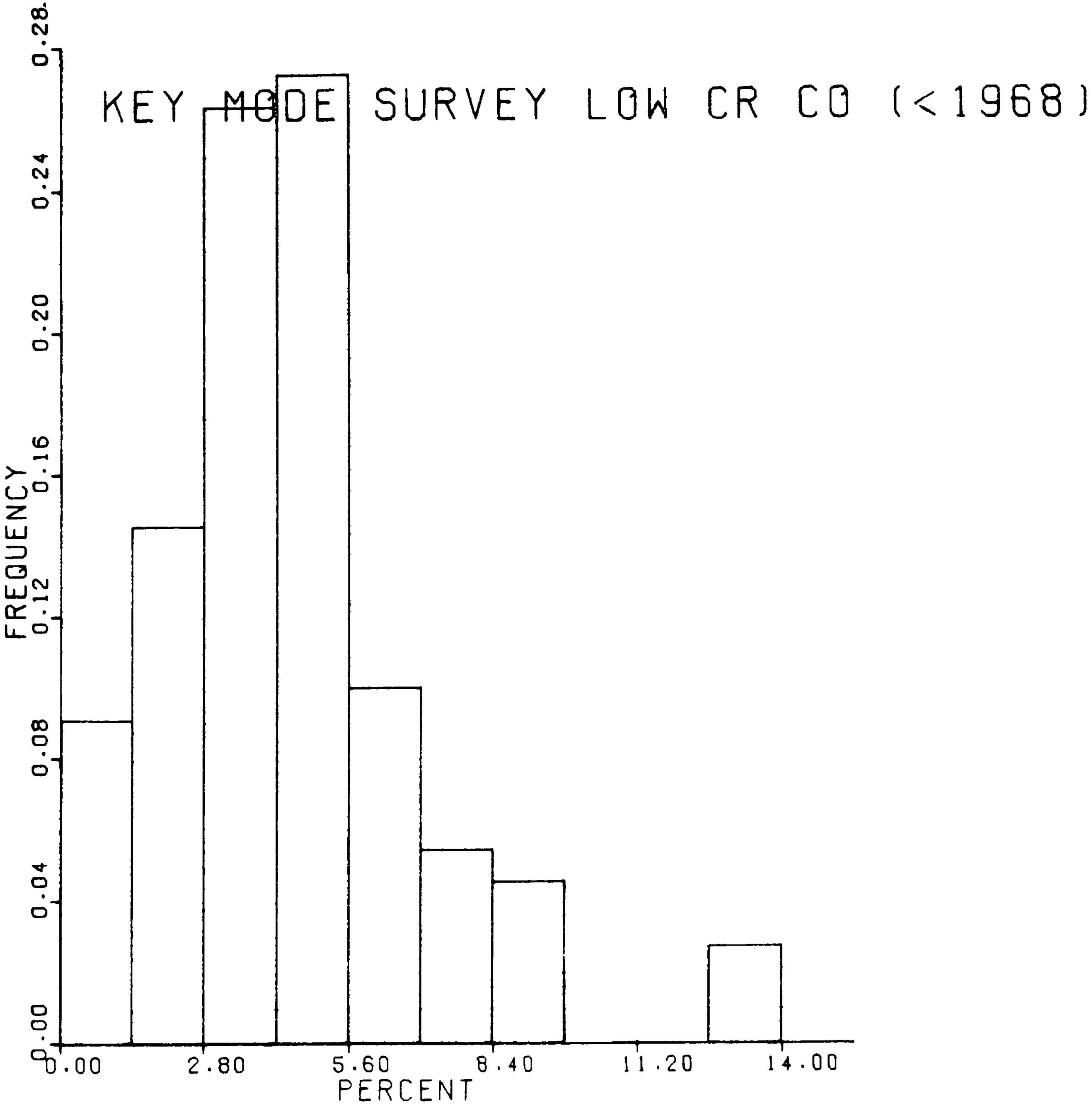

Figure 4-17 Low Cruise CO Frequency Distribution for Pre-Controlled Vehicles

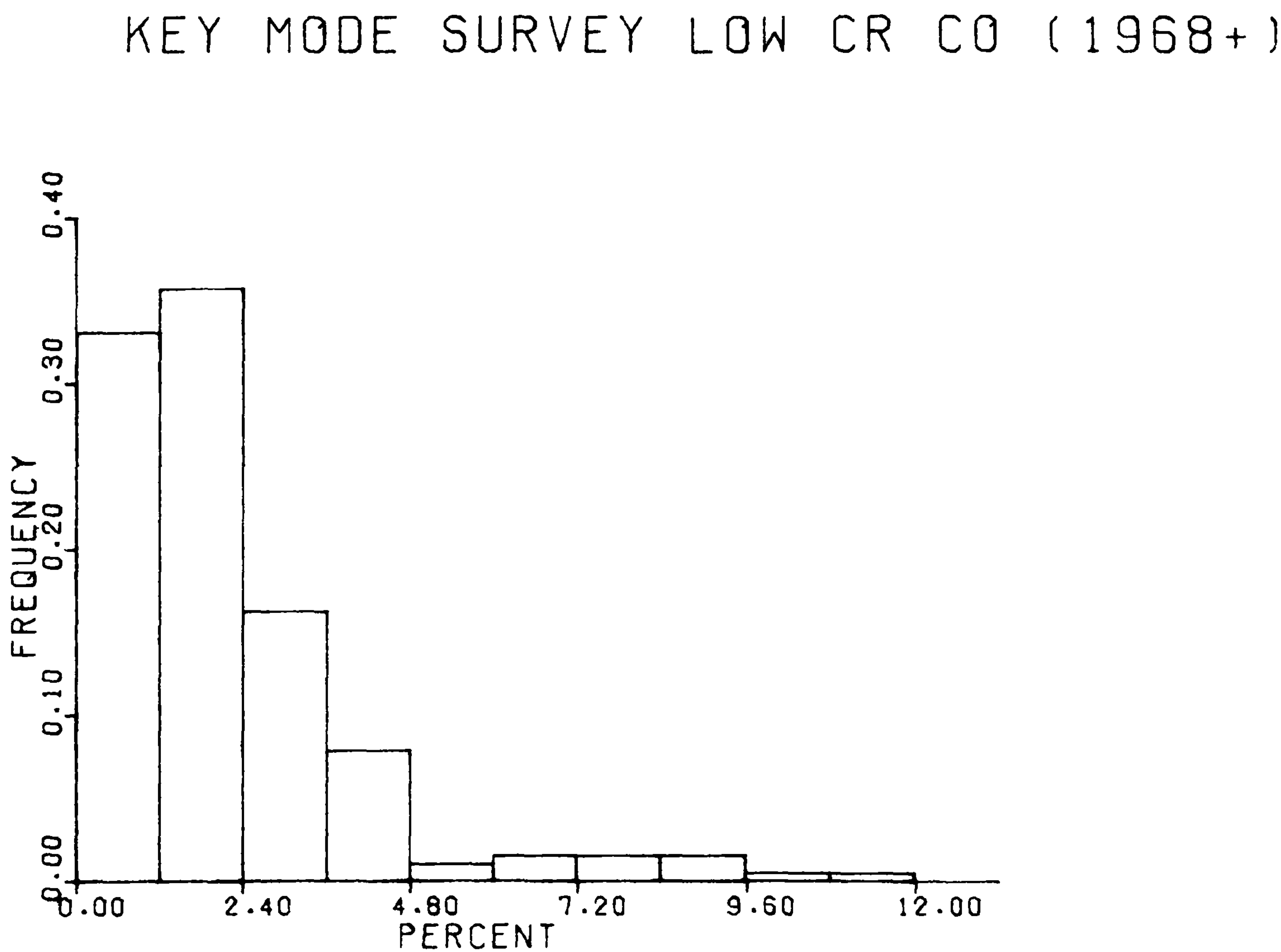

Figure 4-18 Low Cruise CO Frequency Distribution for Controlled Vehicles

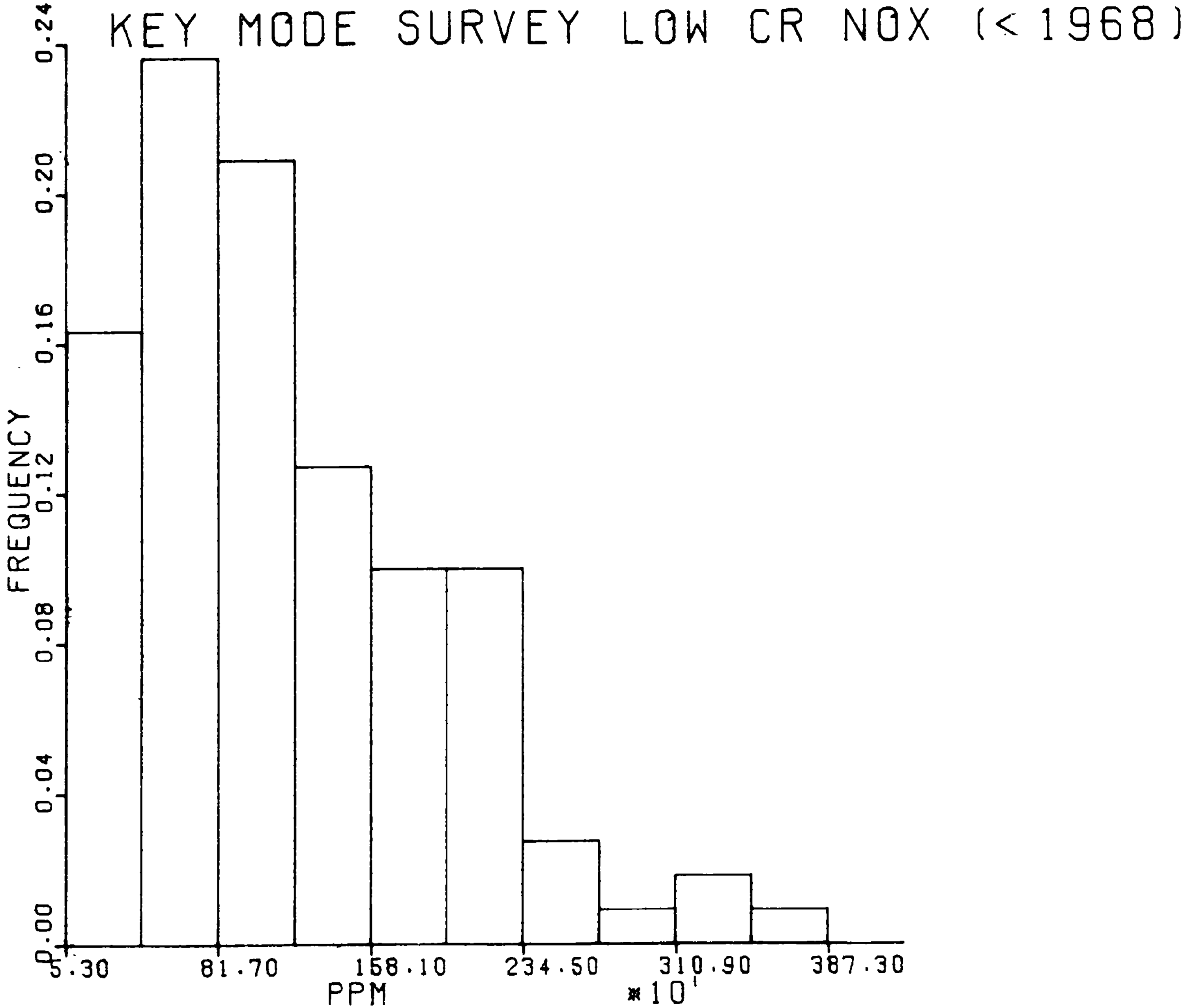

Figure 4-19 Low Cruise NO_x Frequency Distribution for Pre-Controlled Vehicles

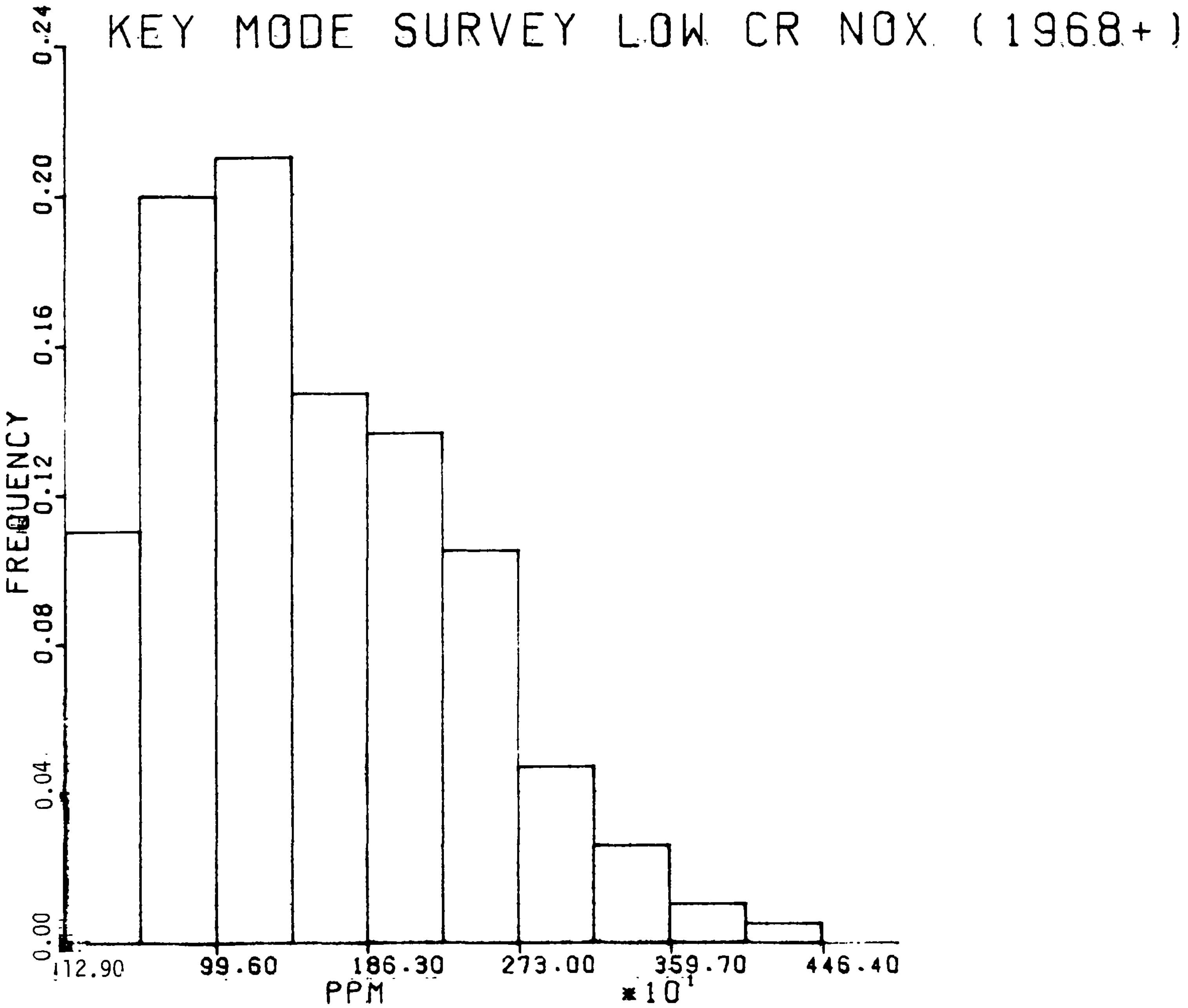

Figure 4-20 Low Cruise NO_x Frequency Distribution for Controlled Vehicles

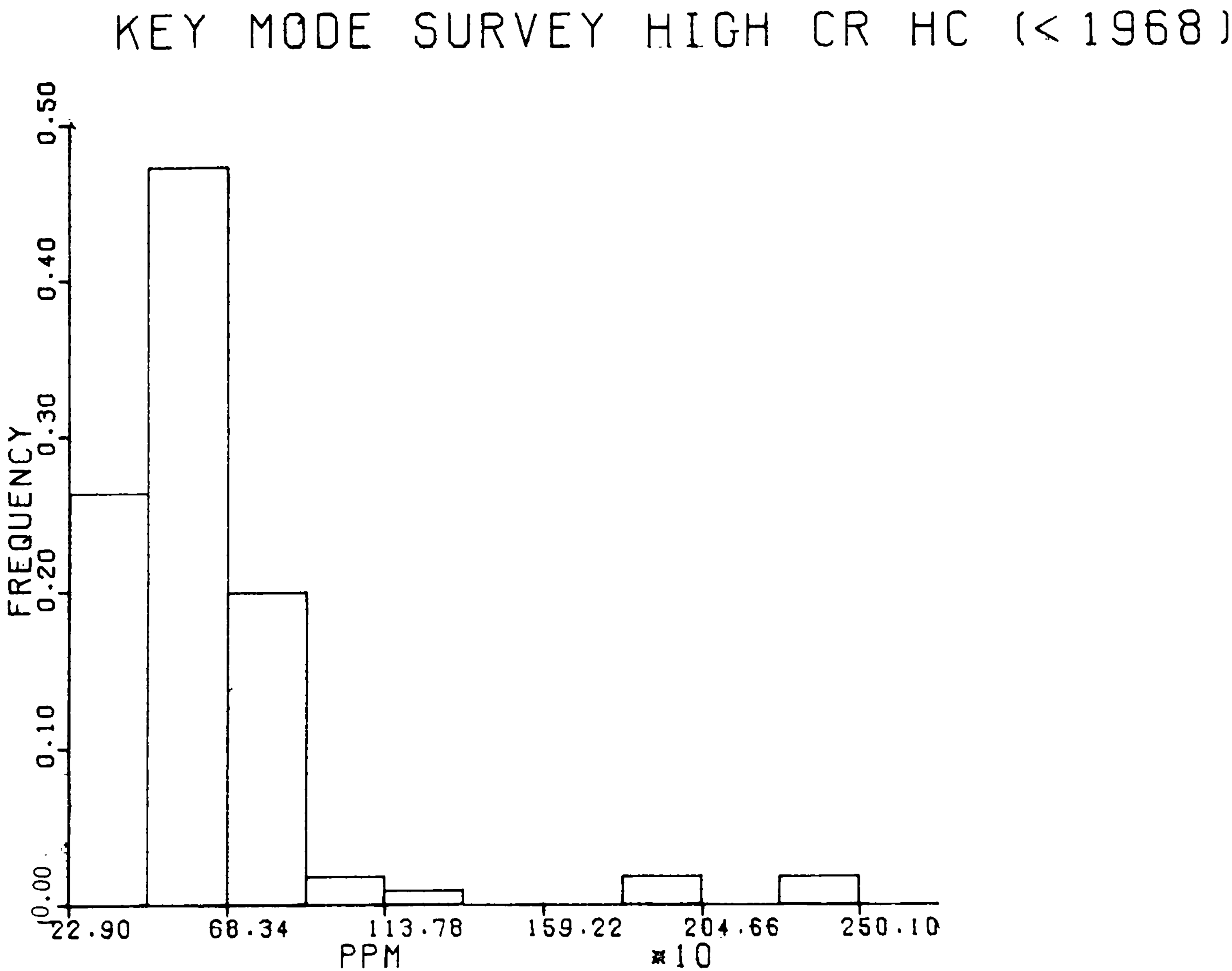

Figure 4-21 High Cruise HC Frequency Distribution for Pre-Controlled Vehicles

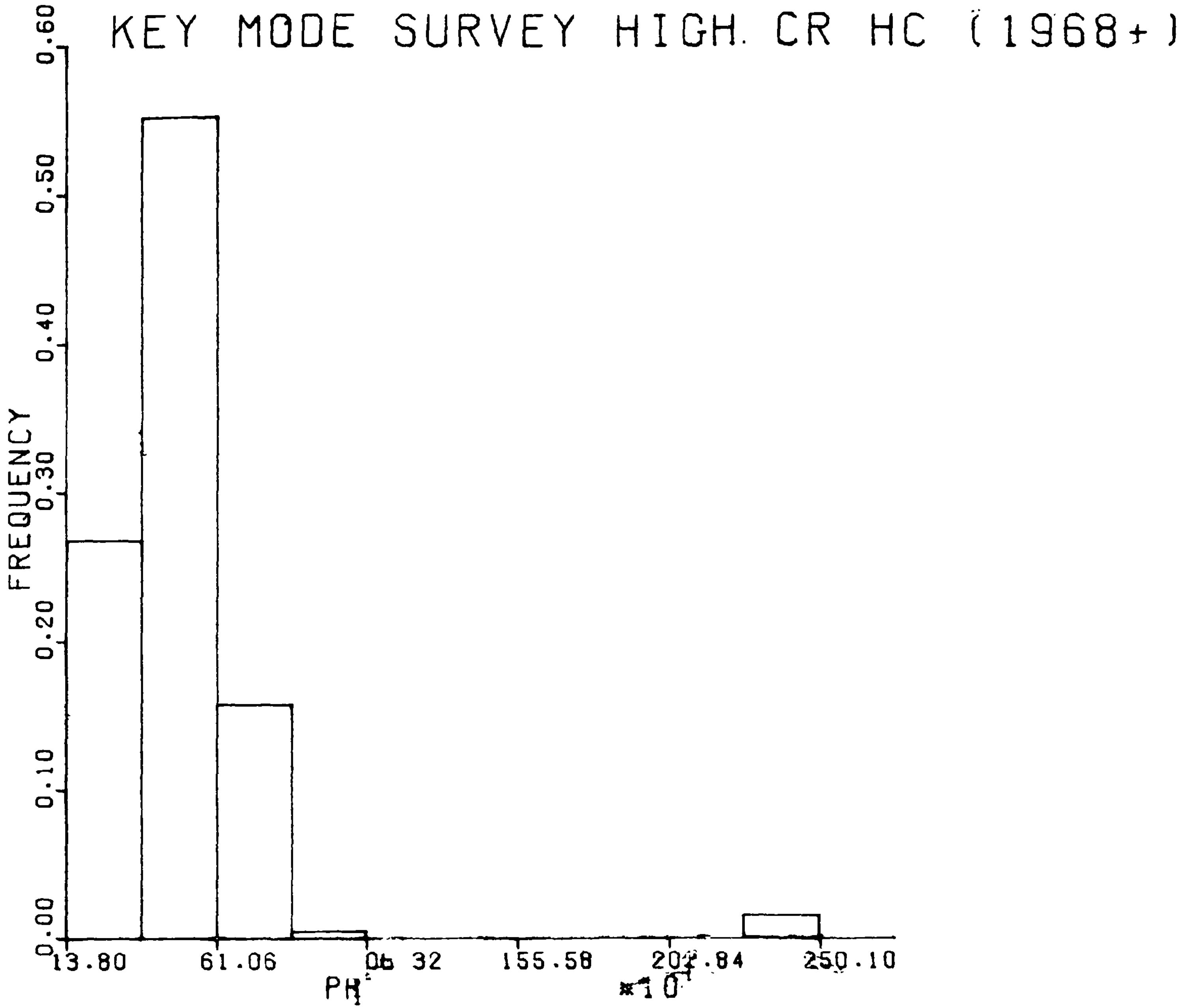

Figure 4-22 High Cruise HC Frequency Distribution for Controlled Vehicles

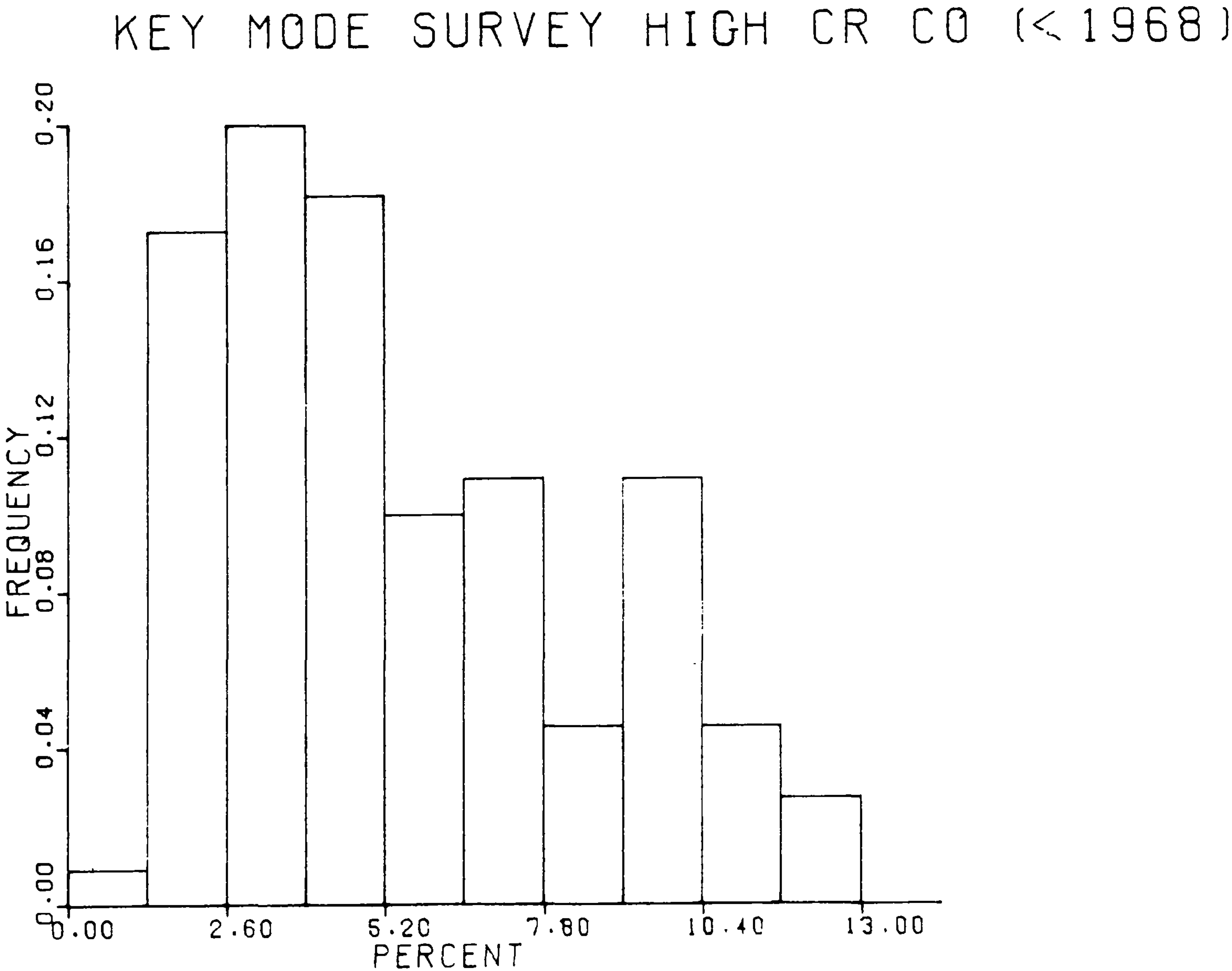

Figure 4-23 High Cruise CO Frequency Distribution for Pre-Controlled Vehicles

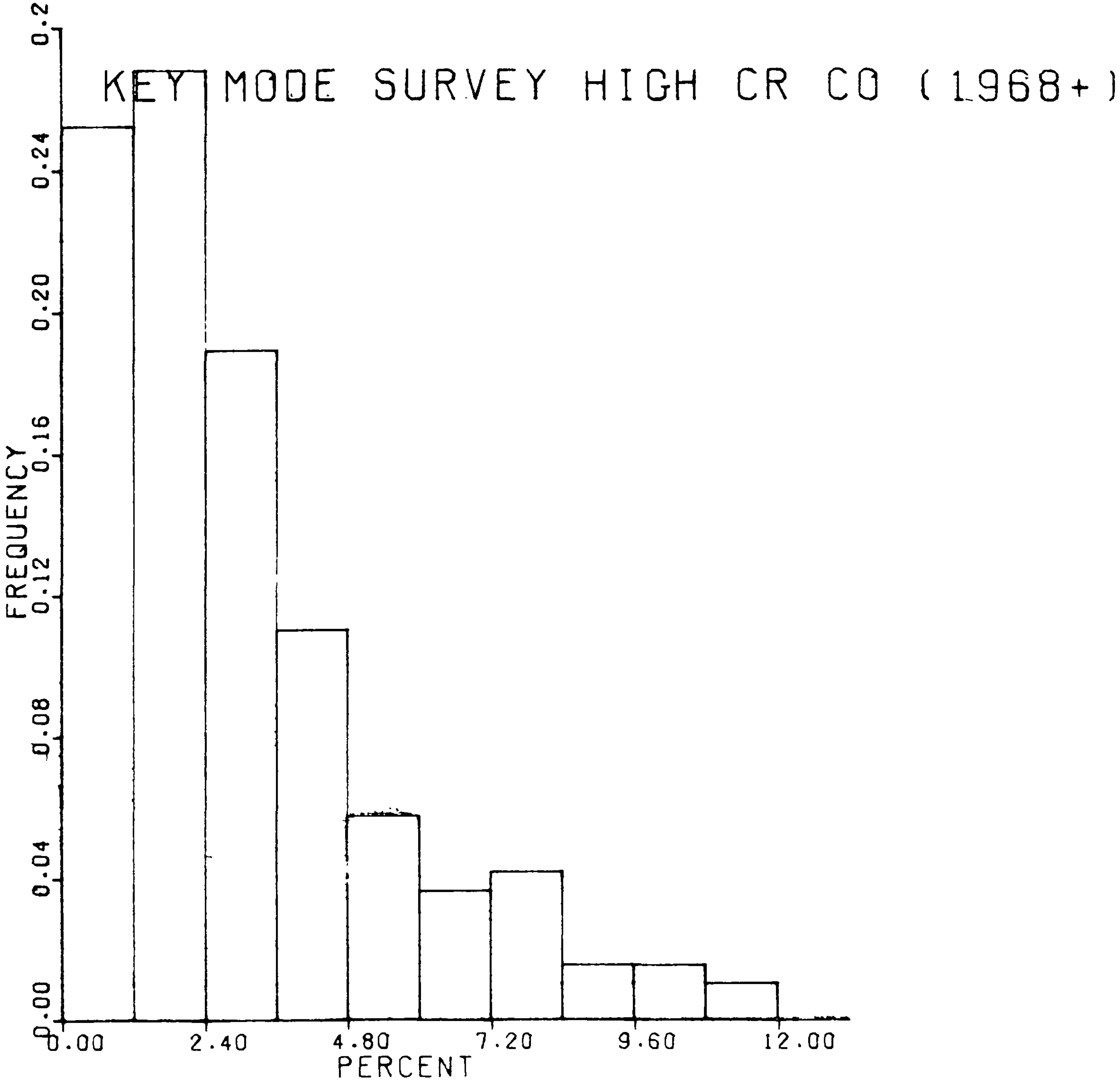

Figure 4-24 High Cruise CO Frequency Distribution for Controlled Vehicles

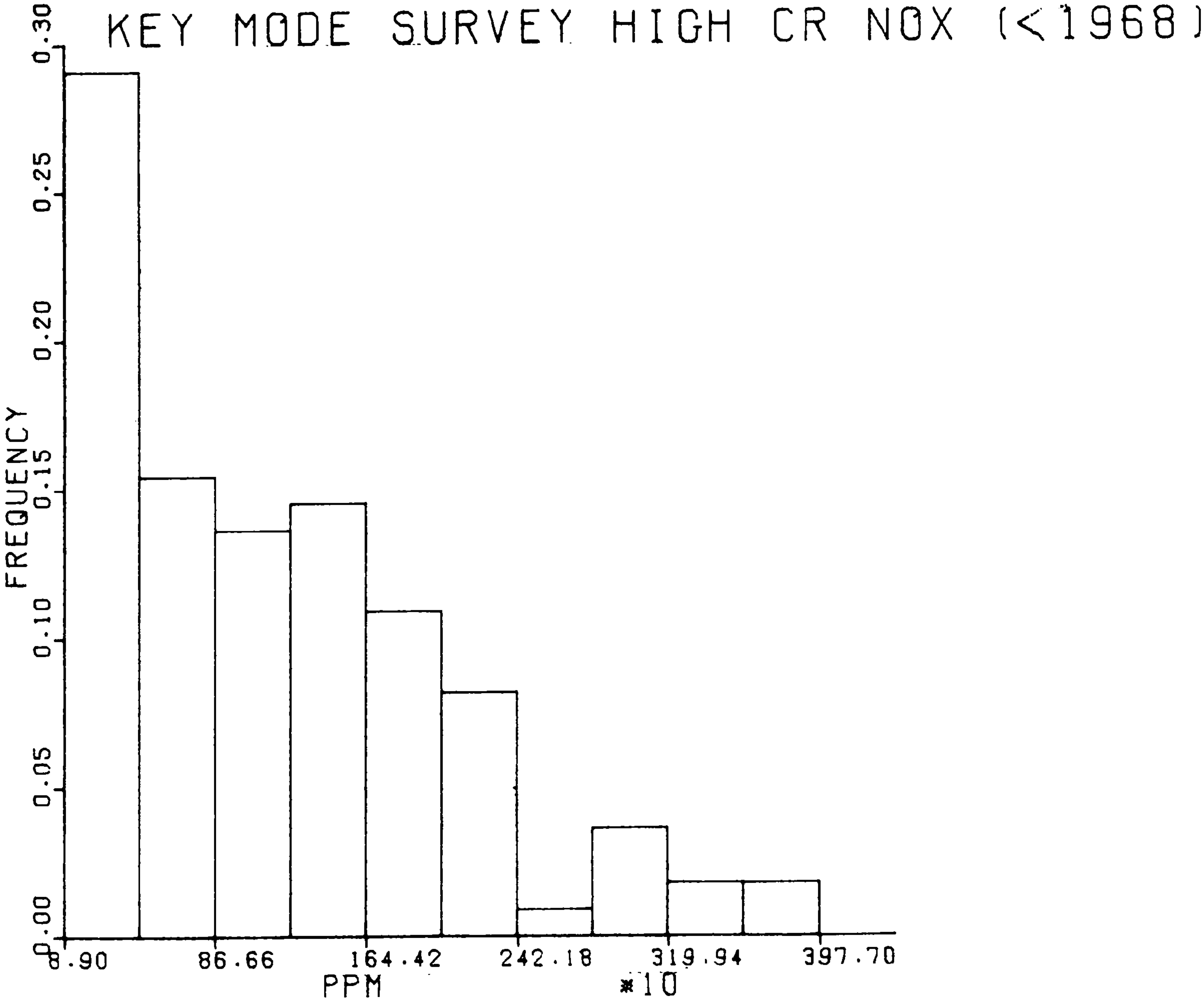

Figure 4-25 High Cruise NO_x Frequency Distribution for Pre-Controlled Vehicles

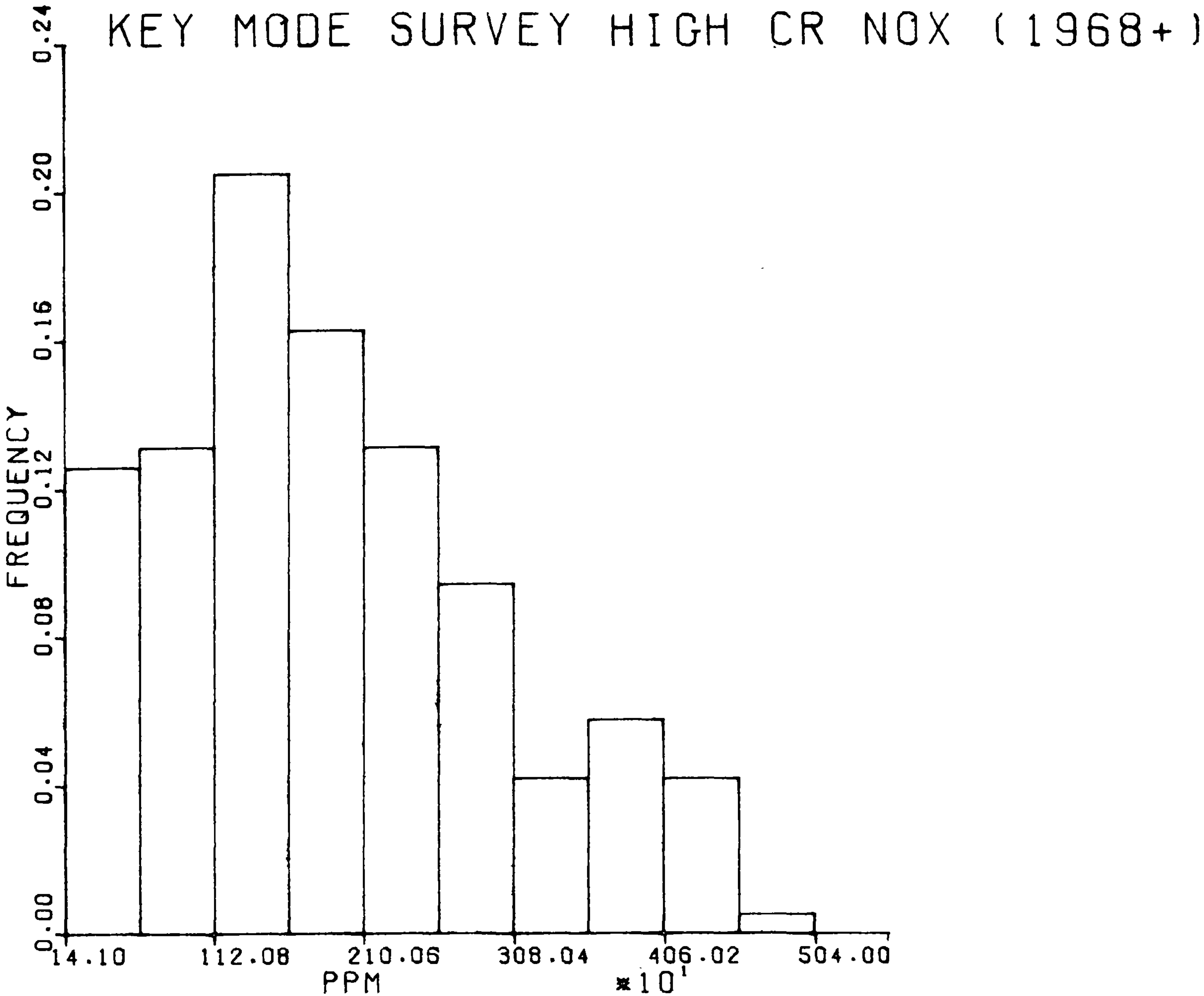

Figure 4-26 High Cruise NO_x Frequency Distribution for Controlled Vehicles

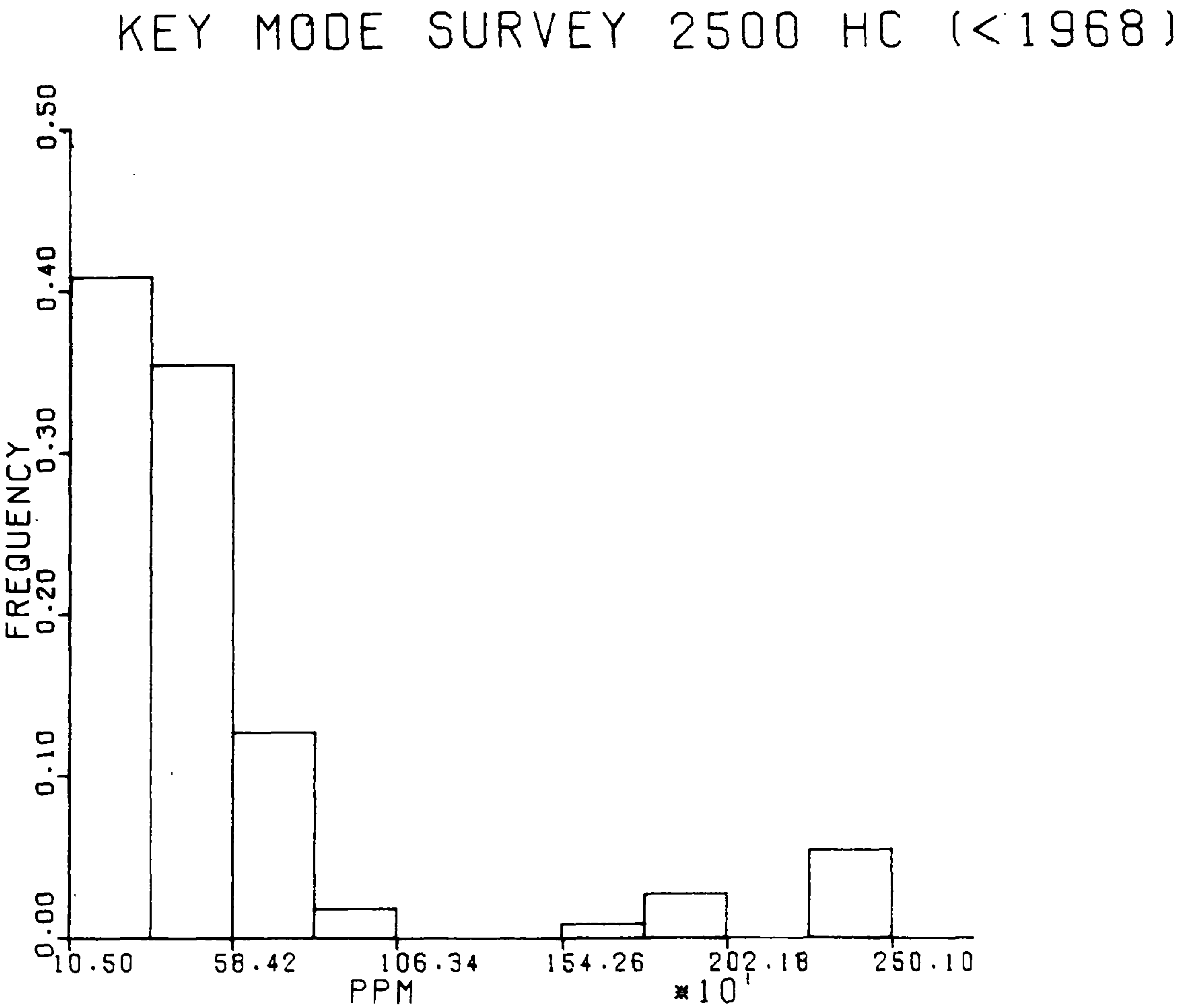

Figure 4-27 HC 2500 Frequency Distribution for Pre-Controlled Vehicles

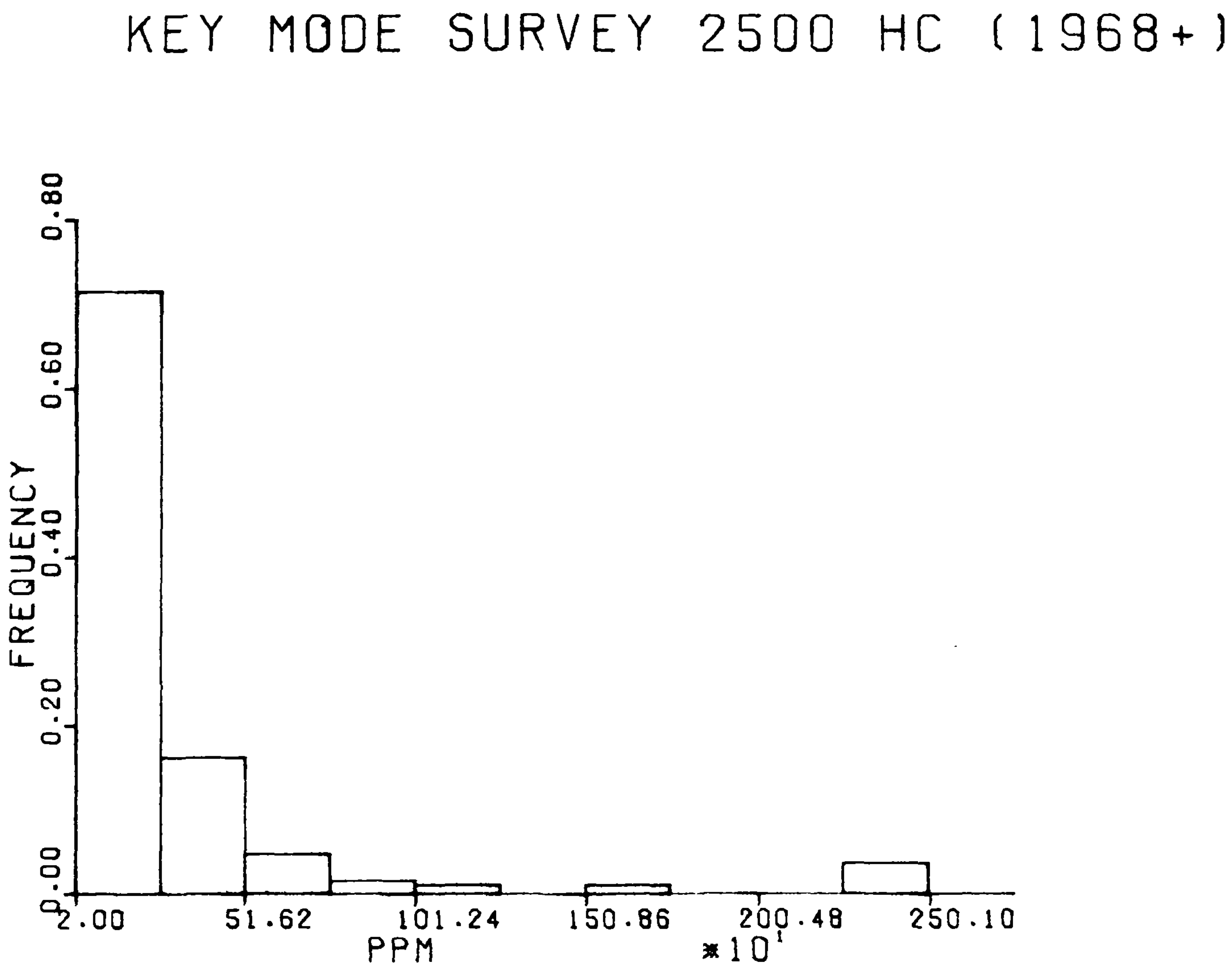

Figure 4-28 HC 2500 Frequency Distribution for Controlled Vehicles

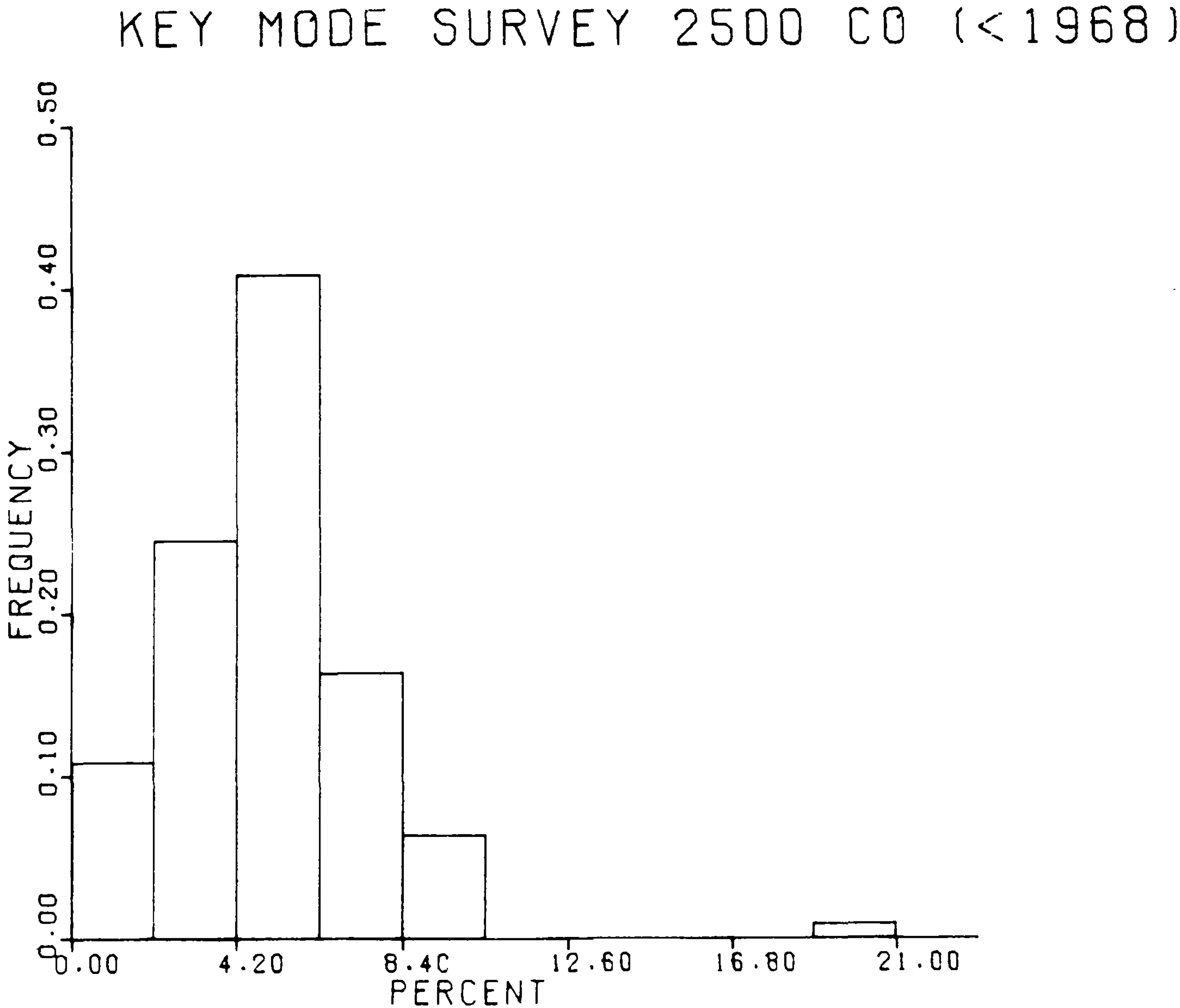

Figure 4-29 CO 2500 Frequency Distribution for Pre-Controlled Vehicles

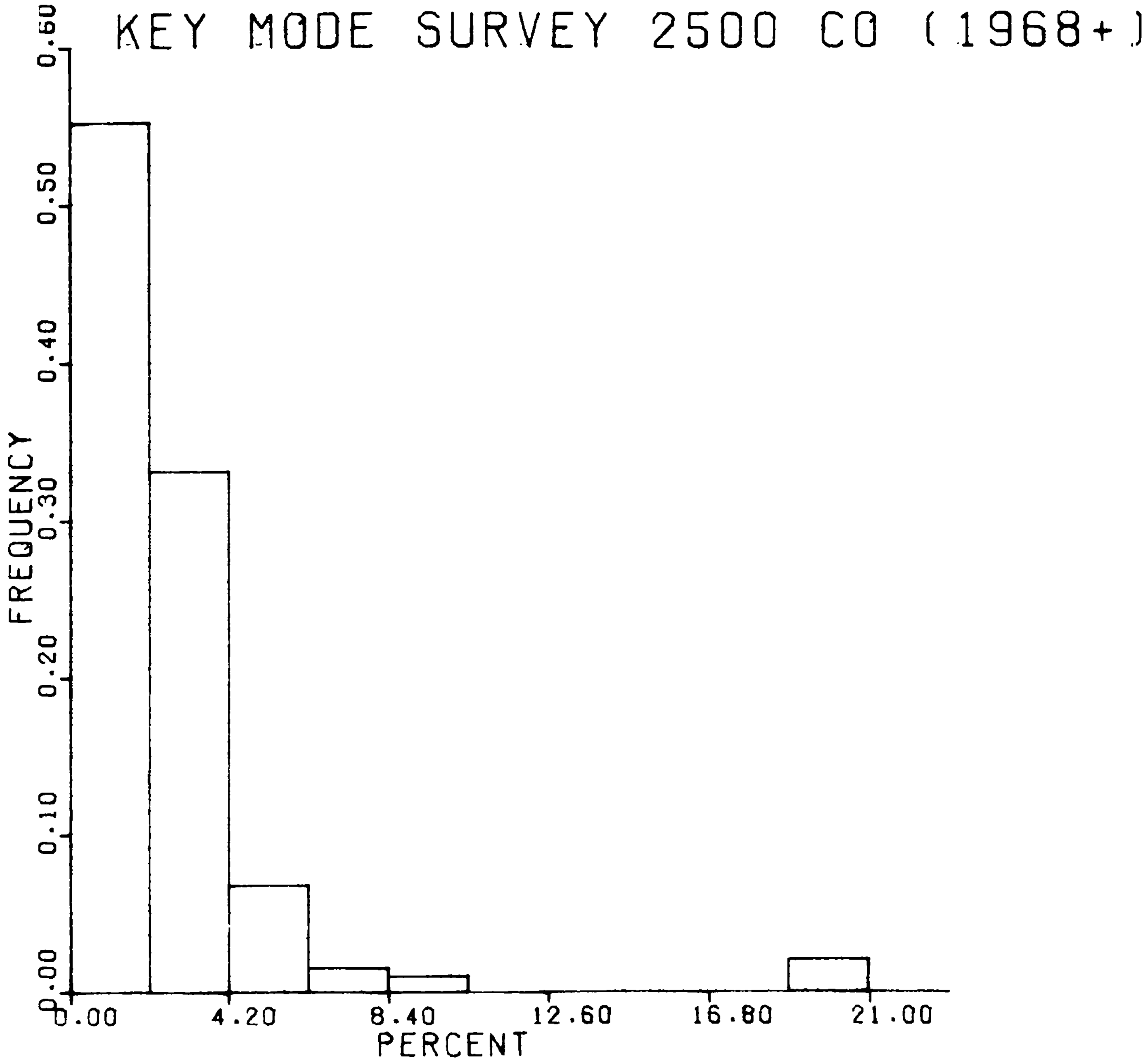

Figure 4-30 CO 2500 Frequency Distribution for Controlled Vehicles

Table 4-10

SURVEY OF CVS MASS EMISSIONS BY MODEL YEAR

	MODEL YEAR					
	PRE 1968		1968+		AVERAGE	
MODE	MEAN	SD	MEAN	SD	MEAN	SD
HC 1975	10.771	5.769	6.361	4.713	7.978	5.541
CO 1975	143.105	52.532	91.333	44.140	110.317	53.488
CO2 1975	395.495	92.519	476.671	122.512	446.91	119.019
NOX 1975	2.113	1.310	2.858	1.390	2.593	1.406
SAMPLE SIZE:	(113)		(180)		(300)	

Table 4-11

SURVEY OF CVS MASS EMISSIONS BY VEHICLE MANUFACTURER

VEHICLE MANUFACTURER

MODE	(GM) MEAN	(GM) SD	(FORD) MEAN	(FORD) SD	(CHRY.) MEAN	(CHRY.) SD	(AMC) MEAN	(AMC) SD	(FOREIGN) MEAN	(FOREIGN) SD
HC 1975	8.816	6.538	7.318	3.933	8.610	6.331	7.329	2.376	5.552	2.431
CO 1975	123.333	59.096	95.737	41.549	125.452	55.246	102.970	27.952	73.906	28.934
CO2 1975	485.176	118.897	455.529	106.027	440.870	90.434	426.370	102.037	293.197	53.041
NOX 1975	2.396	1.225	3.052	1.858	2.479	1.126	2.703	1.271	2.392	.990
SAMPLE SIZE:	(128)		(79)		(50)		(10)		(33)	

Table 4-12

SURVEY OF CVS MASS EMISSIONS BY CUBIC DISPLACEMENT

CUBIC DISPLACEMENT

MODE	(<100) MEAN	(<100) SD	(100-199) MEAN	(100-199) SD	(200-299) MEAN	(200-299) SD	(300-399) MEAN	(300-399) SD	(400+) MEAN	(400+) SD
HC 1975	6.222	2.493	5.423	2.962	8.811	5.857	8.362	5.935	7.365	5.813
CO 1975	76.308	25.543	90.168	37.825	118.234	49.009	113.643	57.655	117.400	57.171
CO2 1975	270.196	38.803	317.444	46.535	380.181	67.869	486.015	74.772	591.628	98.399
NOX 1975	2.210	.852	2.185	1.081	2.262	1.298	2.774	1.544	2.967	1.361
SAMPLE SIZE:	(24)		(25)		(68)		(137)		(46)	

Table 4-13

SURVEY OF CVS MASS EMISSIONS BY VEHICLE WEIGHT

VEHICLE WEIGHT

MODE	1800-2799 MEAN	1800-2799 SD	2800-3799 MEAN	2800-3799 SD	3800-4799 MEAN	3800-4799 SD	4800-5799 MEAN	4800-5799 SD
HC 1975	5.791	2.355	7.571	4.194	9.484	7.385	6.394	3.251
CO 1975	77.861	31.732	103.628	47.107	129.046	59.746	126.633	51.327
CO2 1975	296.539	53.274	424.408	85.239	511.462	95.765	616.513	110.738
NOX 1975	2.358	1.257	2.437	1.249	2.853	1.618	2.699	1.180
SAMPLE SIZE:	(46)		(127)		(112)		(15)	

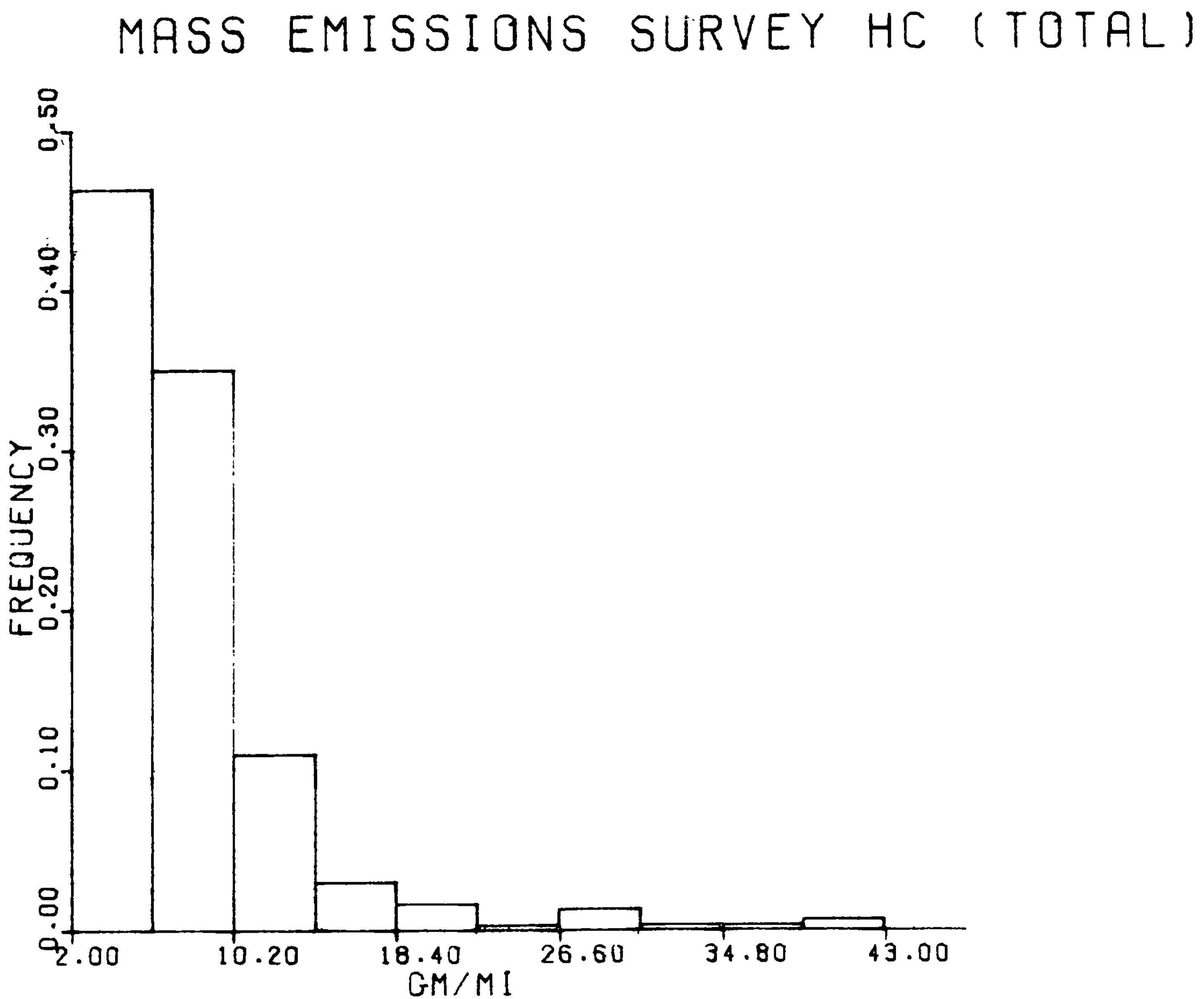

Figure 4-31 HC Mass Emissions Frequency Distribution for Total Vehicle Population

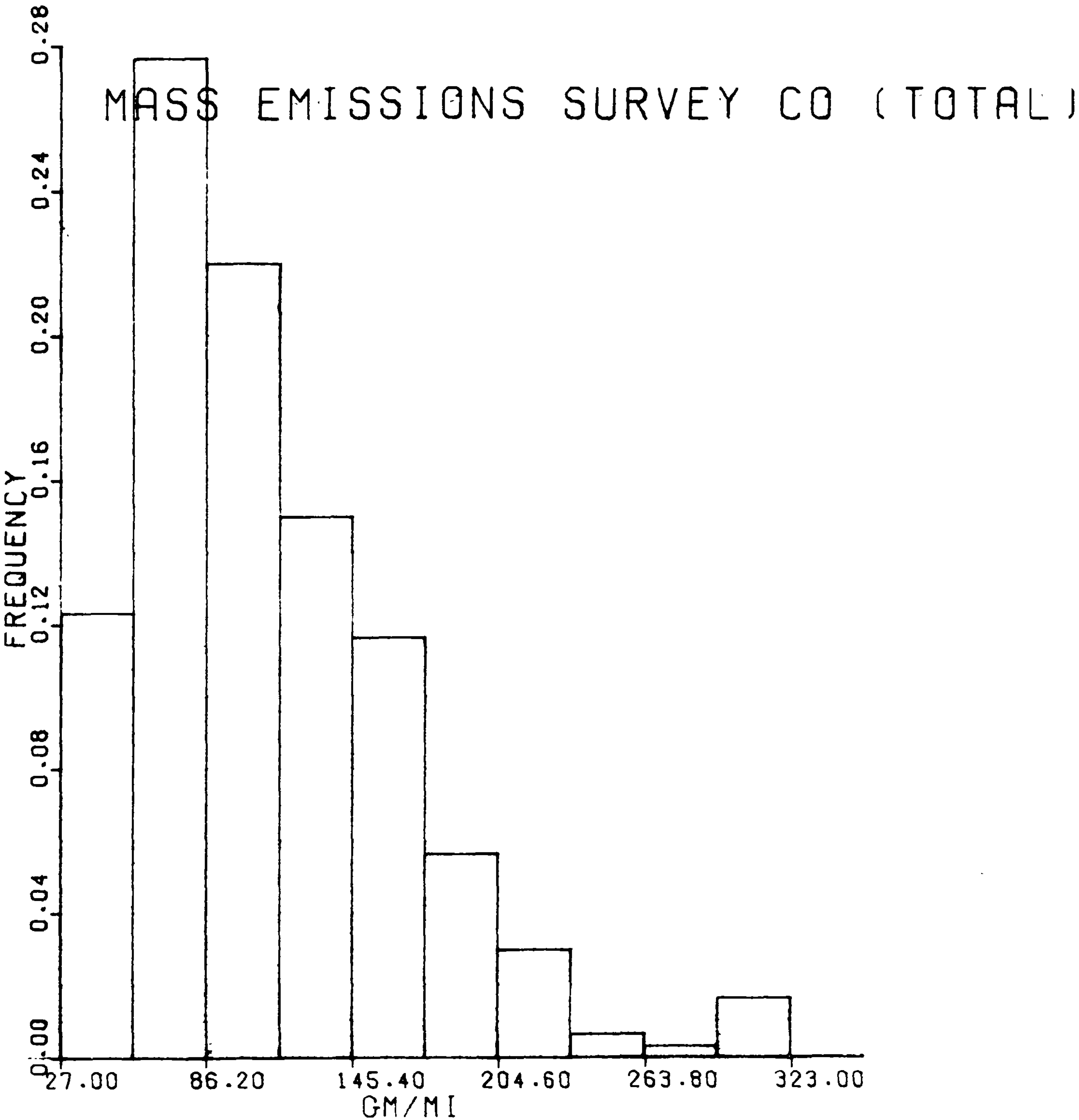

Figure 4-32 CO Mass Emissions Frequency Distribution for Total Vehicle Population

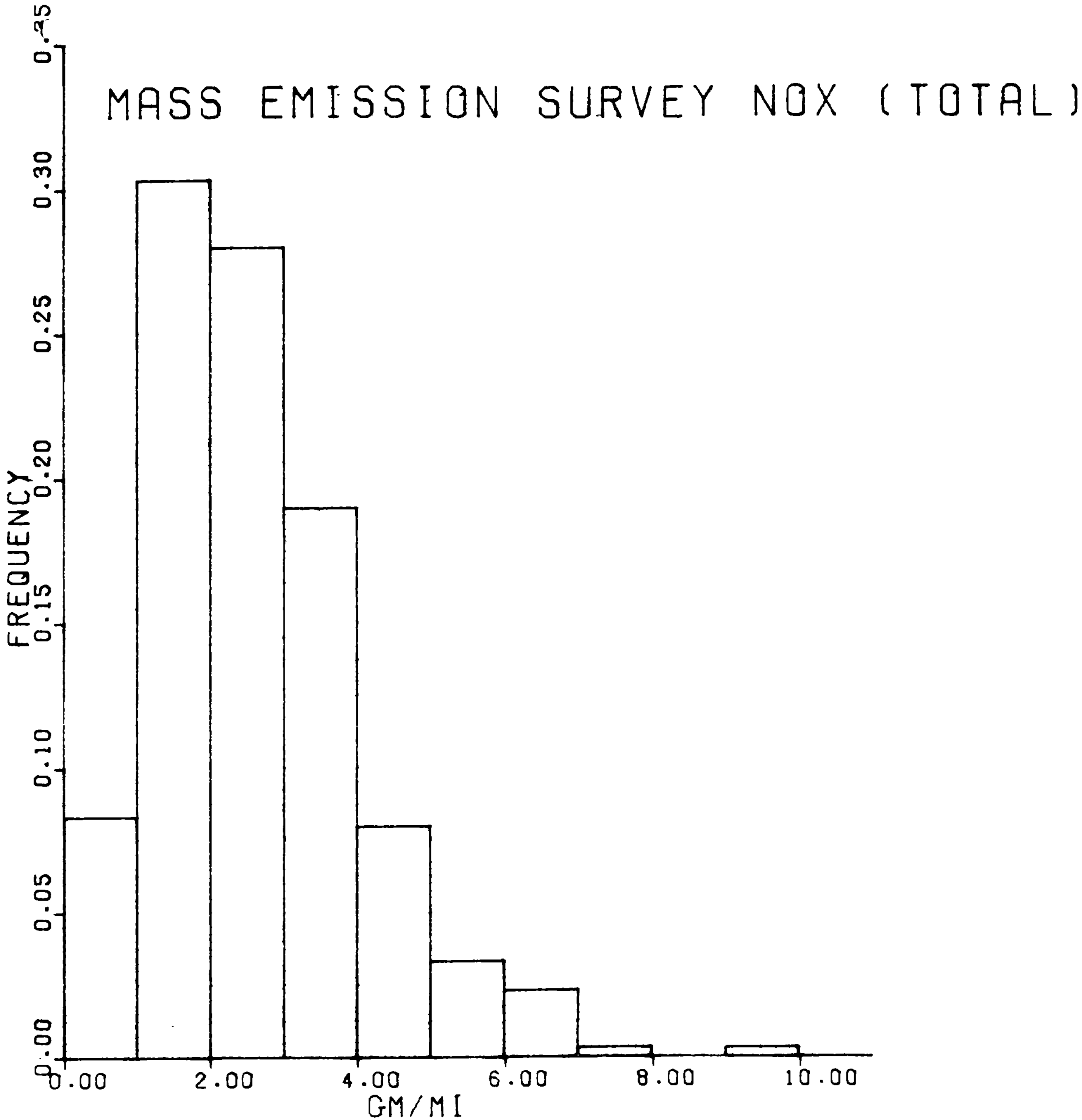

Figure 4-33 NO_x Mass Emissions Frequency Distribution for Total Vehicle Population

5.0 IDLE INSPECTION PROGRAM

Automotive emission control through a program of inspection and maintenance can be accomplished by employing any one of a number of basic alternatives. The experimental program undertaken in this study consisted of the inspecting idle HC and idle CO emissions and determining whether they were in conformance with the prescribed standards. Specific pass/fail standards for both engine parameters and idle emissions were established for pre-controlled vehicles and controlled vehicles as shown in Table 5-1.

The engine maintenance performed on those vehicles failing the idle emission test involved the adjustment of the idle parameters (air/fuel ratio, speed, and timing) followed, if necessary, by additional maintenance in order to ensure compliance with the emission standards.* In effect, the average maintenance treatment can be classified as a "super" idle program. The following sections present an analysis on the effectiveness of the various phases of the idle inspection maintenance program.

5.1 IDLE INSPECTION ACCURACY

The use of emission tests to determine the extent of engine mal-adjustment and malfunctions is desirable from two perspectives. First, the approach tends to have substantially lower costs than the so-called functional tests; and, second it provides some indication of the level of vehicular emissions. Unfortunately, an emission inspection is

* A fifty dollar maximum was assigned as an upper limit on the amount of maintenance that could be performed. A more detailed discussion concerning the maintenance program can be found in Volume II.

Table 5-1

Idle Inspection Pass/Fail Criteria

Measurement	Criteria	
	Pre-Controlled	Controlled
1. Idle HC	800 ppm	330 ppm
2. Idle CO	6%	4%
3. Idle RPM	-80 rpm*	-80 rpm*
4. Basic Timing	1.5 deg*	1.5 deg*

*Criteria established as part of the basic experiment design, but not used in the garage inspection.

confounded by two basic problems:

Errors of omission - Those vehicles passing the inspection that have engine maladjustments or malfunctions.

Errors of commission - Those vehicles failing the inspection that are in a good state of repair.

Errors of omission tend to reduce the effectiveness of the inspection program whereas errors of commission tend to increase program costs. Both effects are normally detected in most applications. The experimental program for Denver was no exception.

Tables 5-2 and 5-3 show the impact of these errors on inspection accuracy for pre-controlled and controlled vehicles, respectively. For illustrative purposes consider the case for idle RPM in Table 5-2 . Out of the 110 vehicles surveyed a total of 16 were found to be outside the pass/fail criterion established for RPM (i.e. -80 rpm). Using an idle HC cutpoint of 800 ppm a total of 46 vehicles were rejected (approximately 42 percent of the total) and of the amount, seven were found with rpm settings beyond the criterion (approximately 15 percent of the total). Thus an idle HC inspection was able to detect nearly 44 percent of the total failures in the population. It should be noted that the percentage failure rate from the inspection (ratio of failed vehicles to rejected vehicles) must be greater than that occurring in the population in order for the screening process to be effective. Otherwise a random selection of vehicles would detect more vehicle failures than the inspection procedures. This situation occurred when using idle CO for detecting rpm maladjustments (13.46% from screening versus 14.55% for actual). For this example, the number of commision errors was 39 (46-7) whereas the number of omission errors was 9 (16-7).

Table 5-2

ANALYSIS OF IDLE INSPECTION ACCURACY FOR PRE 1968 VEHICLES

PARAMETER DIAGNOSTIC MODE	TOTAL SET	CUT POINT	REJECTED		FAILED		FAILED AS PERCENT OF TOTAL	PERCENT OF FAILURES DETECTED
			NO.	PERCENT	NO.	PERCENT		
IDLE RPM(DEV.)	110	≤-80 RPM			16	14.55		
IDLE HC		≥800 PPM	46	41.82	7	15.22	6.36	43.75
IDLE CO		≥6. P.C.	52	47.27	7	13.46	6.36	43.75
TIMING(DEV.)	110	≥1.5 DEG.			40	36.36		
IDLE HC		≥800 PPM	46	41.82	19	41.30	17.27	47.50
IDLE A/F(P.C.)	110	≥6. P.C.			50	45.45		
IDLE CO		≥6. P.C.	52	47.27	23	44.23	20.91	46.00

Table 5-3

ANALYSIS OF IDLE INSPECTION ACCURACY FOR POST 1967 VEHICLES

PARAMETER DIAGNOSTIC MODE	TOTAL SET	CUT POINT	REJECTED NO.	REJECTED PERCENT	FAILED NO.	FAILED PERCENT	FAILED AS PERCENT OF TOTAL	PERCENT OF FAILURES DETECTED
IDLE RPM(DEV.)	190	≤-80 RPM			55	28.95		
IDLE HC		≥330 PPM	85	45.26	26	30.23	13.68	47.27
IDLE CO		≥4. P.C.	96	50.53	32	33.33	16.84	58.18
TIMING(DEV.)	190	≥1.5 DEG.			74	38.95		
IDLE HC		≥330 PPM	86	45.26	28	32.56	14.74	37.84
IDLE A/F(P.C.)	190	≥4. P.C.			100	52.63		
IDLE CO		≥4. P.C.	96	50.53	49	51.04	25.79	49.00

In summary, the analysis showed that idle HC was most effective in detecting rpm and timing maladjustments whereas idle CO was best for determining idle air/fuel ratio maladjustments. A serious problem emerged in relating idle CO measurements to idle air/fuel ratio maladjustments. Typically, there is a one-to-one relation between the two parameters. For this study, however, there was found a large difference between the two as illustrated in the last row of Table 5-3. From the 190 vehicles surveyed, 100 or approximately 53 percent were discovered to have idle air/fuel ratios above 4%.* Using the same criterion for the garage inspection resulted in rejecting 96 vehicles, however, only 49 of these vehicles were found to be outside the pass/fail limits. This apparent inconsistency can be attributed to inaccuracy in the garage measurement procedures.

An analysis of measurement accuracy between the laboratory and garage equipment is shown in Table 5-4. The data show the wide variability between the two sets of measurements. For all model emissions, the garage readings were found to fall within a ± 10 percent band of the laboratory readings is less than 10 percent of the recorded measurements. The highest percentage (approximately 2/3) of the cases found the garage reading lower then the corresponding laboratory readings. This situation, in effect, led to higher rejection rates then had orginally been planned for in the experimental design (50 percent for laboratory versus 59 percent for garage). Certainly improving the quality control of the measurement phase of the inspection program should lead to more effective system performance.

* The extent of engine maladjustments and malfunctions were determined in the laboratory.

Table 5-4

Analysis of Measurement Accuracy Between Laboratory and Garage Equipment*

Emission	Average Lab Reading	Average Garage Reading	Garage Reading Too Low** (Percent)	Garage Within ±10 Percent (Percent)	Garage Reading Too High*** (Percent)	Average Difference Between Readings
Idle HC	563.650	503.883	70.3	6.3	23.3	267.566
2500 HC	405.453	351.173	75.3	6.7	18.0	190.280
Idle CO	5.153	4.534	62.0	8.7	29.3	1.745
2500 CO	3.458	3.150	61.0	6.3	32.7	1.387

Sample Size: 300

* Measurements derived using Sun equipment.

** Garage reading less than 0.9 x Lab reading.

*** Garage reading greater than 1.1 x Lab reading.

5.2 VEHICULAR EXHAUST EMISSION STANDARDS

A crucial element in the design of an effective inspection/maintenance program involves the establishment of automotive exhaust emission standards. The relationship between emission standards and system performance embodies a number of complexities which must be thoroughly understood prior to the implementation of the control program.

Tables 5-5 and 5-6 show vehicle rejection fractions as a function of single idle mode cutpoints for pre-controlled and controlled vehicles, respectively. The reported data was recorded under laboratory conditions. In Table 5-5 the relationship between emissions as measured by both the Beckman and SUN equipment if related to the percent of vehicles rejected. For example, a pass/fail criterion of 860 ppm using the Sun equipment would reject 20 percent of the vehicles whereas the same criterion used with the Beckman equipment would fail nearly 40 percent. The corresponding criterion need to fail 20 percent using the Beckman equipment is 1280 ppm or 420 ppm greater than for the Sun equipment.

As seen in Table 5-6, the correlation between the Beckman and laboratory Sun equipment for CO is much closer. For example, a 5.6% criterion for the Sun instrument yields a rejection rate of 30 percent whereas the same criterion would reject approximately 38 percent using the Beckman analyzer.

Regression analysis between the Beckman and Sun equipment revealed a population weighted average correlation coefficient of 0.7 for HC and 0.94 for CO. More details on the characteristics of the measuring equipment can be found in Section 6.1.5 of Volume II.

The estimated rejection rates in the foregoing analysis are based on a single emission standard. That is, the interactive effects

Table 5-5

Rejection Fractions Versus Idle Mode Cutpoints for Pre-Controlled Vehicles

REJECTION FRACTION (PERCENT)	HC (PPM)	HC BECKMAN (PPM)	HC SUN (PPM)	CO BECKMAN (PERCENT)	CO SUN (PERCENT)	NOX (PPM)
1	38800	2500	2500	12.8	20.0	427
10	16300	1800	1450	10.1	9.6	125
20	11800	1280	860	9.0	8.4	94
30	10000	940	760	8.4	7.6	72
40	8100	850	680	7.3	6.5	61
50	6600	770	600	6.5	5.8	51
60	6000	720	550	5.9	4.8	45
70	5500	650	450	4.7	4.1	36
80	5100	530	400	3.7	3.3	28
90	4300	470	330	2.7	2.0	24
100	2200	240	130	.1	.2	5

Table 5-6

Rejection Fractions Versus Idle Mode Cutpoints for Controlled Vehicles

REJECTION FRACTION (PERCENT)	HC (PPM)	HC BECKMAN (PPM)	HC SUN (PPM)	CO BECKMAN (PERCENT)	CO SUN (PERCENT)	NOX (PPM)
0	40500	2500	2500	12.8	20.0	2590
10	10600	1030	760	9.0	8.2	153
20	6500	780	580	7.2	6.6	101
30	5600	660	440	6.4	5.6	88
40	4700	550	350	5.5	4.8	77
50	4200	490	290	4.7	4.2	70
60	3900	440	250	4.0	3.2	64
70	3400	380	220	3.0	2.7	55
80	2900	330	170	1.9	1.7	50
90	2300	270	130	1.0	.7	38
100	500	0	20	.2	.1	10

between emissions, e.g. idle HC and idle CO, have not been taken into account. In determining an optimal set of emission criteria, however, these interactions must be taken into consideration. Since we have two bases for rejecting a vehicle, HC and CO emissions, a car can be rejected for failing one or the other or both of these tests. If HC or CO were to be used separately then the appropriate cutpoints for them are in Tables 5-5 and 5-6. However, since they are to be used together their interaction must be accounted for.

If the HC and CO emission levels were completely independent of each other then the combined rejection fraction could be calculated simply by taking the union of the two individual rejection fractions:

$$r_{TOTAL} = r_{HC} \cup r_{CO} = r_{HC} + r_{CO} - r_{HC} \times r_{CO}$$

Since there are an infinite number of possible r_{HC}'s and r_{CO}'s which would fulfill this requirement the additional constraint of having r_{HC} equal r_{CO} yields a unique set of cutpoints. Thus, to find the cutpoints with a total rejection fraction of 50 percent one would use the cutpoints for HC and CO at 30 percent as found in Tables 5-5 and 5-6. These values are 940 PPM and 8.4 percent for HC and CO respectively for precontrolled and 660 PPM and 6.4 percent for controlled vehicles. Since the union of 30 percent and 30 percent is 51 percent,use of these cutpoints will results in rejecting 51 percent of the total vehicle population. That is if, indeed, HC and CO emission levels are independent of each other.

Unfortunately, test results have shown that HC and CO are not independent. A vehicle with high HC emissions is also more likely to have high CO emissions than pure randomness would indicate, and vice versa. Consequently, one must consider these interactions in establishing effective emission standards. The results of this investigation is presented in Tables 5-7 and 5-8 for pre-controlled and controlled vehicles, respectively.

Tables 5-7 and 5-8 show the relations between the rejection fractions and mode emission cutpoints including the effects of interactions. These idle key mode emissions are those measured with the Sun instruments. The cutpoints were selected on the basis that the rejection fractions for HC and CO taken separately should be equal. Thus the HC and the CO cutpoints are equally responsible for the net effect of their joint use.

The cutpoints for 50 percent are illustrated further in Table 5-9. This table also includes the standards used in the inspection experiment for the purpose of comparison. Also shown is the rejection fraction due to HC and CO alone and those vehicles which are rejected by both of these tests.

The experimental standards are notable in that they result in rejection fractions somewhat higher than anticipated. Although they were designed for a rejection rate of 50% they in fact produced an actual rate of 61.2% and 58.3% at the laboratory and garage, respectively. There are several reasons for the difference between these three figures:

1. The initial cutpoints were derived without considering the potential interactions between multiple emission criteria.

2. The nature of these tests was to introduce a bias lowering apparent vehicle emissions.

Table 5-7

Rejection Fractions Versus Multiple Idle Key Mode Cutpoints for Pre-Controlled Vehicles

REJECTION (PERCENT)	HC (PPM)	CO (PERCENT)
0	2500.	20.0
10	2500.	10.0
20	1350.	9.4
30	1080.	8.8
40	800.	8.0
50	740.	7.3
60	700.	6.7
70	605.	5.8
80	520.	4.5
90	450.	3.8
100	130.	.2

Table 5-8
Rejection Fractions Versus Multiple Idle Key Mode Cutpoints for Controlled Vehicles

REJECTION (PERCENT)	HC (PPM)	CO (PERCENT)
0	2500.	20.0
10	1250.	9.5
20	730.	7.6
30	575.	6.6
40	440.	5.6
50	360.	4.9
60	320.	4.5
70	265.	3.4
80	220.	2.7
90	175.	1.6
100	20.	.1

Table 5-9

Emission Cutpoints for Vehicles at 50% Rejection Rate

	Cutpoints		Percentage of Vehicles Rejected				
	HC (PPM)	CO (Percent)	By HC Only	By CO Only	By Both HC and CO	Total	
Pre 1968	800	6	12.7	33.6	13.6	59.9	Experimental Standards
Post 1967	330	4	10.5	16.8	34.7	62.0	
Pre 1968	725	7	18.2	20.0	12.7	50.9	Revised Standards
Post 1967	360	5	12.6	11.6	25.3	49.5	

3. Garage emission readings were generally significantly lower than lab readings as reported in Section 5.1.

The revised standards, which yield a 50% rejection rate, represent a more accurate assessment of these important interactions.

The evaluation of specific vehicle attributes represents another important consideration in establishing effective emission standards. Clearly, no one set of standards will necessarily be applicable for the entire vehicle population. Instead, standards based on individual vehicle characteristics, e.g., emission control type, most likely will yield improved results. The more significant emission oriented attributes include: control type, model year, engine block size, gross weight, and manufacturer.

An analysis of variance procedure was used to evaluate the statistical significance of partitioning the vehicle population by control type and engine block size. Results of this evaluation are given for HC, CO and NO_x in Tables 5-10, 5-11 and 5-12, respectively. Shown are idle and CVS emissions means for the partitioned population. These results clearly show that there exists a statistical difference between vehicular control types (as indicated by the large χ^2 scores) for all three emission species (using both idle and CVS procedures). Unfortunately, the case for engine block size produces ambivalent results. The statistical scores for both idle HC and idle CO were not significant, indicating no difference in idle HC and idle CO emissions between small (equal to or less than 200 cubic inches) and large (greater than 200 cubic inches). The computed χ^2 for idle NO_x emissions, however, indicates a statistical difference between the two engine block sizes.

These results indicate that for an idle inspection program (measuring HC and CO) it is unnecessary to differentiate between large and small vehicles. In terms of mass emissions, however, partitioning the vehicle population by engine size does result in statistically significant differences. Since reducing mass emissions is of prime importance in any inspection program, the above observations must be considered when establishing meaningful standards.

The use of a block size criterion of 200 cubic inches was merely to illustrate the impact of this vehicle attribute on defining idle exhaust emission standards. Statistical analyses were performed to determine the significance of several engine sizes on emissions. Figures 5-1 and 5-2 show the significance of engine size on idle and CVS emissions. Plotted on the vertical axis is the probability of occurrance for a particular engine size partition (the lower the probability of occurrance the higher the confidence that the two different classes are different). The developed results for idle emissions (Figure 5-1) are somewhat confounded. For example, the maximum confidence levels, i.e. lowest probability of occurrance, are 400 cubic inches for HC, 200 cubic inches for CO and 200 cubic inches for NO_x. The situation for CVS emissions is much more consistent. Here, the maximum confidence levels for all three species are at 200 cubic inches.

Table 5-10

Analysis of Variance Results for
an Idle HC Emission Inspection

Block Size	Pre 1968	1968-1970	Post 1970
≤ 200	$\overline{X}_{Idle}$ = 1227 ppm $\overline{X}_{CVS}$ = 8.48 g/m	$\overline{X}_{Idle}$ = 1032 ppm $\overline{X}_{CVS}$ = 6.55 g/m	$\overline{X}_{Idle}$ = 631 ppm $\overline{X}_{CVS}$ = 5.28 g/m
> 200	$\overline{X}_{Idle}$ = 889 ppm $\overline{X}_{CVS}$ = 11.05 g/m	$\overline{X}_{Idle}$ = 640 ppm $\overline{X}_{CVS}$ = 7.18 g/m	$\overline{X}_{Idle}$ = 521 ppm $\overline{X}_{CVS}$ = 5.86 g/m

Block Size (rows):

$\chi^2_{Idle} = 0.174$

$\chi^2_{CVS} = 3.130$

Model year (columns):

$\chi^2_{Idle} = 53.352$

$\chi^2_{CVS} = 113.175$

Table 5-11

Analysis of Variance Results for
an Idle CO Emission Inspection

Block Size	Pre 1968	1968-1970	Post 1970
≤ 200	$\overline{X}_{Idle}$ = 5.84% $\overline{X}_{CVS}$ = 96.6 g/m	$\overline{X}_{Idle}$ = 4.60% $\overline{X}_{CVS}$ = 91.6 g/m	$\overline{X}_{Idle}$ = 5.77% $\overline{X}_{CVS}$ = 74.8 g/m
> 200	$\overline{X}_{Idle}$ = 6.34% $\overline{X}_{CVS}$ = 148.8 g/m	$\overline{X}_{Idle}$ = 5.08% $\overline{X}_{CVS}$ = 100.1 g/m	$\overline{X}_{Idle}$ = 4.21% $\overline{X}_{CVS}$ = 88.1 g/m

Block Size (rows):

χ^2_{Idle} = 0.220

χ^2_{CVS} = 13.273

Model Year (columns):

χ^2_{Idle} = 12.646

χ^2_{CVS} = 74.875

Table 5-12

Analysis of Variance Results for an Idle NO_x Emission Inspection

Block Size	Pre 1968	1968-1970	Post 1970
≤ 200	$\bar{X}_{Idle}$ = 58.2 ppm $\bar{X}_{CVS}$ = 1.97 g/m	$\bar{X}_{Idle}$ = 53.9 ppm $\bar{X}_{CVS}$ = 1.88 g/m	$\bar{X}_{Idle}$ = 158.1 ppm $\bar{X}_{CVS}$ = 2.41 g/m
>200	$\bar{X}_{Idle}$ = 67.6 ppm $\bar{X}_{CVS}$ = 2.14 g/m	$\bar{X}_{Idle}$ = 87.0 ppm $\bar{X}_{CVS}$ = 3.30 g/m	$\bar{X}_{Idle}$ = 93.1 ppm $\bar{X}_{CVS}$ = 2.70 g/m

Block Size (rows): χ^2_{Idle} = 3.313, χ^2_{CVS} = 3.130

Model year (columns): χ^2_{Idle} = 14.759, χ^2_{CVS} = 24.952

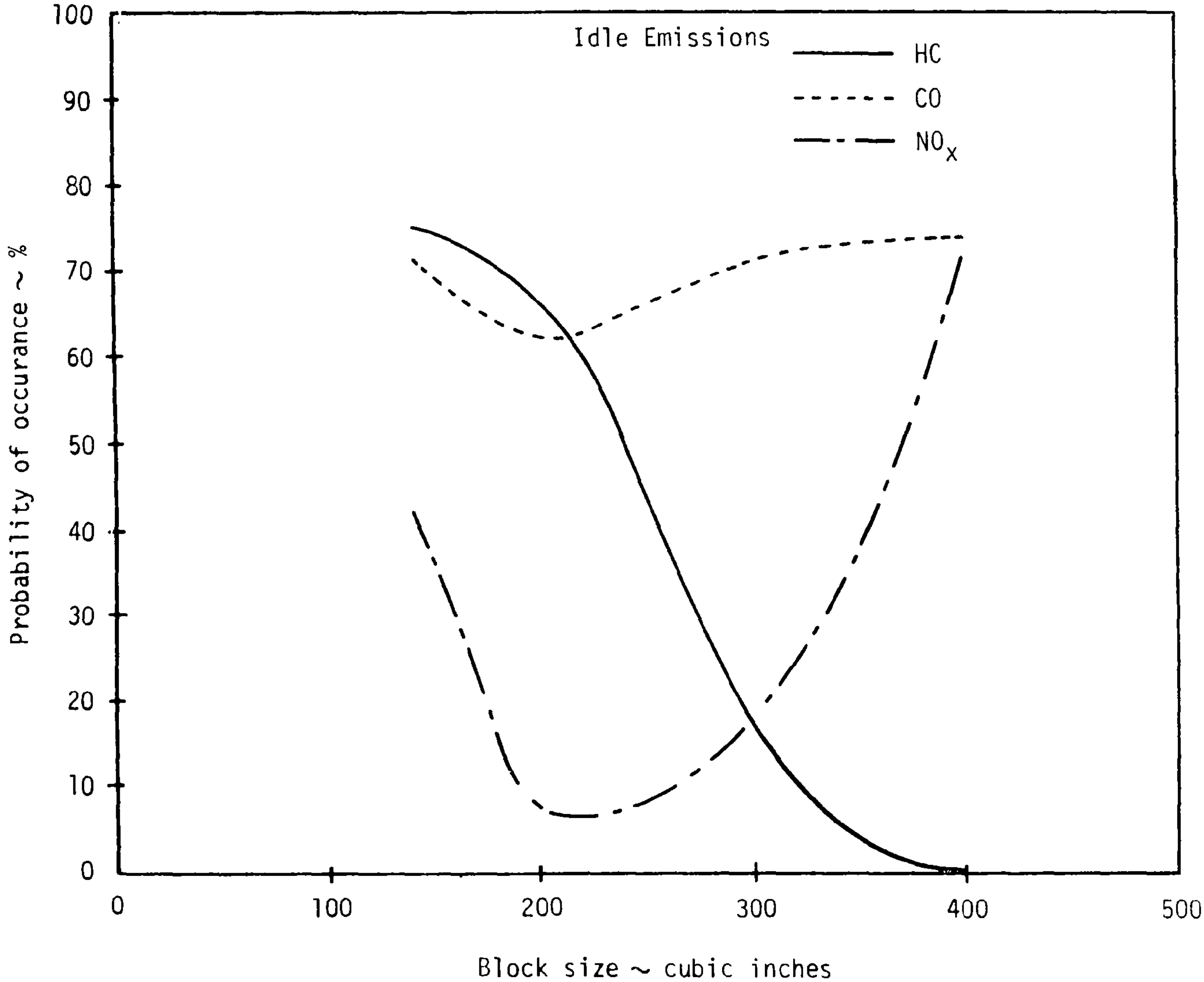

Figure 5-1

Statistical Significance of Partitioning Vehicle
Population by Engine Displacement for Idle Emission Testing

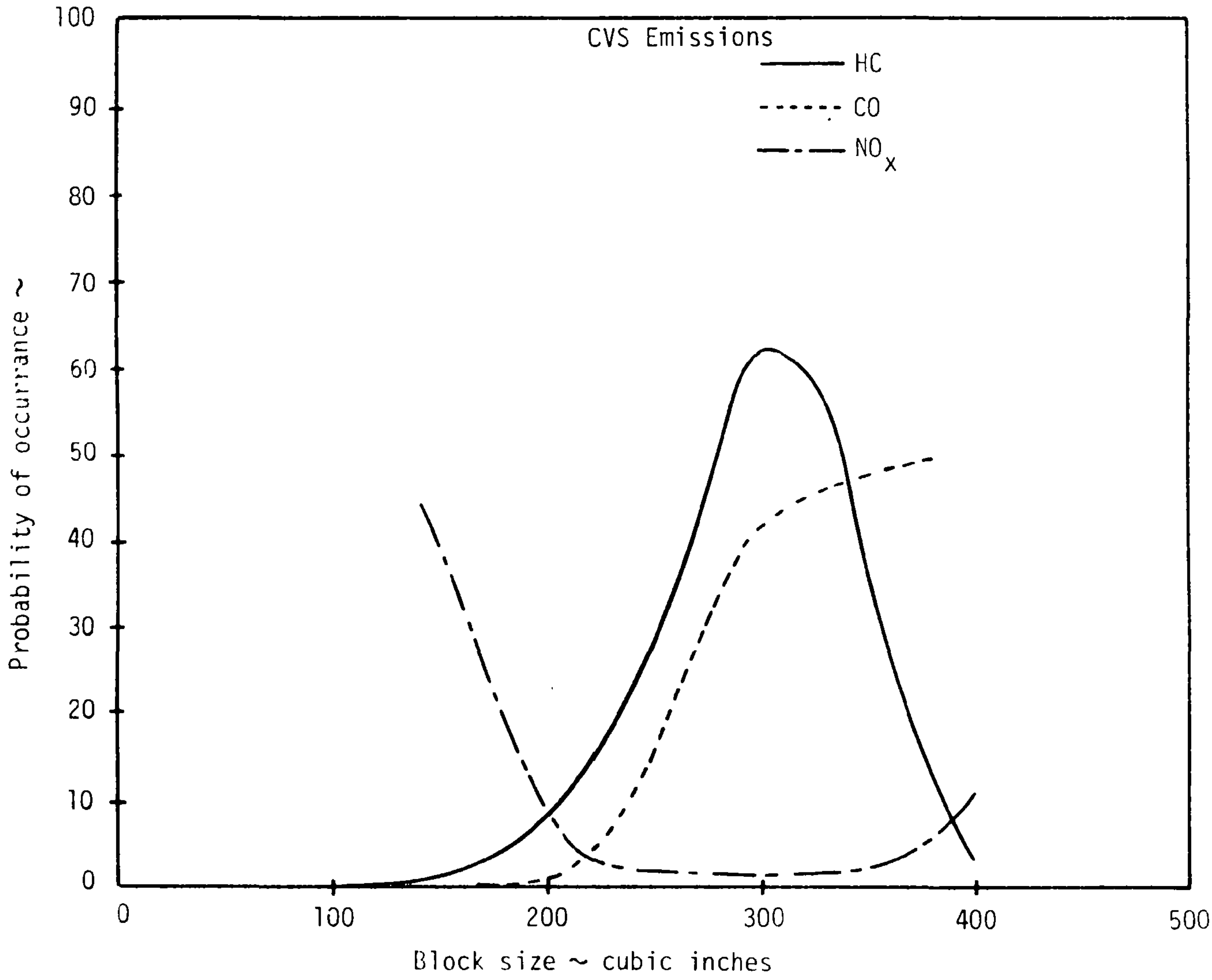

Figure 5-2

Statistical Significance of Partitioning Vehicle
Population by Engine Displacement for CVS Mass Emission Testing

5.3 PROGRAM EFFECTIVENESS

The general effectiveness of an inspection and maintenance program is usually measured in terms of derived emission reductions and associated costs. Typically, the more extensive inspection and maintenance procedures yield higher emission reduction potential at greater costs. The purpose of this section is to summarize the effectiveness and cost results developed from the experimental inspection program.

The effectiveness of an inspection and maintenance program can be measured in several ways. One method focuses on the emission reduction achieved for those vehicles receiving corrective maintenance i.e., those failing the inspection. Another method translates these estimates into weighted averages for the entire population which yield somewhat smaller estimates of performance although they are a truer measure of actual performance . Table 5-13 presents a comparison of emission levels between passed and failed vehicles. The results are shown for both CVS and key mode data. Also given is the percentage difference between means and the corresponding t-score (indicating the level of statistical significance). The most interesting aspect of this table is the large percentage differences computed for most of the emissions (NO_x emissions appear to be the only exceptions). These estimates clearly underscore the basic differences between the two classes of vehicles. The large t-scores support the statistical significance of these observations.

Those vehicles failing the inspection underwent an idle adjustment tune-up, followed if necessary, by more extensive engine repair. Table 5-14 presents a comparison between CVS vehicular emission levels before and after engine maintenance. CVS values are given because they represent the most accurate measure of aggregate exhaust emissions. A substantial reduction in exhaust emissions was achieved for both HC and CO (24.4 and 16.7 percent, respectively). The computed t-score for both emissions is statistically significant. No real reduction was detected for NO_x emissions. It is interesting to note that the standard deviation for all three species was reduced as a result of the maintenance treatment.

These estimates of emission reduction for the failed segment of the fleet, as noted earlier, are not indicative of the entire vehicle population. Table 5-15 reveals the results of weighting with the total population. Basically, this can be accomplished by multiplying the rejection fraction i.e., percentage of vehicles failing the inspection by the predicted emission reductions for those vehicles. The data shown in Table 5-15, however, were derived from actual pre- and post-maintenance measurements. As expected, these weighted results show a lower emission reduction effectiveness compared to the results for the failed vehicles (13.2 percent for HC, 9.2 percent for CO and zero percent for NO_x). Again the t-scores for HC and CO are statistically significant.

These predicted reductions, however, are somewhat static in nature in that they do not account for important temporal effects. Of particular significance is the impact of engine deterioration on exhaust emissions. In an attempt to account for this important effect, the population weighted predictions have been adjusted using the EPA deterioration factors.* These results are also shown in Table 5-15. The estimated reduction effectiveness for an idle inspection program for Denver is 6.6% for HC, 4.6% for CO, and zero for NO_x. These numbers are in general aggreement with those reported for other experimental programs.**

The costs for this inspection program are given in Table 5-16. These cost estimates have been developed based on a representative sample of service garages taken throughout the Denver area. Two types of direct costs are associated with this type of program -- inspection costs and maintenance costs. The average inspection cost for all vehicles participating in the experiment was $4.05. Again, the sample size for this experiment was 300 vehicles. This included the labor involved in measuring HC and CO emissions at idle. The average cost for performing the necessary idle adjustments amounted to $4.53 per tuned vehicle. Some failed vehicles were require to undergo additional engine repair in order to return their emission levels to standard. The cost for this operation was approximately $26.00. Finally, the average inspection and maintenance cost for those vehicles receiving maintenance came to $10.57 whereas the average inspection and maintenance for the entire population was $10.15 per vehicle.

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* While the EPA procedures are admittedly crude they should yield a rough estimate as to the impact of engine deterioration on exhaust emissions. A more definitive characterization of this phenomenon will be available at the end of the current deterioration program.

** TRW, Inc., A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions, Vol. 2, July, 1973.

Table 5-13

COMPARISON OF PASSED AND FAILED VEHICULAR EMISSIONS

Emission**	Passed Mean	Passed SD	Failed Mean	Failed SD	Percentage Difference	T-Score
HC 1975	6.273	3.003	9.197	6.539	46.6%	5.180
CO 1975	94.396	41.055	121.689	58.335	28.9	4.740
NO_x 1975	2.685	1.432	2.527	1.388	0	N.S.*
HC Idle	533.720	284.132	866.234	562.818	62.3	6.687
HC 2500	219.088	162.523	538.571	654.584	145.8	6.174
HC Low Cruise	492.416	170.938	624.589	370.688	26.8	4.127
HC High Cruise	466.560	167.054	591.349	392.958	26.7	3.740
CO Idle	3.850	2.526	6.429	2.841	70.0	8.245
CO 2500	2.688	1.950	4.008	3.629	49.1	4.047
CO Low Cruise	2.443	1.767	3.397	2.788	39.1	3.612
CO High Cruise	3.441	2.748	4.236	2.993	23.1	2.372
NO_x Idle	95.840	71.352	78.943	196.289	-17.6	1.043
NO_x Low Cruise	1426.272	764.897	1375.234	885.958	0	N.S.*
NO_x High Cruise	1650.840	1027.548	1601.000	1123.127	0	N.S.*
Sample Size	125		175			

* N.S. - Not Significant

** All key mode emission measurements presented herein were made with the Beckman equipment (exceptions are HC and CO at 2500 rpm which were made with the Sun laboratory equipment).

Table 5-14

COMPARISON OF EMISSIONS FOR FAILED VEHICLES BEFORE AND AFTER MAINTENANCE*

Emission	Before Maintenance Mean	Before Maintenance SD	After Maintenance Mean	After Maintenance SD	Percent Difference	T-Score
HC 1975	9.197	6.539	7.390	5.601	24.4%	2.769
CO 1975	121.689	58.335	104.271	51.816	16.7	2.945
NO_x	2.527	1.388	2.447	1.212	0	N.S.*

* Sample Size = 300

** N.S. - Not Significant

Table 5-15

COMPARISON OF EMISSIONS FOR TOTAL POPULATION BEFORE AND AFTER MAINTENANCE*

Emission	Before Maintenance Mean	Before Maintenance SD	After Maintenance Mean	After Maintenance SD	Percentage Difference	T-Score	With *** Deterioration
HC 1975	7.978	5.541	6.924	4.722	13.2%	2.50	6.6%
CO 1975	110.317	53.488	100.157	47.804	9.2	2.45	4.6
NO_x 1975	2.593	1.406	2.546	1.311	0	N.S.**	0

* Sample Size = 300

** N.S. - Not Significant

*** EPA deterioration factor of 0.5 applied to emission reduction data.

Table 5-16

Idle Inspection Maintenance Costs

	Cost	
Initial Inspection Cost (average)	$ 4.05	Car
Idle Tune-up Cost (average)	$ 4.53	Tuned Car*
Additional Repair Cost (average)	$26.00	Tuned Car**
Average Total Cost	$10.57	Tuned Car*
Average Total Cost	$10.18	Car
Total Sample Size	300	Cars

* Those vehicles receiving some form of maintenance.

** Those vehicles receiving additional repair only.

6.0 EVALUATION OF MANDATORY ENGINE MAINTENANCE

An evaluation of mandatory engine maintenance was conducted by comparing the emissions from a set of vehicles drawn from the general population with the same vehicles after they had received engine maintenance. A test population of 144 vehicles was used to simulate the impact of mandatory maintenance. Results from the program are shown in Table 6-1. The 'before maintenance' emission data was developed from the initial survey of the vehicle fleet. The 'after maintenance' estimates are based on post maintenance measurements. The data are the CVS (1975 procedure) measurements for HC, CO and NO_x.*

There was a 19.1 percent decline in HC and 9.8 percent in CO which are shown by their respective t-scores to be of statistical significance. (A t-score greater then 1 normally indicates a reasonable level of significance). Furthermore, there was nearly a 7 percent reduction in NO_x emissions. Again, it is interesting to note the relative reduction in the standard deviation after corrective maintenance.

Also shown are estimates of the effectiveness of mandatory maintenance with deterioration. These estimates have been developed using EPA deterioration procedures. The EPA assumes that emission levels return to the pre-maintenance level in one year in a linear fashion. Therefore, at any one time the average reduction in emissions will be one-half the full reduction. Therefore, emissions for the general vehicle population should be reduced by 9.6 percent for HC and 4.9 percent for CO on the average over the period of one year.

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* A detailed description of the actual maintenance performed can be found in Volume II of this report.

Table 6-2 gives the costs per vehicle associated with this reduction. Based on these results, mandatory maintenance is less cost-effective than the idle inspection/maintenance for the emission reductions attained. The average parts cost for this program was $22.23 per vehicle and the average labor cost was $26.87 per vehicle. Thus it appears that the costs breakdown between parts and labor is nearly equal. Clearly, the more attractive approach is to inspect cars initially before requiring maintenance.

Table 6-1

Analysis of Mandatory Maintenance*

Emission	Before Maintenance Mean	Before Maintenance SD	After Maintenance Mean	After Maintenance SD	Percentage Difference	T-Score	With Deterioration**
HC 1975	7.190	5.237	5.818	2.535	19.1	2.82	9.6
CO 1975	99.887	46.760	90.136	42.799	9.8	1.84	4.9
NO_x 1975	2.759	1.392	2.568	1.253	6.9	1.22	3.5

* NOTE: A sample size of 144 vehicles was used in this analysis. The sample size used in Volume II was 155. This slight difference did not have a significant impact on the computed emission reduction results.

** EPA deterioration factor of 0.5 applied to emission reduction data.

Table 6-2

Mandatory Maintenance Costs

Average Parts Cost	=	22.23 $/car
Average Labor Cost	=	26.87 $/car
Average Total Cost	=	49.10 $/car
Sample Size	=	144 cars

7.0 EFFECT OF IDLE ENGINE ADJUSTMENTS ON EXHAUST EMISSIONS

Due to the different atmospheric conditions which prevail at high altitudes the engine parameter settings specified by the automobile manufacturer might not be expected to yield minimal emission levels. Therefore, a basic engine adjustment program was undertaken to determine the effectiveness of readjusting certain of these parameters.

Based on the results of a previous study, a set of four engine parameters were selected for investigation.* These four adjustments were identified as being inexpensive and easy to modify, and emission levels were found to be particularly sensitive to changes in their settings. TRW derived the requisite parameter adjustments from earlier experiments and engineering considrations. These adjustments are presented in Table 7-1.

The idle adjustment experiment was designed to determine the effects of each of the factors (A, B, C, and D) and of the three second order interactions AB, BC, and AC. In the study cited above,it was discovered that the fourth parameter, vacuum choke kick, did not interact with any of the other three. Therefore, the experiment could be simplified to a one-half fractional factorial design involving eight(8) engine settings per car. Twenty-five cars were chosen to represent the total vehicle population.

Each vehicle was adjusted according to the settings given in Table 7-2, and the emission levels were measured and recorded. Settings

* Reported in TRW, Inc., A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions, Vol. IV, July 1972.

2 through 8 were administered in a random order different for each vehicle. Each vehicle was finally set to manufacturers' specifications (setting number 1) and the emission levels measured.

The adjustment in idle air/fuel ratio was measured in terms of an equivalent drop in rpm. More specifically, the setting was decreased until a 200 rpm drop was recorded. This procedure provided a more direct and simple approach for adjusting air/fuel ratio in a garage environment. The resultant influence coefficients were computed based on the 200 rpm drop instead of the actual percentage reduction in idle CO.

The results of the analyses is presented in Table 7-3 through Table 7-8. In Table 7-3 through Table 7-5 the changes in emission levels for each emission type and engine adjustment for each car is shown. The variance in the data is immediately apparent. Some of the adjustments can have precisely opposite effects in different cars. Nevertheless, some patterns are evident and emerge upon analysis. Tables 7-6 through 7-8 present a summary of the essential results. for each emission species. The influence coefficients relating the change in emission level with the parameter adjustment and the confidence level at which the relationship is expressed are shown.

For HC, only one parameter (Idle air/fuel) was found to have even a minimal influence on emissions. This was a surprising development since one would expect HC emissions to be sensitive to timing. The experimental results, however, revealed no significant reductions even though timing was advanced eight(8) degrees. The subdivision of the data into more homogeneous units, e.g. Fords, might yield more effect results. For the present sample size (25), however, this would be difficult to justify. These results are consistent with those revealed in the high altitude retrofit study, where timing advance did not yield significant HC emission reductions contrary to expectations.

The results for CO reveal a much stronger correlation between three primary adjustments and resultant changes in emission levels. There are also significant second-order interactions between idle air fuel and timing.

The effect of the adjustment program on NO_x emission levels was extremely small. None of the measured effects were greater than 50% significant. Since CO and NO_x tend to have an inverse relationship, it was somewhat surprising that no significant inverse correlations were found for NO_x. A future study into the factors influencing NO_x emissions at altitude might be warranted.

In summary, the overall impact of an engine adjustment program appears small. Exceptions to this observation were idle air/fuel ratio and basic timing adjustments on CO emissions. One possible variation on the theme would be to incorporate the adjustment of these parameters as part of the annual inspection program. While the potential impact of this approach has not been measured directly the potential for increasing CO emission reductions at reasonable cost appears good.

Table 7-1

Engine Adjustments Tested by the Experiment

Idle Air/Fuel Ratio(A)	An equivalent 200 ppm drop
Idle RPM(B)	+200.0 RPM
Basic Timing(C)	+8.0 Degrees
Vacuum Choke Kick(D)	+50.0

Table 7-2

Experimental Test Settings*

Setting Number	Setting Value**			
	A	B	C	D
1	-	-	-	-
2	+	-	-	+
3	-	+	-	+
4	+	+	-	-
5	-	-	+	+
6	+	-	+	-
7	-	+	+	-
8	+	+	+	+

* NOTE: A few of the vehicles tested did not undergo the full sequence.

** A = Idle Air/Fuel Ratio

B = Idle RPM

C = Basic Timing

D = Vacuum Choke Kick

+ = Experimental Value

- = Manufacturer's Specification

Table 7-3

Comparison of Adjustment Effects for HC

Run No.	Car No.	Idle CO (A) Effect (g/m)	Idle RPM (B) Effect (g/m)	Timing (C) Effect (g/m)	Choke (A) Effect (g/m)	AB Effect (g/m)	AC Effect (g/m)	BC Effect (g/m)
1	39	-2.237	-0.682	6.308	4.373	6.857	0.727	1.873
2	57	-0.080	-0.005	-0.010	0.435	0.025	-0.050	-0.125
3	59	-1.900	0.375	0.770	-0.785	-0.205	0.160	1.945
4	74	-0.650	-0.435	-0.165	-0.300	0.510	0.030	0.595
5	73	0.842	-0.492	0.803	0.828	0.857	0.563	-0.192
6	103	-0.242	-0.133	0.413	0.282	0.087	-0.267	-0.217
7	106	0.718	0.233	1.323	-0.733	-0.053	-0.093	-1.028
8	111	-0.920	-0.060	-0.755	0.485	-0.665	-1.370	0.090
9	112	-0.090	-0.780	1.360	1.450	0.355	0.785	-1.255
10	113	0.033	0.408	1.088	0.683	0.923	0.372	0.247
11	115	-2.992	0.318	1.513	0.073	-1.577	-2.082	-0.123
12	123	-1.767	-0.777	0.708	0.878	-0.562	-0.828	-1.537
13	149	-2.689	-0.692	0.073	-0.053	0.292	0.497	0.233
14	147	-1.120	0.290	0.695	0.015	0.240	-0.085	-0.085
15	175	-0.520	0.040	0.240	-0.180	-0.470	0.130	0.260
16	193	-1.127	-0.482	-0.552	1.102	-0.187	1.183	0.698
17	183	-0.550	-0.120	0.335	0.315	0.410	-0.885	-0.955
18	181	-3.022	2.643	2.773	-2.772	-2.668	-2.198	2.927
19	180	1.973	-3.052	2.268	-1.517	1.082	-0.397	-3.282
20	179	0.827	-0.827	0.983	0.157	0.607	0.138	-0.157

Table 7-3 (Cont.)

Run No.	Car No.	Idle CO (A) Effect (g/m)	Idle RPM (B) Effect (g/m)	Timing (C) Effect (g/m)	Choke (A) Effect (g/m)	AB Effect (g/m)	AC Effect (g/m)	BC Effect (g/m)
21	210	-0.588	-0.542	0.478	0.612	0.283	0.092	-0.473
22	212	-3.327	-0.542	0.168	0.438	1.173	0.423	0.587
23	214	0.125	1.145	-0.555	-2.785	-0.300	0.180	-1.100
24	198	-3.885	-0.915	0.930	0.540	-0.035	-1.100	-0.910
25	289	-1.308	1.578	-0.232	0.313	-1.148	0.722	-0.043

Table 7-4

Comparison of Adjustment Effects for CO

Run No.	Car No.	Idle CO (A) Effect (g/m)	Idle RPM (B) Effect (g/m)	Timing (C) Effect (g/m)	Choke (D) Effect (g/m)	AB Effect (g/m)	AC Effect (g/m)	BC Effect (g/m)
1	39	1.875	-4.875	-3.075	3.975	-16.075	14.125	-7.425
2	57	0.800	4.050	-8.450	5.900	-8.650	-3.150	-3.100
3	59	-3.500	-3.950	-3.050	-17.900	7.750	-0.150	18.800
4	74	-7.000	4.150	-3.950	-2.800	3.700	-5.700	1.350
5	73	2.700	-4.550	-1.350	7.000	12.700	3.300	-5.250
6	103	-6.100	-6.200	-5.300	2.100	1.300	-1.300	-4.500
7	106	2.500	13.850	1.250	-1.500	6.150	-1.850	-7.000
8	111	-20.275	7.875	-3.975	-25.625	-4.275	-4.125	10.00
9	112	-7.350	-1.750	13.200	21.600	1.050	16.400	-7.300
10	113	-14.600	6.600	5.150	5.550	3.350	8.100	2.600
11	115	-16.225	-5.225	-14.425	0.475	-9.925	-20.125	-14.025
12	123	-13.275	-6.075	11.515	-7.875	2.925	-12.675	-0.525
13	149	-45.825	-0.525	-0.625	0.275	-7.775	-4.275	1.125
14	147	-24.225	-1.125	-1.825	2.675	0.625	0.925	-2.075
15	175	-13.400	-7.100	-13.400	-3.200	0.900	9.200	8.900
16	193	-32.450	-4.300	-6.650	-1.400	-2.700	7.850	-5.300
17	183	-31.825	-7.325	-12.625	4.775	11.475	-6.525	-12.225
18	181	-18.300	0.350	-22.550	7.300	12.300	33.200	5.550
19	180	-14.750	-16.950	-17.400	-14.700	7.000	3.850	17.150
20	179	-8.250	-1.150	-7.350	-13.750	2.350	-1.550	0.850
21	210	-13.950	4.400	1.050	3.900	0.950	1.600	-7.650

Table 7-4 continued

Run No.	Car No.	Idle CO (A) Effect (g/m)	Idle RPM (B) Effect (g/m)	Timing (C) Effect (g/m)	Choke (D) Effect (g/m)	AB Effect (g/m)	AC Effect (g/m)	BC Effect (g/m)
22	212	-32.800	-1.900	1.300	1.200	-0.900	-3.300	0.600
23	214	-47.100	16.100	-6.300	-25.000	-19.250	4.550	7.950
24	198	-49.850	-9.300	-6.250	0.200	6.000	-3.250	-9.600
25	289	-9.175	12.225	2.725	-2.775	0.475	-6.425	4.375

Table 7-5

Comparison of Adjustment Effects for NO_x

Run No.	Car No.	Idle CO (A) Effect (g/m)	Idle RPM (B) Effect (g/m)	Timing (C) Effect (g/m)	Choke (D) Effect (g/m)	AB Effect (g/m)	AC Effect (g/m)	BC Effect (g/m)
1	39	-0.385	0.385	1.585	0.085	0.160	-0.480	0.048
2	57	-0.002	-0.017	0.068	-0.057	0.227	0.062	0.008
3	59	-0.225	0.150	0.085	0.240	-0.288	-0.355	-0.210
4	74	0.265	0.025	0.590	0.360	-0.090	0.455	0.145
5	73	1.722	-0.392	0.778	0.592	0.023	0.852	0.328
6	103	0.112	0.098	0.448	0.073	-0.012	-0.133	0.092
7	106	-0.030	-0.105	0.205	0.100	-0.170	-0.110	-0.155
8	111	0.297	-0.347	-0.292	0.922	0.003	-0.942	-0.657
9	112	1.158	0.533	1.683	1.657	0.568	0.588	-0.617
10	113	0.328	0.058	1.533	-0.357	0.387	0.013	-0.377
11	115	-0.067	0.128	0.453	-0.013	-0.133	-0.028	0.218
12	123	0.058	0.088	0.473	0.082	-0.043	0.192	-0.047
13	149	1.145	0.345	1.440	0.180	0.195	0.450	-0.410
14	147	-0.045	0.450	0.860	0.015	0.080	-0.220	0.055
15	175	-0.008	0.372	0.633	-0.198	-0.232	-0.262	0.027
16	193	0.427	0.242	0.048	0.482	-0.077	0.797	0.282
17	183	0.680	-0.090	1.485	-0.005	0.015	0.110	0.110
18	181	0.005	0.025	1.445	-0.635	-0.505	-0.705	0.125
19	180	0.390	1.210	1.130	-0.130	-0.295	0.255	0.155
20	179	0.410	-0.245	0.765	0.540	0.230	0.310	-0.025
21	210	0.010	-0.410	0.465	0.945	0.665	-0.260	0.280

Table 7-5 continued

Run No.	Car No.	Idle CO (A) Effect (g/m)	Idle RPM (B) Effect (g/m)	Timing (C) Effect (g/m)	Choke (D) Effect (g/m)	AB Effect (g/m)	AC Effect (g/m)	BC Effect (g/m)
22	212	0.380	0.230	0.095	0.095	0.270	0.175	0.285
23	214	0.250	0.565	3.645	0.480	0.040	0.540	0.265
24	198	0.965	-0.185	0.055	-0.025	-0.340	0.170	-0.030
25	289	0.770	0.130	0.425	-0.275	-0.095	0.130	0.460

Table 7-6

Engine Adjustment Influence Coefficients
For HC

Engine Adjustment	Influence Coefficient	Confidence Level (Percent)
Idle Air Fuel (A) (gm/mi/rpm)	0.00461	60
Idle RPM (B) (gm/mi/rpm)	-0.000748	<50
Timing (C) (gm/mi/deg)	0.120	<50
Vacuum Choke Kick (D) (gm/mi/% spec.)	0.00450	<50
AB	-0.000008	<50
AC	0.000069	<50
BC	-0.000046	<50

Table 7-7

Engine Adjustment Influence Coefficients
For CO

Engine Adjustment	Influence Coefficient	Confidence Level
Idle Air Fuel (A) (gm/mi/rpm)	0.08425	99+
Idle RPM (B) (gm/mi/rpm)	-0.003942	<50
Timing (C) (gm/mi/deg)	-0.6769	99+
Vacuum Choke Kick (D) (gm/mi/% spec.)	-0.03584	92
AB	-0.000019	<50
AC	-0.001512	65
BC	-0.000182	<50

Table 7-8

Engine Adjustment Influence Coefficients For NO_x

Engine Adjustment	Influence Coefficients	Confidence Level
Idle Air Fuel (A) (gm/mi/rpm)	-0.001880	<50
Idle RPM (B) (gm/mi/rpm)	0.000688	<50
Timing (C) (gm/mi/deg)	0.108	<50
Vacuum Choke Kick (D) (gm/mi/% spec.)	0.00457	<50
AB	-0.000001	<50
AC	-0.000031	<50
BC	-0.000010	<50

8.0 ASSESSMENT OF SEA LEVEL AND HIGH ALTITUDE RETROFIT DEVICES

The present Colorado Transportation Control Plan calls for the installation of air bleed retrofit on all pre-controlled vehicles and a high altitude modification package on all 1968-1974 vehicles. The estimates of effectiveness for these devices were based primarily on data collected at sea level. Consequently, one of the key experiments of the current test program was to characterize the effectiveness of these and other similar devices at altitude.

Basically, two classes of retrofit systems were tested during the course of the program. First, a total of eight different combinations of "sea level" devices were evaluated using standard CVS measuring procedures. Second, four unique manufacturer-oriented "high altitude" kits, i.e., GM, Ford, Chrysler, and AMC, were tested for these classes of vehicles. In the next two subsections the effectiveness and costs of the several retrofit devices tested are assessed in an attempt to identify the most attractive alternative for effecting emission reductions in the existing vehicle population.

8.1 ANALYSIS OF SEA LEVEL RETROFIT DEVICES

For the purpose of analysis the sea level retrofit devices were divided into two categories based on the vehicle age. Vehicles older than 1968 were placed in one group and newer vehicles in the other group.

Table 8-1 illustrates the performance of the sea level retrofit devices for pre-1968 cars. Three systems were analyzed. The vacuum spark disconnect (VSAD) and air bleed (AIR) system did not produce statistically significant reductions for either HC or CO. The VSAD and exhaust gas reduction (EGR) system, however, achieved statistically significant reductions for all three emission species. The combination AIR + EGR provided somewhat a large reduction for CO (21% versus 11%) but a slightly lower reduction for HC (22% versus 26%). In considering overall effectiveness for HC and CO reduction the AIR/EGR system seems to offer the greatest overall effectiveness.

Table 8-2 shows the costs associated with each of the retrofit devices. The devices' affects on mileage is also shown although these may not be statistically significant. The actual benefits derived from these devices in using them on pre-1968 cars must be considered in the light of the fact that the pre-1968 car population is decreasing continuously. Installing retrofit devices on pre-1968 cars may not be worthwhile according to the forecasts presented in section 9.0 of this report. Similar results and conclusions were also reached in a previous study concerning this issue.*

The performance of retrofit devices of post-1968 cars is shown in Table 8-3. The following observations summarize the results obtained from the experimental program.

First, air bleed (AIR) produces a decrease in HC and CO emissions but also creates a increase in NO_x emissions. Exhaust gas recirculation (EGR) operating alone produces a large reduction in NO_x but has no discernable effect on HC and CO. When the two are combined (AIR/EGR) they complement one another very well. The combination effects a decrease in HC and CO as large as or larger than that achieved by AIR alone. Also the reduction in NO_x produced by EGR countered the increase

* In TRW, Inc., A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions, Vol. II, July 1972.

by AIR so that the combination has no net effect on NO_x. In fact, the raw data indicated a 28 percent reduction of NO_x by the AIR/EGR system but the effect had a large variance which yielded non-statistically significant results.

Secondly, carburetor float bowl pressure regulation (CARB) had a statistically significant effect only on HC.

Thirdly, the catalyst device (CAT) showed very large and statistically significant declines in HC and CO as shown by the t-scores.

Clearly CAT is the most effective device followed by AIR + EGR and with CARB third. However, a comprehensive consideration must include costs as well as benefits. The costs of the devices are shown in Table 8-4. A simple estimate of cost effectiveness can be made by taking ratios of the cost of installing a device and the reduction in emission levels produced by the device. Table 8-5 presents these ratios and provides a rough guide to the relative efficiency in terms of cost for each of the major competing sea level retrofit devices for post-1967 cars. Some points to consider in evaluating Tables 8-3, 8-4 and 8-5 are the facts that:

- CARB produces no reduction of CO.
- Although CAT and AIR + EGR closely compete on a cost effectiveness basis the reductions that can be achieved with AIR + EGR are much smaller than those for CAT.
- The expense of installing CAT is very high .
- AIR + EGR is more efficient in reducing CO than CAT.
- CARB is more efficient in reducing HC than either CAT or AIR + EGR.

8.2 ANALYSIS OF HIGH ALTITUDE DEVICES

The relative performance of the high altitude emission devices is clearly shown in Table 8-6. The results are indeed discouraging. The AMC device produced no significant effects. It should be noted, however, that there were only four data points for the AMC device. The GM and Ford devices did even less well producing an increase in NO_x emissions while having no statistically significant effect on HC or CO. The Chrysler system while it had an even worse effect on NO_x did manage to produce reductions in HC and CO. Basically the data show the high altitude retrofit devices were generally ineffective, or when they worked produced large counteracting increases in NO_x emission levels.

Table 8-7 gives the costs associated with the high altitude retrofit devices.

Table 8-1

Comparison of Sea Level Retrofit Systems for Pre-1968 Vehicles

	VSAD + AIR		VSAD + EGR		AIR + EGR	
	% Diff	T-Score	% Diff	T-Score	% Diff	T-Score
HC	0	N.S.(5)	26.1	1.92(8)	22.4	1.73(7)
CO	0	N.S.(5)	11.2	1.17(8)	21.2	1.25(7)
NO_x	46.7	1.59(5)	27.6	1.30(8)	0	N.S.(7)

Table 8-2

Sea level Retrofit Cost Analysis for Pre-1968 Vehicles

Device	Installation Cost	Sample Size	Mileage Effect*
VSAD + AIR	24.95	5	-1.20
VSAD + EGR	25.00	8	.05
AIR + EGR	36.95	7	.09

* Reflects an increase in gasoline consumption (measured in mi/gal)

Table 8-3

Comparison of Sea Level Retrofit Systems for Post-1967 Vehicles

	CAT		AIR		EGR		AIR + EGR		CARB	
	% DIFF	T-SCORE	% DIFF	T-SCORE	% DIFF	T-SCORE	% DIFF	T-SCORE	% DIFF	T-SCORE
HC	72.3	8.61 (4)	17.5	2.83 (6)	0	N.S. (5)	17.1	1.66 (4)	17.3	1.77 (5)
CO	83.5	2.91 (4)	41.9	1.89 (6)	0	N.S. (5)	47.9	2.07 (4)	0	N.S. (5)
NO_x	0	N.S. (4)	-23.6	-1.59 (6)	42.8	1.95 (5)	0	N.S. (4)	0	N.S. (5)

NOTE: N.S. = Not statistically significant.

Table 8-4

Sea Level Retrofit Cost Analysis for Post-1967 Vehicles

Device	Installation Cost	Sample Size	Mileage Effect*
CAT	$155.00	4	-.39
AIR	24.99	6	.45
EGR	32.15	5	-.84
AIR + EGR	36.95	4	-.15
CARB	24.10	5	-.11

* Reflects an increase in gasoline consumption(measured in mi/gal)

Table 8-5

Sea Level Retrofit Cost-Effectiveness Ratios of the Major Competing Devices for Post-1967 Cars

Device	\$/1 percent Reduction in HC	\$/1 percent Reduction in CO
CAT	2.14	1.86
AIR + EGR	2.16	0.77
CARB	1.21	--

Table 8-6

High Altitude Retrofit Performance Data

	GM		FORD		CHRY		AMC	
	% DIFF	T-SCORE	% DIFF	T-SCORE	% DIFF	T-SCORE	% DIFF	T-SCORE
HC	0	N.S. (48)	0	N.S. (33)	26.1	1.59 (15)	0	N.S. (4)
CO	0	N.S. (48)	0	N.S. (33)	54.2	4.73 (15)	0	N.S. (4)
NO	-28.9	-2.83 (48)	-16.3	-1.21 (33)	-84.4	4.44 (15)	0	N.S. (4)

Table 8-7

High Altitude Retrofit Cost Analysis

Device	Labor Cost	Parts Cost	Total Installation Cost	Sample Size	Mileage Effect*
Ford	$7.61	$2.06	$9.67	33	.25
GM	8.88	3.74	12.62	48	.73
Chrysler	7.44	1.63	9.07	15	.85
AMC	6.30	1.35	7.65	4	.56

*Reflects an increase in gasoline consumption (measured in mi/gal)

9.0 IMPACT OF TEST RESULTS ON TRANSPORTATION CONTROL PLAN

The following discussion focuses on the potential impact of changes in the assumed effectiveness of the proposed strategy due to the results of the emission test program. Table 9-1 summarizes the percentage reduction in vehicular emissions claimed in the Denver plan, as well as the reductions measured during the current emissions testing program. These results clearly indicate that additional controls will be necessary to achieve the national standard. Forecasts of emission levels by 1977 were prepared in order to ascertain the requirements for additional transportation control.

9.1 EMISSION FORECASTS FOR 1977

Forecasts of emission levels for 1977 were developed using the TRW model and the reduction data given in Table 9-1. Specifically, two cases were examined under the proposed strategy:

1) Determine the impact of the original plan using the measured experimental data.

2) Estimate the effectiveness of a "revised" plan using the measured experimental data.

The results from these forecasts are summarized in Table 9-2. Shown are the assumed and measured estimates for the original plan and the measured results for the revised plan. The forecasts clearly show that additional emission reductions will be necessary in order to match those projected in the transportation control plan. These results indicate the need for an additional 20 percent reduction in CO and a 7 percent reduction in HC for LDV. The main reason for lower efficiencies can be attributed to the general ineffectiveness of the

Table 9-1

Assumed and Measured Reductions for Transportation Control Plan

	Measure	Application	Assumed Per Vehicle Reduction (%)		Measured Per Vehicle Reduction (%)	
			CO	HC	CO	HC
1.	Inspection/Maintenance	all autos	11	8	6.9 (1)	9.9 (1)
2.	Air Bleed Retrofit	Pre-1968 autos	50	25	21 (2)	22 (2)
3.	High Altitude Mod.	1968-74 autos	25	15	11 (3)	5.2 (3)

(1) These percentages assume a semi-annual inspection. On an annual basis the values are 4.6% and 6.6% for CO and HC, respectively.

(2) Tests were conducted for air bleed + exhaust gas recirculation (EGR) (no tests were conducted for air bleed alone).

(3) This result may be optimistic, since only a subset of Chrysler autos responded significantly to the modifications.

Table 9-2

Comparison of Effectiveness Between Original and Revised Transportation Control Plan For 1977

Measure (LDV only)	Application	Original Plan Assumed		Original Plan Measured		Revised Plan Measured	
		CO	HC	CO	HC	CO	HC
1. Inspection/Maintenance*	All autos	11.0%	8.0%	6.9%	9.9%	4.6%	6.6%
2. Air Bleed Retrofit	Pre-1968 Autos	6.8	3.4	2.9	3.0	2.9	3.0
3. High Altitude	1968-1974 Autos	21.6	13.0	9.5	4.5	---	---
4. AIR/EGR Retrofit	1968-1974 Autos	---	---	---	---	41.4	14.8
	TOTAL	36.3**	23.1**	18.4**	16.7**	46.9**	23.2**

* Original Plan called for a semi-annual inspection program. Revised plan involves an annual program.

** These total percentage reductions include the interaction of inspection/maintenance with the retrofit system.

high altitude modification measures. The experimental results showed that these systems yielded extremely marginal reductions. In fact, nearly all of the results were not statistically significant and consequently, the estimates given in Table 9-1 should be viewed as somewhat optimistic.

Forecasted estimates are also given for a revised transportation plan. This plan calls for an annual inspection program and the use of AIR/EGR systems on 1968-1974 vehicles instead of the high altitude kit. These results in terms of HC and CO reductions, appear more consistent with the original plan estimates. Nevertheless, it would seem quite appropriate to re-evaluate, in more detail, the entire transportation control plan with respect to the new data.

9.2 RETROFIT FOR OLDER VEHICLES

One area of particular concern in the development of an effective control plan involves the retrofitting of older vehicles. Because of the dynamic nature of vehicle attrition and replacement many older cars on the road today will be replaced within a few years. This turnover in the automobile population, especially pre-1968 vehicles, makes it difficult to justify the installation of retrofit system on older vehicles.

To help quantify this phenomenon, forecasts were prepared showing the relative effectiveness of the AIR/EGR system for pre-controlled vehicles as a function of time. These estimates are given in Figure 9-1. As can be seen, the relative effectiveness as compared to the total LDV emission level reduces to zero by 1980. Even for 1977 the effectiveness is only 3.5 percent and 6 percent for HC and CO, respectively. These

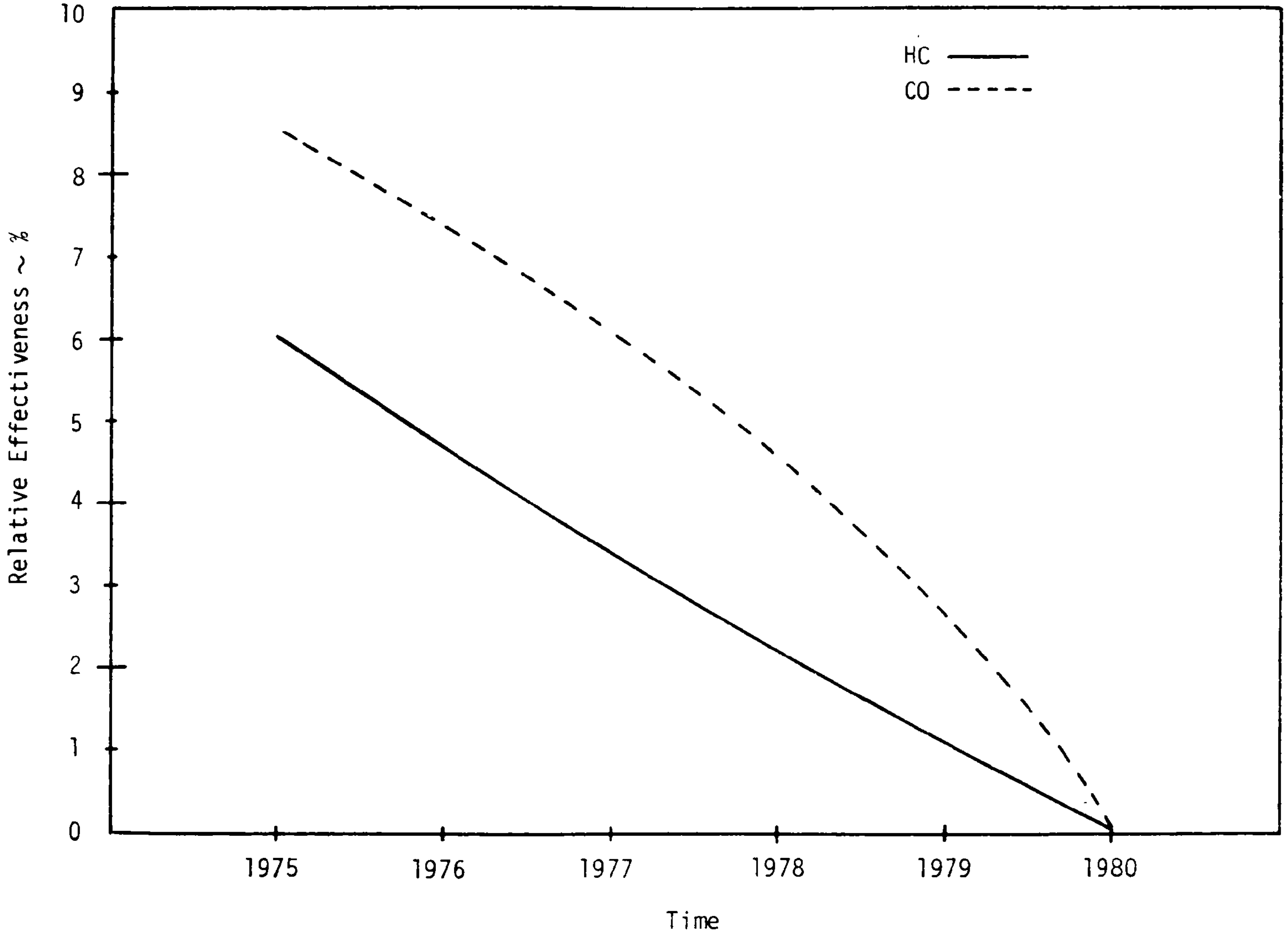

Figure 9-1
Predicted Emission Reduction Effectiveness for Pre-1968 Vehicles with Retrofit

relatively low values seem to indicate the marginal potential of this control alternative. The basic difference between the revised original plan involves the substitution of the AIR/EGR system for the high altitude kit for the 1968-1974 segment of the vehicle population. The revised plan yields over a 9 percent improvement in HC reductions compared to the original plan and equals the original estimate for CO reductions. While these results look encouraging, it must be noted that the effectiveness of the AIR/EGR system was based on a small sample size (4 vehicles). Further testing of this system must be undertaken before finalizing the structure of the control plan.