HIGH ALTITUDE VEHICULAR EMISSION CONTROL PROGRAM

VOLUME I. EXECUTIVE SUMMARY

FINAL REPORT

JANUARY 1974

PREPARED FOR:

STATE OF COLORADO
DEPARTMENT OF HEALTH
ER, COLORADO 80220

ENVIRONMENTAL PROTECTION AGENCY
REGION VIII
DENVER, COLORADO 80203

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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, 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 VI. Lastly, Volume VII 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. Olson Laboratories evaluated the feasibility of conducting an emission control program for the Denver area.

ACKNOWLEDGEMENTS

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

The contributions of Messrs. Don Sorrels and Robert Taylor and Ms. Lindsay Tipton of the Colorado State Department of Health were of particular significance. Mr. Dale M. Wells of Region VIII provided key guidance and served as the EPA Project Officer.

Additionally, the contractors wish to acknowledge the assistance given by the following firms: American Motors Corporation, Central Motive Power, Chrysler Corporation, Colspan Environmental Systems, Inc., Dana Corporation, Echlin Manufacturing Co., Ford Motor Company, General Motors Corporation, and STP Corporation.

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1.0 CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations presented herein highlight the findings from the experimental program. A more definitive set of study observations can be found in each of the technical reports (Volumes II through VII).

Conclusions

- The results from the experimental program indicate that the strategy effectiveness estimates used in the original transportation control plan were optimistic. The experimental results further show that an idle inspection program and an air bleed/exhaust gas recirculation retrofit program provide the best balanced approach for controlling exhaust emissions in the Denver AQCR.

- An annual idle inspection and maintenance program, consisting of the measurement of idle HC and CO followed, as necessary, by corrective engine maintenance appears relatively attractive as a control measure (6.6% reduction for HC, 4.6% 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.

- The costs associated with the idle program performed in a privately licensed garage ($4.05 for the inspection and an additional $10.57 for those vehicles undergoing maintenance) are well within an acceptable range as revealed by a recent survey of the motoring public. The average cost for both inspection and maintenance for all vehicles is $10.35.

- Idle emissions inspection at newly constructed, state-operated facilities would cost the vehicle owner approximately $2.10 for an annual inspection.

- A combined statewide safety-emissions inspection system, consisting of approximately 4200 privately operated, licensed stations would need to be upgraded to include emission testing capabilities. For a state-operated system, 66 fixed sites and 23 mobile units would be required at an initial investment cost of $11 million and an annual operating cost of $9.8 million.

- The results derived from the experimental program are typical of the general class of vehicles operating in the Denver AQCR. The performance characteristics of specific vehicles operating in the region may not be consistent with these trends.

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

- A combination of air bleed and exhaust gas recirculation retrofit system appears most cost-effective for both pre-controlled and controlled vehicles. Average emission reductions for pre-controlled vehicles was 22% for HC and 21% for CO and for controlled vehicles the reductions were 17% for HC and 48% for CO. NO_x emissions were not affected by this retrofit system. The installation cost with approximately $37.00.

- The results from the high altitude retrofit experiments revealed no statistically significant emission reductions for either HC and CO. The installation of these systems had an adverse effect on NO_x emissions, ranging from 16% to 84%.

- The adjustment of idle CO (air/fuel) and basic timing were found to have a significant effect on CO emissions. However, these adjustments had little effect on HC or NO_x emissions. The adjustment of rpm and choke did not have a significant impact on either HC, CO or NO_x emissions.

- Altitude was found to have a significant impact on exhaust emissions. At 5000 feet HC and CO emissions were nearly 50 percent larger than at sea level. At 10,000 feet these emissions were over twice as large compared to sea level values. NO_x emissions at both altitudes were substantially lower than measurements taken at sea level.

- The establishment of minimum statewide emission standards does not appear technically feasible. This can be attributed primarily to the variable effect of altitude on exhaust emissions.

Recommendations

- An interim mandatory idle inspection program for fleet vehicles should be implemented to determine

the actual effectiveness of this control approach. This program would provide the mechanism for developing and refining operational and logistical procedures. A one year pilot program starting July 1975 should provide the necessary information (costs and effectiveness) to finalize system design prior to full implementation.

- A voluntary program for fleet vehicle operating in the Denver AQCR should be considered for the third quarter of 1974.

- A program of retrofit certification and training for all inspectors, mechanics, and investigators should be initiated during 1974. Specific performance criteria should be established for certifying the retrofit devices.

- In developing exhaust emission standards for the idle program three classes of vehicles should be considered: fleet vehicles (10 or more vehicles under common ownership), pre-controlled vehicles (1967 and older vehicles), and controlled vehicles (1968 through 1974 model year). Additionally, standards based on other vehicle characteristics, e.g. engine block size,should be considered.

- An independent emissions surveillance and management information system should be established as part of the overall transportation control plan. The primary objective of the system would be to evaluate the operational effectiveness of the various control measures.

- The current transportation control plan should be updated to reflect the new experimental emissions data.

- A detailed plan should be prepared for implementing the emission control program. This plan should include budgetary information and the required legislation for achieving the program objectives.

2.0 INTRODUCTION

This is the final report of the High Altitude Vehicular Emission Control Program. The overall objective of this program was to examine the feasibility of implementing several vehicular emission control alternatives in the Denver AQCR. Both the achievable exhaust emission reductions and associated control costs were used in the feasibility assessment. This volume provides a summary overview of the results from the experimental program.

The rationale for conducting this experimental program was to develop actual emission performance data from vehicles operating at high altitude.* This type of information is of crucial importance in designing an effective transportation control plan. While comprehensive in scope, the original plan utilized assumed performance data for the various control measures. The current study provides a consistent and accurate emissions data base for evaluating the real effects of the proposed exhaust control measures.

An important aspect of this program was to develop estimates of control effectiveness for the candidate procedures based upon firm experimental data. The program, therefore, involved the design and execution of a series of experiments to acquire data in support of this evaluation. The actual testing program consisted of the following experiments:

* The EPA has recognized the need for considering the impact of altitude on vehicular emissions. It has recently proposed a ruling calling for the certification of new vehicles intended for initial sale at high altitude (Federal Register, Vol. 38, No. 197, October 12, 1973).

- A survey to establish the frequency and extent of engine maladjustments and malfunctions in the vehicle population. The survey also included the measurement of key mode and CVS emissions from the sample population.

- Experiments to characterize the costs and effectiveness of both an idle inspection and repair program and a mandatory engine maintenance program.

- A survey to establish the effectiveness with which garages measure emissions and diagnose and repair those engine malfunctions and maladjustments found to be important in an inspection and maintenance program.

- Experiments to determine the costs and effectiveness of several sea level and high altitude retrofit systems for controlling exhaust emissions.

- Experiments to establish the influence of selected engine adjustments on vehicular emissions.

- Experiments to ascertain the effect of altitude on vehicular emissions.

- Experiments to estimate the rates with which engine adjustments and exhaust emissions deteriorate with vehicle use.*

The experimental data developed from the testing program was reduced and synthesized using TRW's Data Management System. The results of these experiments are reviewed in Section 4.0 of this document and are presented in detail in separate volumes of this report. The processed performance information was used to partially update the original transportation control plan. A comparison between the assumed and actual effectiveness of the several control measures indicated some differences in performance, especially for the high altitude modification kits. These observed differences in control effectiveness are highlighted in this report.

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* To be completed in June 1974.

Finally, a preliminary evaluation was performed to develop the tasks and schedules required to implement the proposed control plan. A tentative schedule is presented which lays out the basic operational activities between now and 1977. Those individuals requiring a more in-depth assessment of the experimental program are referred to the specific technical volumes listed in the preface.

3.0 EMISSION TEST PROGRAM

The test program involved a series of experiments designed to characterize the fundamental elements of several emission control alternatives. Field surveys (to determine the current state of emissions and engine systems in the population), preliminary testing (to ascertain the impact of altitude on vehicular emissions), experimental simulation (to characterize the costs and effectiveness of idle inspection and mandatory maintenance), hardware evaluation (to assess the emission reduction potential of both sea level and high altitude retrofit kits), and finally, scientifically-controlled experiments (to measure the relationship between emissions and engine adjustments) provided the basic data to evaluate each control alternative.

Field studies (using 300 vehicles sampled from the general population) were performed to determine the extent and frequency of malfunctions known or suspected of having effects on exhaust emissions* Ten engine parameters were found to be frequently out of specification, resulting in significant increases in emissions. These were the idle adjustments (fuel-to-air mixture, rpm, timing and dwell), the ignition system when causing misfire or NO_x control malfunction, and several induction system components (air injection system, PCV valve, air cleaner and choke). Table 3-1 summarizes the survey results for both the pre-controlled (pre-1968) and controlled (1968-1974) segments of the vehicle population.

The engine parameters are separated into two basic categories -- distributed and nondistributed. Distributed parameters are those of a

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* The selected sample are representative of the 1964-1973 vehicle distribution in the Denver AQCR.

continuous nature, e.g. basic timing. Nondistributed engine parameters, on the other hand, are either operating or not operating. An example of a nondistributed engine parameter is the PCV valve. The survey found that 88 percent of all PCV valves were operating satisfactorily. One interesting observation from this data is the relatively high level of incipient misfire found in the population. On the average 14 percent of the vehicles surveyed were detected misfiring which is approximately four times larger than recorded at sea level.

In addition to the engine evaluation, the survey also measured key mode (idle, low cruise and high cruise) and CVS mass emissions. A set of mass emission frequency distributions are presented in Figures 3-1 through 3-3 for HC, CO and NO_x, respectively. These plots tend to confirm the relatively small number of high emitting vehicles. Repair of these vehicles, nevertheless, will yield disproportionately larger emission reductions. An effective program of vehicle inspection and maintenance should be designed towards detecting and repairing these high emitters.

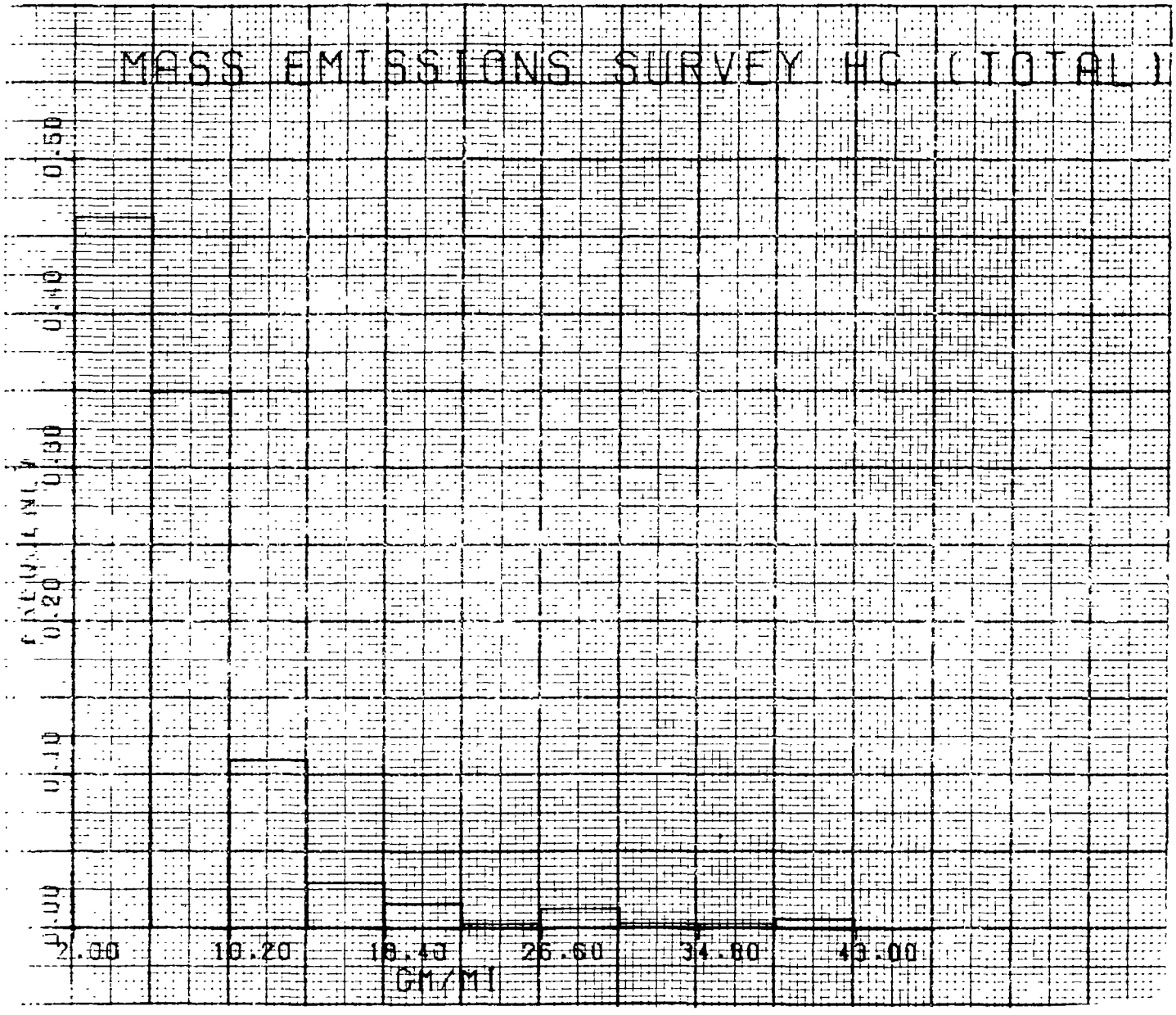
Using the survey data as a baseline, a series of tests were undertaken to experimentally simulate the operational characteristics of an idle inspection and maintenance program. This program was conducted in 10 repair garages of differing types (2 dealerships, 3 independents and 5 service stations) and the results validated at ATL's Laboratory. The test consisted of measuring HC and CO emissions at idle and comparing the recorded measurements against a pre-established set of pass/fail criteria.* Those vehicles failing either the HC or CO standard underwent

* The actual criteria were: idle HC-800 ppm for pre-controlled vehicles and 330 ppm for controlled vehicles; idle CO-6% for pre-controlled vehicles and 4% for controlled vehicles. These criteria were designed to fail approximately 50 percent of the vehicle population.

Table 3-1
Survey of Engine States by Model Year

Parameter	Distributed Parameters (<1968) Mean	SD	(1968+) Mean	SD	Average Mean	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	4.879	0.513	6.230
Dwell	-.791	4.030	-.047	4.098	-0. 20	4.082
Sample Size	(110)		(190)		(300)	

	Nondistributed Parameters (Percent) Yes	No	Yes	No	Yes	No
PCV	87	13	89	11	88	12
Sample Size:	(91)		(168)		(259)	
Air Cleaner	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)	
NO_x	0	0	80	20	80	20
Sample Size:	(0)		(30)		(30)	



ure 3-1 HC Mass Emissions Frequency Distribution for Total Vehicle Population

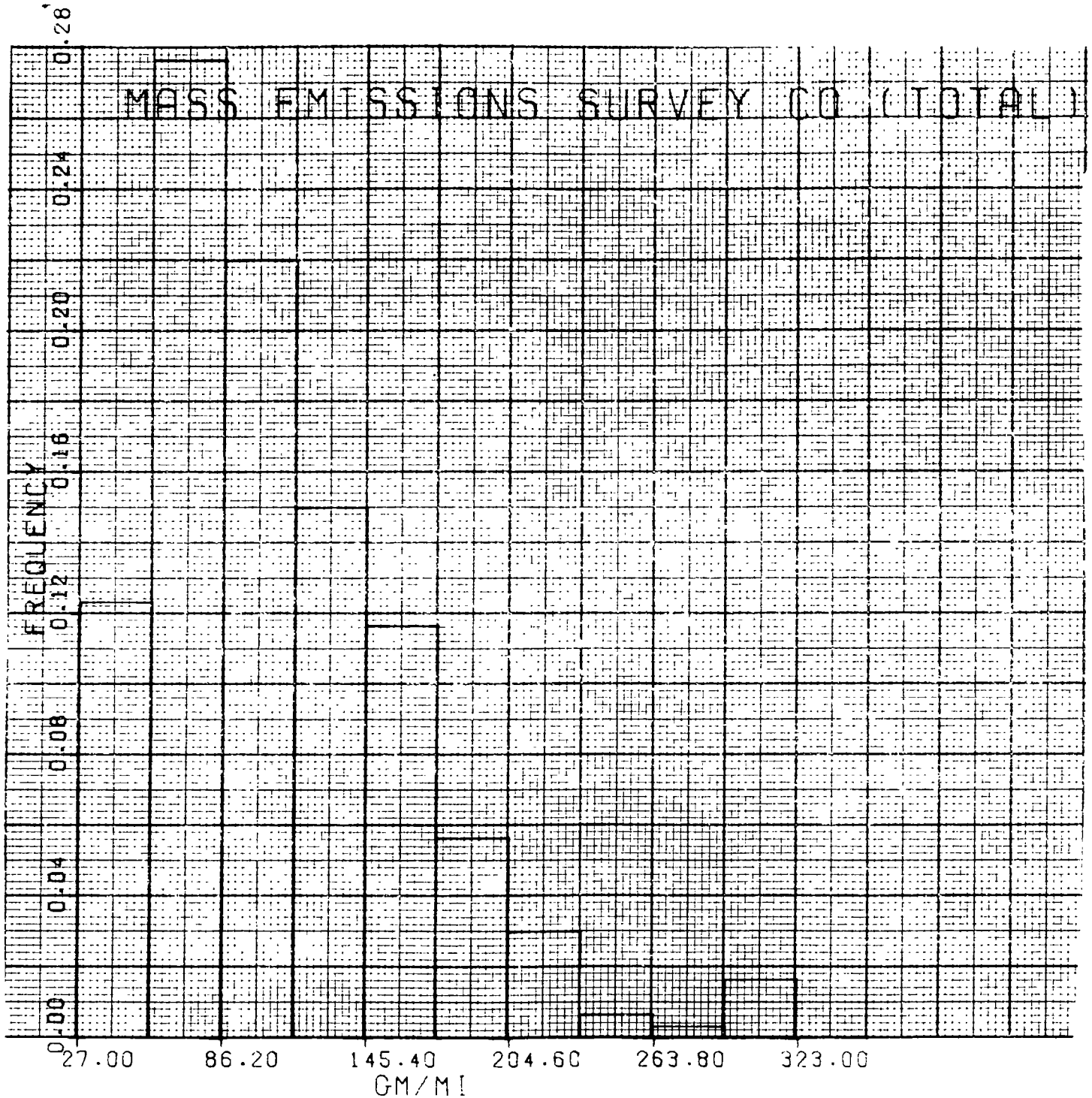


Figure 3-2 CO Mass Emissions Frequency Distribution for Total Population

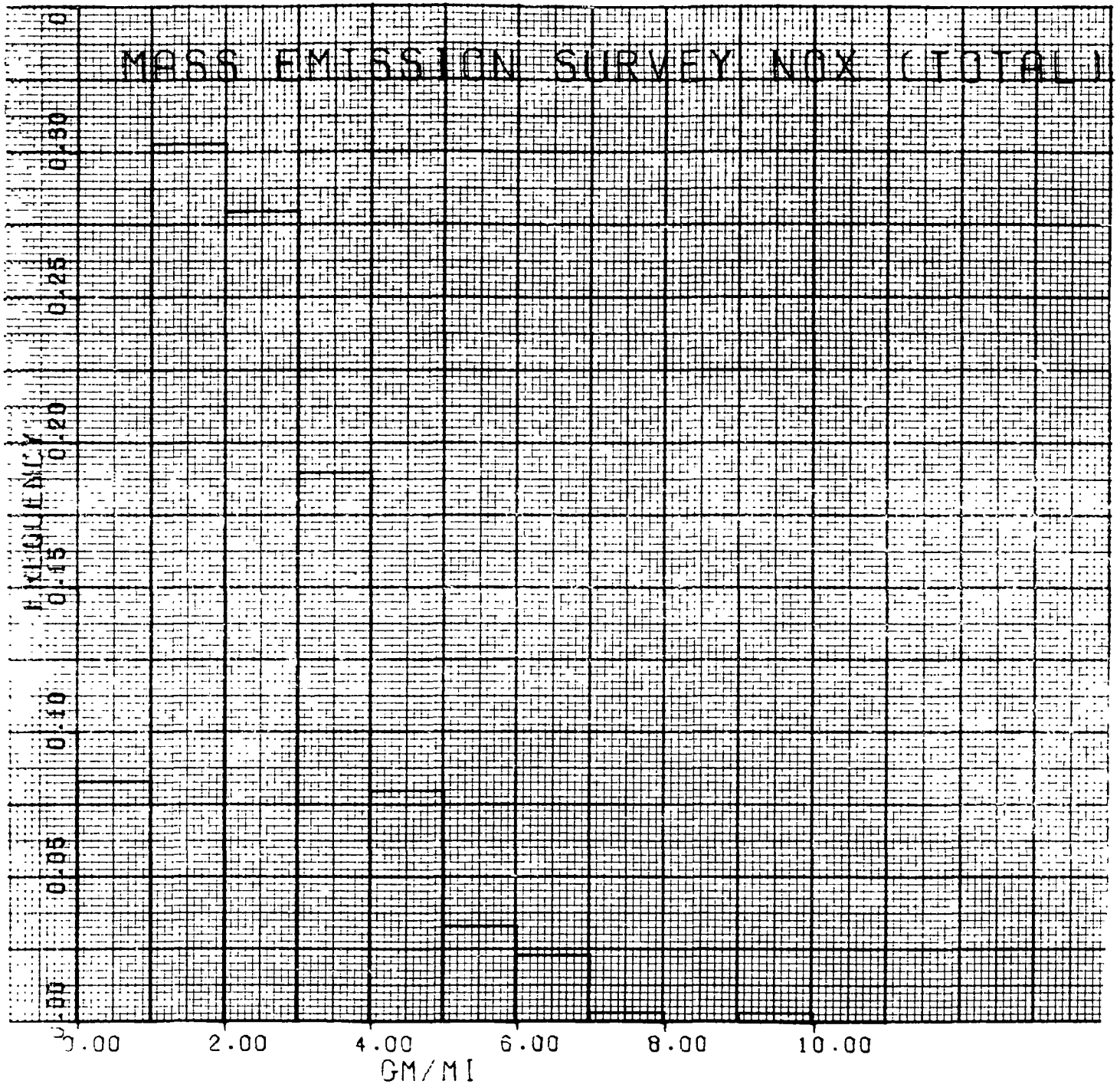


Figure 3-3 NO_x Mass Emissions Frequency Distribution for Total Vehicle Population

specific engine maintenance. Data collected from this experiment included:

- accuracy of inspection
  - instruments
  - personnel
- garage repair effectiveness
- emission reduction
- costs of inspection
- costs of maintenance adjustment
- costs of additional repair

This information was utilized to evaluate the overall cost effectiveness of an idle inspection and maintenance program.

In addition to the idle program, tests were also conducted to assess the feasibility of mandatory engine maintenance. A program of mandatory maintenance simply requires that all vehicles undergo periodic engine repair based on procedures set forth by the vehicle manufacturer. This approach eliminates the need for inspection (except for tests required to diagnose specific engine malfunctions). Its chief disadvantage is that it tends to be more expensive and that the adjustment of <u>all</u> vehicles to manufacturer's specification may yield only marginal emission reductions (as opposed to repairing only those vehicles with maladjustments that tend to increase exhaust emissions).

The effectiveness of a mandatory maintenance program was evaluated as part of the experimental program. Here, approximately 150 vehicles were tuned-up according to manufacturer's specification and their emissions recorded using key mode and CVS procedures. The resultant emission reductions were then evaluated in light of the required costs for the tune-up.

An extensive retrofit evaluation program was carried out to determine the effectiveness of these systems on vehicles operating at altitude. Basically, two classes of systems were evaluated: 1) sea level retrofit and 2) high altitude retrofit. Within the first class five different types of systems were analyzed.

- Vacuum Spark Advance Disconnect (VSAD)
- Air Bleed (AIR)
- Exhaust Gas Recirculation (EGR)
- Catalytic Converters (CAT
- Carburetor Float Bowl Pressure Regulation (CARB)

Additionally, VSAD, AIR and EGR were tested in paired combinations.

The high altitude modification kit consisted of various carburetor and distributor parts specified by the manufacturer. In some instances, an idle adjustment procedure was also implemented. The test program was limited to kits supplied or recommended by the four major U.S. automobile manufacturers (AMC, Chrysler, Ford and GM). In general, the procedures included leaning main fuel metering jets, modifying mixture enrichment staging springs, advancing basic ignition timing and adjusting idle air/fuel ratio.

All vehicles participating in the retrofit experiments were tuned to manufacturer's specification prior to the installation of the retrofit device. Emission measurement (key mode and CVS) were performed both before and after installation.

A series of scientifically designed experiments were performed to establish quantitative relationships between the state of engine adjustments and vehicle exhaust emissions. These data are required to predict

the emission changes resulting from corrective engine maintenance. Twenty-five vehicles were chosen to represent the total population.

The tests involved a systematic variation of four engine adjustments (idle air/fuel ratios, rpm, timing and choke) which were estimated to have a pronounced effect on exhaust emissions. These four were also identified as being easy and inexpensive to adjust. This experiment was designed to accommodate a fractional factoral analysis of variance. A one-half replicate of the total possible number of combinations of test variables (8 out of a total of 16) was performed. This design provides information on the four main effects (A, B, C and D) as well as three interaction effects (AB, AC, BC). Based on engineering considerations it was determined that the choke system does not interact with the other three adjustments.

A key experiment in the test program involved measuring the effect of altitude on exhaust emission levels. As previously noted, a baseline emissions data bank (from the survey) was developed for vehicles operating at 5,500 feet (Aurora). Additionally, key mode tests were conducted on a set of vehicles operating at 10,000 feet (Leadville). Data from the key mode measurements were transformed into equivalent CVS units using numerically derived regression equations for HC, CO and NO_x. These results were then compared to the values recorded at sea level and 5500 feet. A set of emission-to-altitude curves have been developed and are presented in Section 4.0.

The final element of the experimental program involved an evaluation of engine and emission deterioration.* The objective of this experiment

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* At this writing the deterioration program is still in progress and the results from the study will be presented in Volume VII of this report.

was to determine the rate of variation (change per mile of vehicle use) of exhaust emissions and engine parameters. A group of 150 cars were selected from the total sample of 300 privately owned vehicles. Engine states and emission levels were measured initially and at the end of six months of normal vehicle operation. Specific engine parameters were marked in order to ascertain the extent of normal and unauthorized engine maintenance that has occurred during the intervening period. A full series of CVS tests will be performed on these vehicles at the end of six months and these measurements will be contrasted with those developed during the initial survey.

4.0 ANALYSIS OF RESULTS

The nature and extent of the experimental test program required the application of a total data management and analysis system. The data system, developed as part of the Coordinating Research Council CAPE-13 Project, provides comprehensive capability for evaluating multi-dimensional emission test programs. Figure 4-1 presents a schematic overview of the TRW Data Management and Analysis 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 experimental data. ATL was responsible for reducing the CVS mass emission data and preparing the raw data files for the inspection, maintenance, retrofit, and adjustment experiments. TRW performed the data reduction, storage and statistical analysis of these results.

Evaluation of Procedures Effectiveness

An extensive analysis of the experimental results was conducted using the analytical methodology outlined in Figure 4-1. The analysis focused on both the effectiveness as well as costs of each of the control measures that were tested. Additionally, estimates were prepared on the impact of these measures on fuel economy.

Table 4-1 summarizes the results from the experimental program for the three operationally defined control measures (idle inspection and maintenance, mandatory engine maintenance and retrofit installation). An evaluation of these results leads to several direct conclusions. First, an idle inspection and maintenance program is, in the aggregate

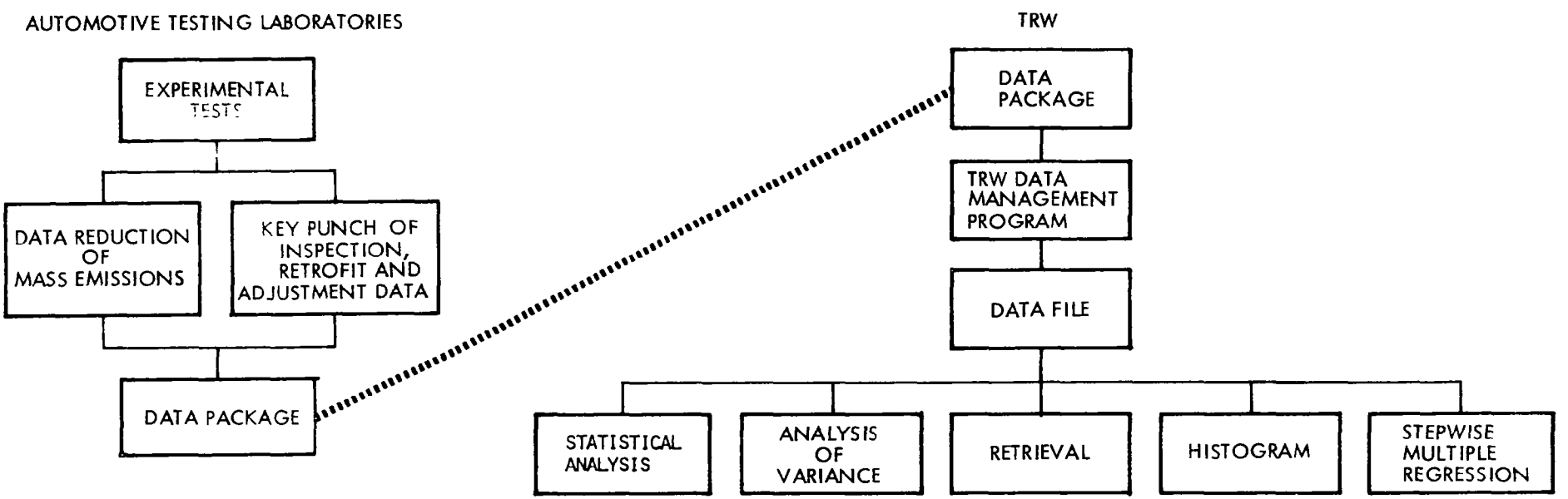

Figure 4-1
Data Management Approach

more cost-effective than a mandatory program of periodic engine maintenance. While the emission reduction effectiveness for an engine tune-up program is slightly greater than the idle inspection approach (9.6% versus 6.6% for HC, 4.9% versus 4.6% for CO, and 3.5% versus 0% for NO_x) the corresponding costs are nearly five times as great ($49.10 versus $10.18). In all fairness, however, it should be noted that a significant amount of the cost for mandatory repair is already being paid out by the motoring public as an integral part of voluntary engine care.

The emission performance estimates for both procedures reflect the effect of engine deterioration. For this case, the EPA deterioration schedule was used to modify the basic emission reductions achieved from the test program. These predictions should be revised as the data from the ongoing deterioration program become available.*

Based on these predictions, the most attractive approach is to inspect cars initially before performing maintenance. The inspection process helps differentiate between these vehicles requiring emission oriented maintenance and those whose engine is in good repair. Lastly, both approaches tend to improve fuel economy. For example, the average improvement in fuel economy for the idle program was over 0.3 miles per gallon.

The case for identifying the most effective retrofit system is more complicated, due primarily to the larger number of devices examined. As noted earlier, two classes of the system were evaluated --

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* The schedule assumes that emission levels return to their pre-maintenance state in one year (linearly).

sea level devices and high altitude kits. Furthermore, the sea level devices were tested separately on both pre-controlled and controlled vehicles. Results for the pre-controlled vehicles indicate that the combination of air bleed and exhaust gas recirculation yielded the best balance in terms of HC and CO emission reductions, although at somewhat higher costs. This sytem also recorded the only positive improvement in fuel economy of the three devices tested for older vehicles. If NO_x reductions are of primary concern then the combination of vacuum spark advance disconnect and exhaust gas recirculation appears more attractive for pre-controlled vehicles. One particular problem in equipping older vehicles with retrofit devices involves the rather high attrition rate for this class of vehicles. By 1980 the pre-controlled segment will constitute less then three percent of the vehicle population. This rather low percentage value makes it difficult to justify the installation of retrofit systems on pre-1968 vehicles.

As can be seen in Table 4-1, a wide range of effectiveness and costs were obtained for the retrofit devices tested on the control vehicles. In terms of emission performance, the catalytic devices produced the largest reductions for HC (72.3%) and CO (83.5%). The largest NO_x reduction was recorded for the exhaust gas recirculation system (42.8%). As in the case for pre-controlled vehicles, the combination of AIR/EGR produces what appears to be the best balance between costs and emission reduction effectiveness for HC and CO. Unlike either AIR or EGR used separately, the combination of these two devices did not adversely affect fuel economy.

Table 4-1

Comparison of Alternative Control Measures

Control Measure	Emission Reduction Effectiveness HC	CO	NO_x	Average Costs Per Vehicle	Improvement In Fuel Economy (MPG)*
1. Idle Inspection and Maintenance**	6.6%	4.6%	0%	$10.18	0.3
2. Mandatory Engine Maintenance**	9.6	4.9	3.5	49.10	----
3. Retrofit Installation					
o Sea Level					
VSAD + AIR (Pre-Controlled)	0	0	46.7	24.95	-1.11
VSAD + EGR (Pre-Controlled)	26.1	11.2	27.6	25.00	-0.06
AIR + EGR (Pre-Controlled)	22.4	21.2	0	36.95	0.31
CAT (Controlled)	72.3	83.5	0	155.00	0.25
AIR (Controlled)	17.5	41.9	-23.6	24.99	-0.15
EGR (Controlled)	0	0	42.8	32.15	-1.39
AIR + EGR (Controlled)	17.1	47.9	0	36.95	0.02
CARB (Controlled)	17.9	0	0	24.10	0.35
o High Altitude					
AMC	0	0	0	9.67	0.22
Chrysler	26.1	54.2	-84.4	12.62	1.32
Ford	0	0	-16.3	9.07	0.46
GM	0	0	-28.9	7.65	0.46

* A negative value indicates a decrease in fuel economy.
** Effectiveness estimates account for engine deterioration.

Finally, the results for the high altitude kits are somewhat discouraging. With the exception of the Dodges (Chrysler family) none yielded statistically significant reductions for either HC or CO. Furthermore, the Chrysler, Ford and GM devices had a adverse effect on NO_x emissions. While the costs for these systems is substantially lower than for the conventional sea level systems the overall cost effectiveness is extremely poor. Fuel economy tended to improve slightly with the use of the high altitude kit.

The idle engine adjustment experiment, although not designed for direct application, did provide substantial information of the effects of specific adjustments on exhaust emissions. As expected, the largest effect on CO emissions (approximately 15%) was achieved by adjusting idle air/fuel ratio (adjustment equivalent to a 200 drop in rpm). Timing had the second largest impact on CO emissions while adjustments in vacuum choke kick yielded moderately lower CO emission levels. None of these engine parameters, including rpm, had a significant effect on either HC or NO_x emissions. These results probably represent a limiting case, since the excursion range for these adjustments was greater than can be normally performed in a service garage.

Impact of Altitude on Emissions

The analysis of the impact of altitude on emissions was performed in two phases. First, regression equations were developed for relating key mode and vehicle characteristic variables, e.g. model year, to CVS mass emission levels at 5500 feet.* Specific relationships were

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* The variables included idle, idle at 2500, low cruise, high cruise, model year and vehicle weight.

computed for HC, CO and NO_x emissions.* Second, these equations were then used to predict CVS mass emissions at 10,000 feet (Leadville) using the key mode data recorded at that altitude. The predicted CVS levels at 10,000 feet were compared with those recorded at other altitudes (sea level and 5,500 feet) to chart the overall response effect. Figure 4-2 presents the developed emission-to-altitude curves for HC, CO and NO_x CVS emissions. Both HC and CO emissions tend to increase with altitude while NO_x emissions decrease with altitude.

Another area of concern involves the establishment of minimum exhaust emission standards throughout the state. As seen in Figure 4-2, emissions can vary substantially as a function of altitude and thus for Colorado this phenomenon poses a difficult problem in designing meaningful statewide standards. Panels A and B of Figure 4-2 illustrate the impact of altitude on the relationship between emission criteria and vehicle rejection rate for idle HC and idle CO, respectively. Applying the standard used in the Denver idle test program for pre-controlled vehicles (330 ppm for HC and 6% for CO) results in a much higher rejection rate in Leadville for HC (50% versus 25%) and a substantially lower rejection rate for CO (20% versus 45%). The reversal in rejection fractions for CO can be attributed to engine modifications that have been performed by the vehicle owner in the Leadville area. This confounding effect along with the direct impact of altitude tends to complicate the task of specifying effective standards for various regions within the state.

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* The determination of correlation (R^2) for these relationships were 0.67 for HC, 0.73 for CO and 0.73 for NO_x.

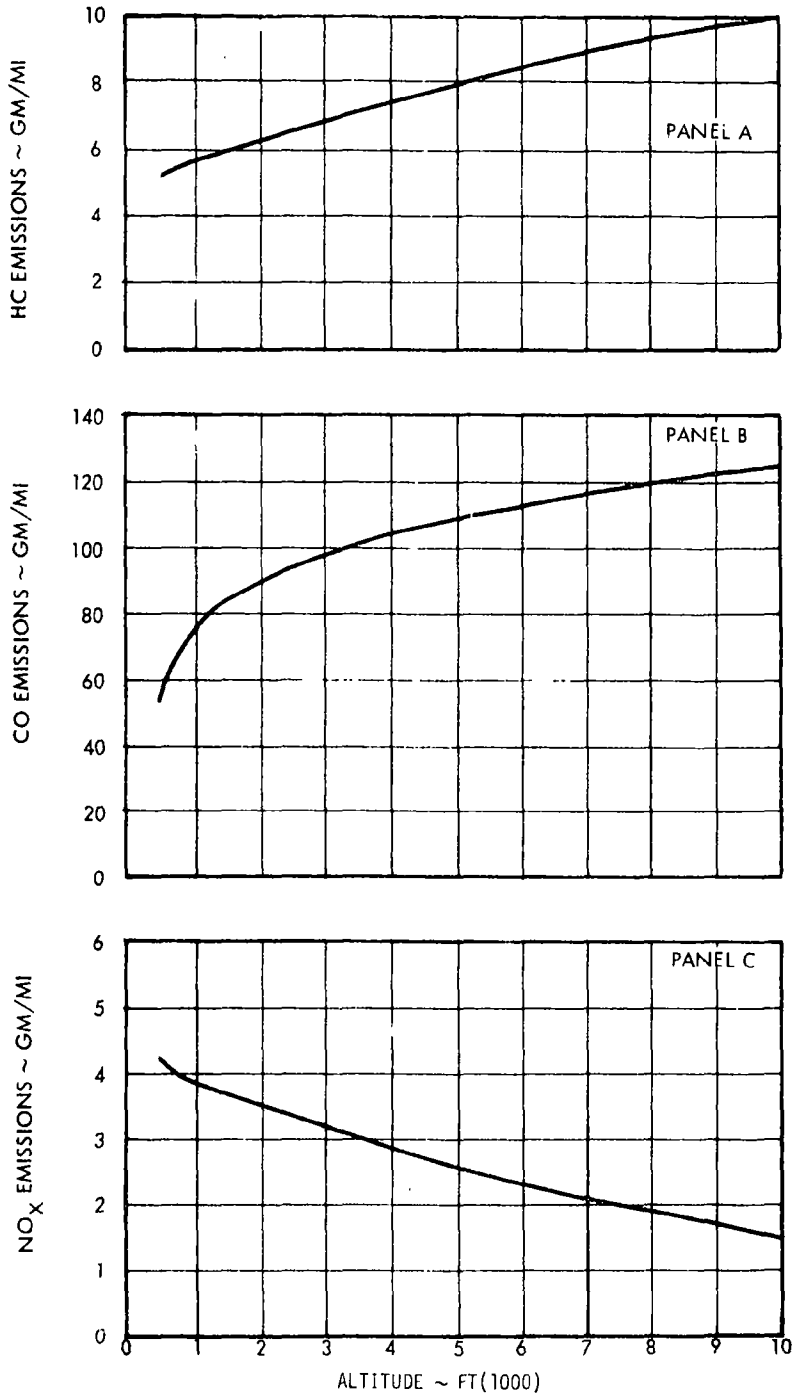
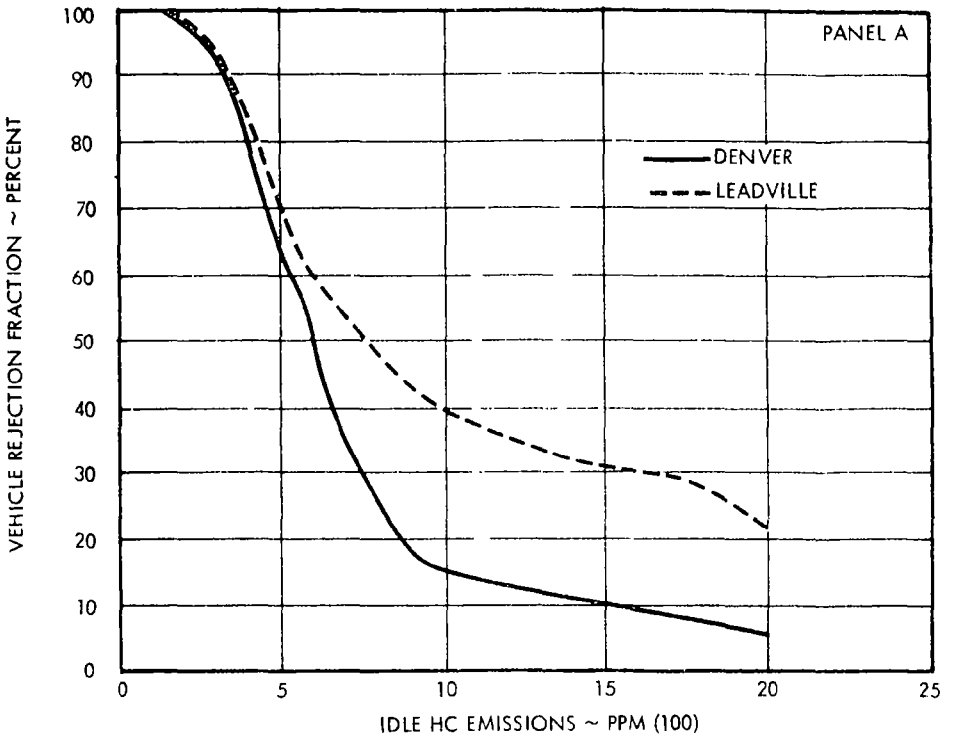


Figure 4-2

Impact of Altitude on Vehicular Mass Emissions



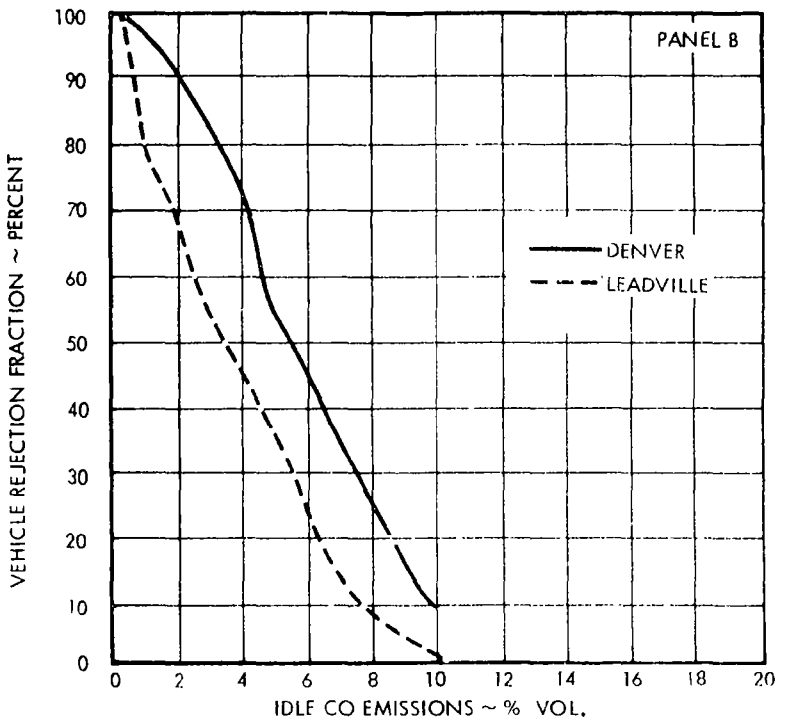


Figure 4-3

Impact of Altitude on Vehicle Rejection Rates
For Pre-Controlled Vehicles

Assessment of Transportation Control Plan

One of the major objectives of the test program was to validate the assumed emission reduction estimates used in the Transportation Control Plan. Table 4-2 compares the percentage emission reductions claimed in the Colorado Plan with those developed from the test program. These results clearly indicate that additional controls will be necessary to achieve the national ambient air standards for the Denver AQCR. The primary concern is with the high altitude modification kits. Even the measured results appear optimistic since they were based on a small subset of the vehicles involved in the high altitude tests (only Dodges showed statistically significant results).

Forecasts of emission levels by 1977 were prepared in order to ascertain the requirements for additional transportation control. Specifically, two cases were examined:

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 4-3. Shown are the assumed and measured estimates for the original plan and the measured results for the revised plan. These forecasts indicate the need for an additional 18 percent reduction in CO and a 7 percent reduction in HC for light duty vehicles.

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

Table 4-2

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 4-3

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

Measure (LDV only)	Application	Original Plan Assumed CO	Original Plan Assumed HC	Original Plan Measured CO	Original Plan Measured HC	Revised Plan Measured CO	Revised Plan Measured 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	6.3	3.1	2.7	2.8	2.7	2.8
3. High Altitude	1968-1974 Autos	17.5	10.5	7.7	3.6	---	---
4. AIR/EGR Retrofit	1968-1974 Autos	---	---	---	---	33.5	12.0
	TOTAL	32.2**	20.5**	16.6**	15.7**	39.1**	20.4**

* Mid-Year 1977

** 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.

consistent with the original plan estimates. Nevertheless, it would seem quite appropriate to re-evaluate, in more detail, the entire plan with respect to the new data.

5.0 CONTROL PLAN DEVELOPMENT

The current test program represents merely a first step in the development of an effective control plan for the Denver AQCR. Having identified what appears to be a reasonable control strategy, the next step is to lay out specific activities required to implement the defined program. The purpose of this section is to sketch out a preliminary timetable to accomplish this goal.

A tentative schedule for implementing the various plan activities is shown in Figure 5-1. The figure is generally self-explanatory. The key activity in 1973 was the experimental test program. The schedule shows the program continuing into 1974 with the completion of the engine deterioration experiment. The next step in the schedule involves the development of the actual control plan and the specification of the organization structure. This task should be completed by the middle of 1974. Key elements emerging from the planning effort are the training and certification programs. Both of these programs should be initiated shortly after the completion of the planning phase and will require approximately one year to develop the necessary procedures and techniques (middle of 1975).

The interim mandatory inspection program for fleet vehicles should be initiated during July 1975 and operated for 12 months (10 months for testing and 2 months for analysis and review). A voluntary inspection program should be established in late 1974 in order to develop and refine operational procedures. At the same time, the system's design for the surveillance and monitoring network should be undertaken and completed by the first quarter of 1976.

Finally, the retrofit program, pending legislative approval should begin by January 1976 to allow sufficient time to equip the vehicle population. The fully developed inspection system should be ready for operation by January 1977. Simultaneously, the emissions surveillance and monitoring network should be in full operation.

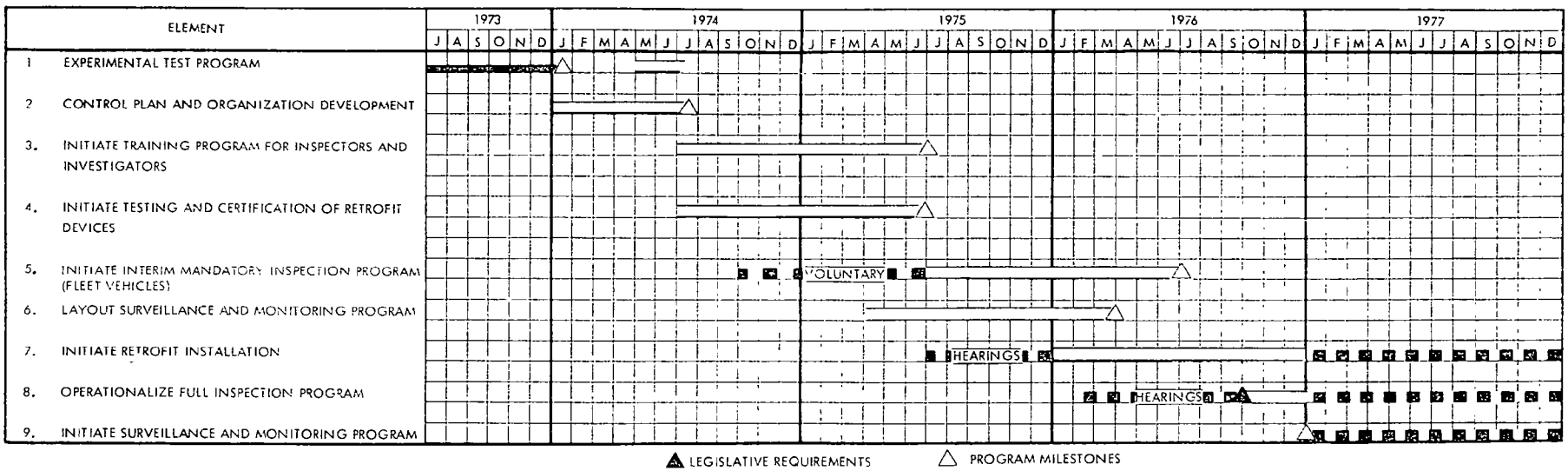


Figure 5-1

Tentative Control Plan Schedule