957

No. 71Y240A

MANDATORY VEHICLE EMISSION INSPECTION AND MAINTENANCE
PART B - FINAL REPORT

VOLUME V

PART 2
TECHNICAL ANALYSIS AND RESULTS

Prepared Under Contract

Contract ARB 1522
with
State of California
Air Resources Board

Approved by

R. L. Gibney, Vice President
Environmental Systems

10 December 1971

NORTHROP CORPORATION
Electro-Mechanical Division
500 East Orangethorpe Avenue
Anaheim, California 92801

in association with

OLSON LABORATORIES, INC.

FOREWORD

The Second Annual Report of the Air Resources Board, titled "Air Pollution Control in California," published in January 1970, documents the activities of the Board during 1969. In addition to a review of the Air Resources Board's many accomplishments, it was stressed that many problems remained to be solved. One of these was to determine the effects of various maintenance procedures on exhaust emissions and to develop a practical vehicle inspection program. In accordance with a legislative directive (AB76), the Air Resources Board issued a Request for Proposal on July 3, 1970 to conduct a Vehicle Emission Inspection and Maintenance Study that would determine the feasibility of such a program. Northrop Corporation, Electro-Mechanical Division, was selected to perform this study; Standard Agreement number ARB-1522 was consummated on November 30, 1970.

Part A of the study addressed the overall feasibility and public acceptability of a program of mandatory vehicle emission inspection and maintenance. It was completed in June 1971 and documented in four volumes. Volume I, Summary, provided a synopsis of the analytical methodology employed to determine and evaluate the feasibility of a statewide inspection program. The findings and results of the analyses were summarized, and recommendations for further effort were provided. Volume II described the Recommended Vehicle Emission Inspection and Maintenance Program. Volume III, Technical and Economic Feasibility Analyses, described the conduct of the study; provided the findings, results, and conclusions of the analyses; and recommended areas for further investigation. Volume IV included the Appendices of data references, relevant correspondence, instrumentation survey data sheets, and other substantiating documentation.

Part B of the total study was designed to acquire operational data on automotive emission reductions that can be achieved through vehicle inspection and maintenance. Volume V of the total study report documents the results of the vehicle test phase and contains summary information previously reported ; thus, Volume V can be utilized without reference to Volumes I through IV. Volume V is presented in two parts, each under separate cover: Part 1 - Summary and Part 2 - Technical Analysis and Results.

CONTENTS

360

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

TABLES

TABLES (Continued)

SECTION 1

INTRODUCTION

This volume of the Vehicle Emission Inspection and Maintenance Study Final Report, Part B, describes the conduct of the study, and provides the findings, results, and conclusions of the analyses.

1.1 STATEMENT OF THE PROBLEM

Approximately 55 percent of the total California passenger vehicles (pre-1966 vintage) do not have any exhaust emission control devices or systems. Although these uncontrolled vehicles are diminishing in numbers with each calendar year, those remaining will continue to contaminate the air in far greater proportion than their number would indicate. Numerous studies have been conducted to determine the factors that influence vehicle emissions. Based on these investigations and the institution of both State and Federal regulations, manufacturers are developing and producing vehicles with exhausts that are becoming increasingly "cleaner" with each newer model-year vehicle. However, two significant problems still remain to be resolved. First, there are no State-certified and approved control devices currently available for installation on the pre-1966 or uncontrolled vehicles that would significantly decrease exhaust emissions of hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NO_X). Second, as both the controlled and uncontrolled vehicles accumulate time and mileage, deterioration of vehicle emissions may occur.

Studies conducted by governmental agencies and the automotive industry have shown that corrective maintenance and adjustments can affect rising emission levels. Many feel that a vehicle emission inspection program, that would identify those vehicles requiring corrective maintenance and adjustments, could become an effective method of reducing exhaust pollutants. There are many different inspection schemes, each purported to be the best for a statewide program. The California Air Resources Board has identified five inspection and test concepts as possible candidates for implementation. These concepts cover the total spectrum of sophistication, from the reasonably simple to the relatively complex. They are the Certificate of Compliance, the Annual Adjustment and Maintenance Procedure, the Idle Test, the Key-Mode Test, and the Diagnostic Test.

1.2 INSPECTION AND MAINTENANCE PROGRAM OBJECTIVES

The overall objective addressed in this study is to assist the State of California in achieving improved air quality by reducing vehicle emissions of HC, CO, and NO_X. To meet this objective, the California State Legislature wishes to consider the implementation of a statewide network of inspection facilities. Before recommending such a program, the Air Resources Board requires information on the overall technical and economic feasibility, and the public acceptability and benefits of a mandatory periodic inspection and maintenance program. Volumes I through IV of this report provided preliminary information based upon half of the vehicles tested in the Part B test program. This volume (V) includes data on all testing and documents the findings.

The recent upsurge of interest in the control, regulation, surveillance, and instrumentation of vehicle exhaust emission is well founded. The second annual report of the Secretary of HEW to Congress stated that automotive sources continue to emit more air pollutants than all stationary sources combined (Reference 1*). Thus, the State program objective in seeking a means of reducing HC, CO, and NO_x from the atmosphere will contribute directly to alleviating the total air pollution problem.

Although control measures have been effected in California for several years, the absolute amount of emissions by automobiles is still very high. The Air Resources Board in its annual report to the Governor (Reference 2) estimated that in 1970 in the South Coast Basin (Los Angeles Area) automobiles produced over 2300 tons of HC per day. These emissions represented approximately 70 percent of the HC and 67 percent of the NO_x emitted from all sources in the basin.

1.3 STUDY PURPOSE

The purpose of this study, therefore, is to determine if the State of California should institute any of these, or other, test concepts in a program of mandatory vehicle emission inspection. To resolve the issue, questions similar to those listed below are answered in the study:

a. Which test concept is most desirable for statewide implementation?

b. Is the test concept technically feasible and realizable using current technology, instrumentation, and technical personnel?

c. What are the attendant costs, both to the State and the vehicle owner?

d. What degree of participation should the State and private industry have in the management, ownership, and operation of statewide facilities?

e. What is the general public's reaction to a mandatory inspection program?

f. What benefits will the State and the public realize from this program?

In brief, this study evaluates the technical feasibility of various test concepts, identifies and quantifies program costs, elicits and analyzes public opinions, and describes total program benefits.

1.4 STUDY SCOPE

The total study has been contractually divided into two parts. Part A of the study delves into the questions related to technical and economic feasibility, as well as public acceptability and benefits. Part B of the study is structured to obtain empirical operational data from vehicle testing and maintenance performed in accordance with the five test concepts. The data is analyzed and used as inputs to the feasibility analyses of Part A.

---

*All References are listed in Section 7.

This report summarizes the investigation conducted under Part A of the study. Each of the five test regimes is investigated in terms of technical feasibility; total program implementation costs, including State and vehicle owner's costs; and public acceptability and benefits. In addition, some preliminary analysis of the technical and economic aspects of a Constant Volume Sampling (CVS) system is conducted in anticipation of possible future requirements.

Part B is a 12-month study involving 1215 privately owned vehicles (less than 6001 pounds) to be inspected and serviced as determined by procedures of the five test regimes. The study was separated into two operating phases: a learning phase involving 120 vehicles, and the main-test phase involving 1095 vehicles. A Learning Phase Final Report covering the activities of the initial 120-vehicle pilot program was issued to the Air Resources Board on 22 January 1971.

SECTION 2

TEST PROGRAM DESCRIPTION

2.1 BACKGROUND

2.1.1 Effect of Automobile Emission on Air Quality

Since the early 1950s, the automobile has been identified as a factor in the deterioration of air quality in California. High atmospheric concentrations of carbon monoxide (CO), volatile hydrocarbons (HC), oxides of nitrogen (NO_x), and particulate matter (PM) are, in large part, directly attributable to automobile exhausts.

Additional large quantities of HC are emitted by evaporation from automobiles and from the operation of filling stations. The production of photochemical smog by the atmospheric reaction of HC and NO, under the influence of solar irradiation, has been investigated and documented by Haagen-Smit and others (References 3 and 4).

The emission of air contaminants is a basic characteristic of the modern internal combustion engine. However, the amount of pollutants emitted per mile of operation can vary widely, depending on engine design factors and on conditions of operation. Proper understanding and application of these factors can result in a significant reduction of pollutant emissions by cars. Added equipment can be installed on automobile engines to further reduce the quantity of pollutants emitted.

All three approaches have been applied to the reduction of harmful exhaust emissions. To meet increasingly more stringent standards, automobile manufacturers have installed emission control devices on existing engines, revised recommended engine operating parameters, and redesigned basic engine characteristics.

2.1.1.1 Nonexhaust Emissions - Automobiles use organic lubricants and fuels which contain volatile components. In pre-1963 automobiles, these compounds were normally emitted as vapor from the crankcase vent, the fuel tank vent, and the carburetor. Abnormal sources included fuel line and fuel pump leaks, and faulty or missing crankcase caps and air cleaner housings.

During engine operation, the crankcase vent was a source of excessive HC in engines with worn or defective compression rings or cylinders which allowed "blowby" of significant quantities of unburned air-fuel mixtures. In many cases, over 25 percent of the total HC emissions from a car could be attributed to vented blowby gases.

Evaporative emissions can amount to over 15 percent of the total. These losses result from evaporation of fuel from the fuel tank and carburetor vents.

2.1.1.2 Exhaust Emissions - Automobile exhaust gases include not only HC, but CO and NO_x. Approximately 60 percent of the HC emission is contained in the exhaust gases. This results from lack of combustion of fuel vapors in the "quench zone" near cylinder walls and in the space between the cylinder and piston above the first piston ring. Poor carburetion and incomplete mixing of air and fuel can aggravate this normal condition.

NO is produced in the normal combustion process. High combustion temperatures and lean air-fuel mixtures (to the point of stoichiometry) increase the concentrations of NO in the exhaust gases. NO converts to NO_2 and other oxides of nitrogen in the atmosphere, and the reactions which take place are major factors in the formation of photochemical smog.

CO is a product of partial combustion of the fuel and is produced in high concentrations at the high combustion temperatures encountered in the internal combustion engine. With adequate quantities of oxygen and time, most of the CO would be oxidized to CO_2 at temperatures between combustion and exhaust. However, cooling occurs at a high rate in the exhaust system, allowing little opportunity for CO oxidation. Furthermore, the air-fuel ratio is usually not optimum for CO oxidation. As a result, all uncontrolled engines produce significant quantities of CO.

Modification of engine operating parameters, including idle speed, air-fuel ratio and spark timing can all affect the concentration of these pollutants in exhaust gases from normal engines. The objective of applying these modifications is to optimize the engine operation with respect to exhaust emissions. Unfortunately, when HC and CO are minimized NO emissions may increase. (When air-fuel ratios exceed stoichiometric ratios, NO formation actually decreases.) When adjustments are made which optimize engine performance with respect to emissions, the vehicle performance such as acceleration and drivability may be degraded with respect to presently acceptable standards.

2.1.2 Emission Control Techniques

2.1.2.1 Blowby and Evaporative Emissions - Early attempts at vehicle emission control included the mandatory installation of crankcase controls on all new cars sold in California beginning in 1963. (The auto manufacturers voluntarily installed these devices on California cars beginning in 1961.) The desired result of this action was to materially reduce the amount of HC emitted through the crankcase vent. The system generally consists of a tube connecting the crankcase and the engine air intake. The tube usually contains a positive crankcase ventilation (PCV) valve which controls the flow of crankcase gases into the engine air intake. An inlet port with a filter on the crankcase prevents a vacuum buildup in the crankcase.

The following paragraphs discuss auto emission control techniques as the data to the requirements for a mandatory inspection program. A more comprehensive treatment appears in the report of the Federal Government on this subject (Reference 5).

To further reduce HC emissions, all 1970 and subsequent model cars sold in California have been equipped with devices to nearly eliminate evaporative emissions. The most common of these are activated carbon filters which absorb HC vapors from the fuel tank and carburetor.until they are purged into the intake system during certain modes of operation. Evaluation of crankcase and evaporative emission control components usually consists of a simple inspection to assure they are installed properly and ae are functioning according to manufacturers' specifications.

2.1.2.2 Exhaust Emissions - A large part of the HC emissions and all of the CO and NO produced by the automobile engine is emitted in the exhaust gases. The control of exhaust emissions has been accomplished for new automobiles by establishing standards and prescribing test procedures to evaluate these exhaust emissions. The various automobile manufacturers have defined and developed the methods to meet the standards.

Exhaust emission standards for CO and HC became effective in California with the 1966 model-year domestic vehicles. The standards were expressed in concentration units (percent CO and ppm HC) and were based on the weighted average of values observed with the automobile engine operating in seven different modes.

To meet these initial emission standards, the automobile manufacturers took one of two approaches. Of the major U.S. manufacturers, Chrysler incorporated engine modifications which resulted in leaner air-fuel ratios during idle and low speed cruise and during engine warmup. Spart timing was retarded to assure ignition of these leaner mixtures. The spark timing was automatically advanced during closed throttle deceleration to lengthen combustion time. The ability of the Chrysler engines to meet the more stringent 1966 and subsequent standards depends, among other things, on careful adjustment of the carburetor and ignition system and on the proper functioning of the distributor vacuum control valve.

To meet 1966 standards, the other major domestic manufacturers installed an air pump which provided air for the hot exhaust gases as they left the engine cylinders. This resulted in a more complete oxidation of CO and HC. Other adjustments on the air-injection-equipped cars included a modified spark advance schedule, increased idling speed, and an intake manifold relief valve which prevented backfiring during closed throttle deceleration. The air-injection system was used on most car models for only 1 or 2 years.

Improvements in engine control systems and in engine design have subsequently resulted in better emission control and improved reliability on all domestic and foreign cars. Additional design improvements include redesigned combustion chambers and air-intake systems. Better controls include tighter manufacturing and adjustment tolerances on carburetors, and optimizing spark advance control to obtain low emissions.

All of these improvements were required because exhaust emission standards were revised to lower levels in 1970. At the same time, the standards were redefined in terms of units of pollutant by weight per mile of vehicle operation. This change was incorporated to take into account the size factor (engine displacement) of the various cars.

California exhaust emission standards have existed for new cars since 1966. In this study, all domestic cars of 1965 or earlier are referred to as "uncontrolled" - those of 1966 and later as "controlled."

Although the Federal Government has specifically preempted the authority to set emission standards for new vehicles, a special waiver provision permits the State of California to establish and enforce more restrictive standards and procedures than the national standards. California has already established standards for NO_x, beginning with the 1971 models, becoming more stringent in 1972, and still more stringent in 1974. The California standards for HC in 1972 are also more strict than existing Federal standards. Table 2-1 indicates the trends in emission limits (concentration measurement) as imposed by the Federal and California regulations. Table 2-2 shows the emission control requirements using Constant Volume Sampler

Table 2-1. FEDERAL TEST PROCEDURE EMISSION CONTROL REQUIREMENTS - PASSENGER CAR AND LIGHT TRUCK (UNDER 6001 LB G.V.W.)

Emission (Grams/Mile)	FTP (Concentration Measurement)			
	Pre-1966 (Uncontrolled)	1966 Calif 1968 Fed.	1970 Calif Fed.	1971 Calif Fed.
Hydrocarbons	11	3.5	2.2	2.2
Carbon Monoxide	80	36	23	23
Nitrogen Oxides	4 - 6	NR	NR	4 NR
Evaporation (Grams/Test)	50	NR	6 NR	6

NR - No Requirement

Table 2-2. CVS TEST PROCEDURE EMISSION CONTROL REQUIREMENTS - PASSENGER CAR AND LIGHT TRUCK (UNDER 6001 LB G.V.W.)

Emission (Grams/Mile)	CVS (Mass Measurement)				
	1972 Calif Fed.	1973 Calif Fed.	1974 Calif Fed.	1975 Calif Fed.	1976 Nation
Hydrocarbons	3.2 3.4	3.2 3.4	3.2 3.4	0.46	0.46
Carbon Monoxide	39	39	39	4.7	4.7
Nitrogen Oxides	3.2* NR	3.0	1.3 3.0	1.3 3.0	0.4
Evaporation (Grams/Test)**	2	2	2	2	2

NR - No Requirement
*Two hot cycles (FTP test)
**Proposed

(CVS) mass measurement that becomes effective on 1972 vehicles. The basic difference between the Federal test procedure (FTP) and the CVS procedure is that the CVS method collects a proportional bag sample of the exhaust over the entire cycle and the FTP method measures discrete modes during the cycle. These modes are then assigned certain weighting factors to arrive at a composite value. All calculations contained in this report were based upon concentration measurements.

2.1.3 Deterioration and Effects of Maintenance

The criteria and standards established for automobile exhaust emissions have been applied mainly to automobiles at the time of initial manufacture or subsequent transfer of title. Except for apprehension of flagrant smoke emitters, little effort has been expended to ensure continued performance of emission control systems. Some cars which initially meet the standards deteriorate in performance during their lifetime. This may be due either to wear or to deliberate maladjustment of engine performance parameters by the owners.

Studies already completed show that acceptable emission performance for most cars can be achieved and sustained by proper maintenance and repair (References 6 and 7). The maintenance work must be emission-reduction oriented to achieve the desired results, indicating a necessity for established standards of training and experience of the mechanic.

One of the earlier investigations was conducted by the California Motor Vehicle Pollution Control Board (now the Air Resources Board) in conjunction with Scott Research Laboratories, San Bernardino. This investigation evaluated the cost-effectiveness of various tuneup approaches in reducing exhaust emissions of uncontrolled vehicles (Reference 8).

The experiment divided the sample of vehicles into four groups. After general tuneup was performed by representative garages and service stations on the first group of vehicles, the average changes in emissions were insignificant. The second group of cars was given tuneups by new car dealers using instructions provided by the Automobile Manufacturers' Association. Results obtained were similar to that of the first group. For the third group, Scott Laboratory used a chassis dynamometer and oscilloscope to perform detailed engine diagnostic tests. Indicated deficiencies were corrected, idle air-fuel ratio was adjusted on the lean side, and idle rpm was adjusted to 75 rpm above the manufacturer's specification. As a result, HC decreased by an average 28.9 percent, while CO decreased by 13.4 percent. For those vehicles that received carburetor overhaul by Scott, the average decrease in HC was 44.8 percent, while CO decreased by 25.6 percent. For the fourth group, Scott Laboratory performed a "package" tuneup during which spark plugs and distributor points were arbitrarily replaced annually, high-tension wires and air cleaner elements were replaced every 2 years, the idle air-fuel ratio was adjusted on the lean side, the idle speed was set 50 rpm faster than the manufacturer's specification, and spark timing was retarded 5 degrees. Average reductions for this group were 27 percent of HC and 21 percent of CO.

Data on cost of inspection and maintenance were collected. These generally indicate that effective emission control procedures are more costly than ineffective methods. The study was significant in that it showed that only those tuneups conceived to reduce exhaust emissions were really effective in this regard.

In another study that investigated exhaust emissions from controlled vehicles, it was demonstrated that high emissions can be lowered, in most cases, with engine adjustments and tuneups performed by a qualified commercial garage (Reference 6). A study dealing with 1966 model General Motors cars equipped with Air Injection Reactor (AIR) control systems showed that the need for proper maintenance becomes very important (Reference 7). For this study, the vehicles were divided into four mileage groups: 4,000, 8,000, 18,000, and 21,000 miles. Within each group, the average

HC and CO emissions were reduced after restoring the engine to proper operating conditions with normal tuneup procedures and periodic replacement of air-cleaner elements.

The results of all studies examined may be summarized in two points. First, the incorporation of emission controls on cars does not assure continued low emissions. The control systems tend to deteriorate in their performance. Second, with proper maintenance and adjustments, vehicles will operate with lower emission levels. The issue, then, is to determine the best method of identifying these vehicles that require the necessary adjustments and maintenance and to accomplish the necessary repairs or adjustments. The following paragraphs describe various inspection and test regimes considered in this study for this purpose.

2.2 TEST REGIMES DEFINITIONS

In this study, various short test cycles were evaluated with reference to the hot-start version of the standard seven-mode test. This hot-start test is a modification of the seven-mode seven-cycle test presently specified by California and Federal agencies. The seven-cycle seven-mode certification test is designed to determine HC, CO, and NO_x concentrations as emitted by a vehicle on an average metropolitan trip of 17 minutes duration. A chassis dynamometer is used to simulate typical road-load conditions. The total test is comprised of two parts. These are: four seven-mode warmup cycles, and three hot cycles. Each seven-mode test consists of two periods of acceleration, two cruises, two decelerations, and one idle period. The average concentrations for the two parts are weighted and combined to yield a composite value for each of the three concentrations.

The standard cold-start test requires that the vehicle not be operated for a period of about 12 hours immediately before testing. To ease scheduling problems and to provide a more uniform referral test, the seven-mode hot-start test is used in this program. This test is the last two complete cycles of the standard test. The vehicle is preconditioned by operating it until normal operating temperature equilibrium is attained (8 to 15 minutes), after which two cycles of seven-mode (two accelerations, two cruises, two decelerations, and one idle) are run. As in the standard test, a single value is derived for each of the three pollutants. In this study, the results of five short-form tests are being compared to results of the seven-mode hot-cycle test. These five are: Certificate of Compliance, Annual Adjustment and Maintenance Procedure (AAMP), Idle Test, Key-Mode Test, and Diagnostic Test regimes. Detailed descriptions of the five test regimes follow. A copy of the test procedures and instructions which were sent to the participating garages are described in Appendices A through E.

2.2.1 Certificate of Compliance Test Regime

In accordance with the requirements of Chapter 4, Part 1, Division 26, of the Health and Safety Code and the rules and regulations of the Air Resources Board, a Certificate of Compliance is issued to indicate that the identified vehicle is properly equipped with the motor vehicle pollution control device(s) required by law. Ordinarily, the certification is required and obtained during transfer of ownership as directed by the Vehicle Code. However, the certificate may be requested by the California Highway Patrol and issued any time proof of compliance is desired. The Certificate of Compliance inspection and servicing procedure involves the following sequence of operations. For uncontrolled vehicles, service the crankcase device, and remove and replace if necessary. For controlled vehicles, visually inspect pertinent connections and perform required engine adjustments. In this program, some basic adjustments (recommended by the Air Resources Board) beyond present certification requirements were added for uncontrolled vehicles.

2.2.1.1 Crankcase Devices - The following synopsis of events has been extracted from the CHP handbook (Reference 8).

a. Identify and confirm that the vehicle has an approved device installed.

b. Test the device for satisfactory operation with the engine warm and at idle condition.

c. Clean, service, or replace the device in case of unsatisfactory operation. Use the manufacturer's recommended instructions.

2.2.1.2 Exhaust Emission Control Systems - To continue meeting California emission standards, the necessary maintenance and adjustments must be accomplished according to manufacturer's recommendations and specifications. The control system inspection involves checking those items and adjustments of an engine which affect exhaust emissions. The procedures are:

a. Visually check all installation connections to the air pump, hoses, valves, and air distribution manifolds while the engine is stopped.

b. With the engine at a normal operating temperature, check and/or adjust ignition timing, idle mixture, and idle speed to the manufacturer's specification.

2.2.1.3 Additional Procedures for Uncontrolled Vehicles - To achieve a greater emission reduction on uncontrolled vehicles, the Air Resources Board has recommended that Northrop also include the basic idle adjustments as an integral part of the Certificate of Compliance procedures. The following recommendations were implemented in the vehicle testing portion of the study, Part B. A copy of the instructions for the participating garages is contained in Appendix A.

a. Measure idle rpm and adjust, if necessary, to a speed no slower than manufacturer's specifications.

b. Measure the ignition timing and point dwell; adjust, if necessary, to manufacturer's specifications. For certification purposes, adjustment is required only when the timing is advanced more than 3 degrees from the manufacturer's recommended setting.

c. Measure the air-fuel ratio and adjust, if necessary, to 12.5 to 13.5.

2.2.2 Idle Inspection Test Regime

As previously described, the seven-mode test involves operating the vehicle under simulated load conditions in various driving phases that included two accelerations, two cruises, two decelerations, and an idle mode. A mathematical approach, based on decision analysis, has been used to determine whether or not any of the modes could identify the high emitters of HC and CO (Reference 9). The analysis of data obtained and used in previous studies conducted by the Auto Club, the Air Resources Board, and the State of New Jersey revealed that the measurement at idle is capable of identifying high emitters of CO or HC.

In this inspection and test regime, the tested vehicle is operated until proper engine temperature is achieved. While the vehicle is operating at idle, a sample of the exhaust is analyzed for HC and CO concentration in the gas analyzers, and the results are recorded. If the vehicle does not pass the established emission limits, the vehicle then will be required to receive corrective action.

The term "idle inspection" is somewhat misleading since the vehicle is also operated at higher rpm (2500) as part of the inspection test cycle. The test mode is more accurately described as a static or light-load test, as the vehicle engine is operated without benefit of vehicle road loads. It has been demonstrated that vehicle system malfunctions which result in high emission characteristics at idle rpm frequently contribute to high emissions over a typical load/speed range as measured by the standard seven-mode test. However, the sensitivity of idle testing can be improved by performing additional testing at higher engine speeds. The engine loads experienced during higher rpm operations provide an opportunity to measure effectiveness of off-idle carburetor circuits and to detect additional malfunctions that may contribute to high emissions. During the Idle Test procedure, engine operations and emission measurements are accomplished at 2500 rpm prior to performing idle measurements. This sequence provides the opportunity for engine temperature stabilization. A copy of the test procedure for the participating garages is provided in Appendix B.

2.2.3 Annual Adjustment and Maintenance Procedure

A type of inspection program which has been suggested is one which is performed on all vehicles at existing repair facilities (Reference 10). The contention is that all vehicles can be tuned to their minimum pollution capability and, as such, should be periodically inspected and/or repaired. The name given to this type of inspection is the Annual Adjustment and Maintenance Procedure (AAMP).

The test, conducted at the repair facility, requires the use of HC/CO analyzers similar to those used in the Idle Test. The car is subjected to adjustment and repair instructions with the aid of the analyzers, and is repaired as required. A detailed description of the test is provided in Appendix C.

2.2.4 Key-Mode Inspection Test Regime

One type of engine diagnostic technique based on experimentally derived data indicates that unnecessarily high emissions are caused by specific maladjustments or malfunctions. When these deficiencies are corrected, the emission characteristics of the vehicle engine are as good as can be obtained by the repair facility. The technique was developed by determining the minimum number and variety of operating modes required to expose these deficiencies and defects.

Those operating modes that most reliably exposed these engine faults were labeled "Key" Modes (Reference 11). These modes have been named high cruise, low cruise, and idle. For each of these modes, different failure limits are established for HC and CO concentrations. By referring to a logic diagram termed a "truth" chart, corresponding probable engine malfunctions and adjustments are denoted as an aid to the repair technician. Test vehicles must be operated on a chassis dynamometer during the Key-Mode Test and inspection procedures. A sample probe is inserted in the exhaust tailpipe, the gas is drawn off, and analyses of CO and HC are made by the appropriate gas analyzers.

Key-Mode testing is a test process that was developed by the Clayton Manufacturing Company. The test is performed on a simple chassis dynamometer at vehicle speed and load modes that are calculated to reliably expose engine faults. The operational modes are idle, low cruise, and high cruise. After vehicle pretest activities are performed, the vehicle is positioned on the dynamometer and emission test equipment attached. The initial test mode is at high cruise conditions. The driver accelerates to a speed and load range of 44 to 50 mph and 21 to 30 hp, depending upon vehicle weight. During this period, the engine temperature is stabilized. High cruise emission measurements are performed and the vehicle speed and load is reduced to 22 to 30 mph and 6 to 12 hp, depending again upon vehicle weight. After measurement, the vehicle is allowed to return to idle for final measurements prior to post-test operations.

An optional full throttle maximum load mode is shown in dotted lines. This mode, if performed, would reveal certain load-related failures that the lighter load modes may not detect.

A set of repair aids has been developed by Clayton in the form of truth tables. The table, when used as an inspection aid, provides diagnostic information to the repair station. In addition to the truth tables, a manual containing usage examples is provided to the repair facility. The procedure and manual for the participating garages are described in Appendix D.

2.2.5 Diagnostic Inspection Test Regime

The most sophisticated inspection and test concept involves the utilization of a diagnostician, chassis dynamometer, oscilloscope, and other engine analysis equipments. A skilled and trained diagnostician, following a set of well-developed procedures, can accurately analyze faulty engine operation and also specify the necessary service (Reference 12). The chassis dynamometer is used to simulate driving and road conditions designed to represent the steady-state modes of operation of idle, full throttle at 60 mph, cruise at 50 mph, and a transient deceleration mode. During each of the operating modes, the exhaust is analyzed for concentrations of HC. CO is measured in all modes except deceleration. Vehicles failing the established limits are diagnosed by the diagnostician using the oscilloscope console. The scope patterns for common engine discrepancies are documented and serve as a diagnostic aid.

The Diagnostic Test procedure, if accomplished effectively, identifies specific component failures and allows direction to the vehicle owner to accomplish specific repair functions. This technique may result in reduced repair costs to the vehicle owner. Additionally, the longevity of engine emission control performance may be enhanced.

The test procedure includes engine load modes that tend to stress certain emission-critical components. Components that fail during the stress conditions may be marginal under normal operating conditions. Replacement of these marginal components may preclude subsequent failure and resultant high exhaust emissions. A copy of the test procedure is provided in Appendix E.

2.2.6 Other Test Regimes

Other test regimes which have been proposed for possible short-cycle liaison testing is the New Jersey ACID cycle and the General Motors EXIT cycle. These short-cycle tests were not evaluated in this study but are described below for information purposes.

2.2.6.1 ACID Cycle - New Jersey has developed the ACID short-test cycle (Reference 13). The test consists of the following modes: acceleration, cruise, deceleration, and idle. A dynamometer is required to impose a duty cycle (simulated road and acceleration load) at the vehicle wheels. The road load varies as the cube of simulated road speed, with a rating of 3.5 hp at 30 mph. The acceleration load is set at 3000 pounds and is simulated by an inertia wheel.

The New Jersey ACID cycle consists of, sequentially:

a. Constant acceleration from zero to 30 mph in a period of 14 seconds
b. Cruise at 30 mph for 16 seconds
c. Constant deceleration from 30 to 0 mph in 14 seconds
d. Zero mph (idle) for 16 seconds.

2.2.6.2 General Motors EXIT Cycle - General Motors has developed a rapid test which was based upon a study of the application of the New Jersey ACID cycle to assembly line conditions. The final cycle developed is performed as follows:

a. The driver receives the car at the end of the assembly line and drives it forward onto a set of powered dynamometer rolls.

b. The driver then inserts a punched card into a card reader which inputs the computer vehicle information such as engine size, transmission type, and other options. The computer then establishes the specifications which must be met by that vehicle.

c. The driver accelerates the vehicle to approximately 35 mph, at which time the computer takes over and maintains driving speed at exactly 35 mph.

2.3 EXPERIMENT DESIGN

Part B of the total study was devised to obtain empirical data on vehicle emission inspection and maintenance. Both parts of the total study commenced on 1 December 1970, with Part A, the feasibility study, scheduled and contracted for completion within 6 months; and Part B, the vehicle testing study, scheduled for completion in November 1971. To obtain statistically valid data, a carefully conceived experiment design was developed prior to the commencement of vehicle testing. Discussed below are the considerations that went into designing the experiment, gathering the test data, and analyzing the information obtained.

2.3.1 Hypothesis Testing

The purpose of this study is to compare the relative merits of the five test regimes in reducing vehicle emissions of HC, CO, and NO_x. In statistical terminology, the intent is to test the following hypotheses:

a. There is no difference between test results as determined by the five test regimes

b. There is no difference between test results on the total population before and after vehicle maintenance service

c. There is no difference in emission reductions achievable by each of the five test regimes.

Hypothesis a, above, states that the five test regimes are equal in their ability to identify high emitters. Hypothesis b states that vehicle maintenance, if required, will not affect emission levels. Hypothesis c states that if reductions are realizable, they will be the same for each pollutant regardless of test regime. Very likely there will be differences, and the experiment was designed to identify and quantify these differences.

2.3.2 Experiment Design

The testing pattern chosen was structured to pass an equal number of cars through each test type. The structure assures that a representative cross section of the vehicle population, based on age, make, and model, is exposed to each type of test. Importantly, the matching of individual vehicles to test and maintenance station types should be purely random.

The 1200-vehicle sample shown in Table 2-3 is representative of the current statewide population of privately owned passenger automobiles under 6001 pounds gross weight. Selection is based on registration data provided by Rueben H. Donnelly Corporation, one of two firms who have access to California Department of Motor Vehicles registration data. The resulting distribution is based on a population of approximately 8.5 million vehicles, each sample vehicle representing approximately 7000 registered vehicles. For the 1200-vehicle test sample, strict proportion was adhered to in all but two cases: imported cars and Chrysler Imperials.

The imported-car portion of the total vehicle population other than Volkswagen (VW) is completely described by two vehicle classes, P/C-6 and P/C-7. The criterion for assigning a given import to one of these classes is the manufacturer's suggested retail base price. Strict proportion would have distributed 57 vehicles over more than 20 makes including VW within the P/C-6 class. However, since the VW comprised 40 percent of the late-model foreign car market in California, and the second and third (Toyota and Datsun) represented the vast majority of all other cars sold within this category, it was decided to distribute the foreign makes over these three manufacturers (Reference 14).

Table 2-4 lists those vehicles within the P/C-7 class or those foreign vehicles with a base price over $3500. A survey of current registration figures and of the car makes of which that class is comprised indicated that strict proportion would have distributed 3 percent of the total sample over 21 different makes, each representing a very small portion of the total vehicle population of the State. At the same time, each such make would have involved highly individualized maintenance requirements. For these reasons, the class P/C-7 vehicles were eliminated from further consideration. The requisite number of these vehicles were distributed proportionally among the major makes of domestic cars of comparable size.

In refence to the Chrysler Imperials previously mentioned, the registration figures would have required that a total of three be in the samples as determined on a strict proportional basis. However, the registrations data showed that no single model year was sufficiently large (at least 7000) to warrant the inclusion of an Imperial. Consequently, for every three model years, one Imperial was selected as representative of that block.

2.3.2.1 Vehicle Assignment - Table 2-5 identifies the test variables under observation during this experiment. The assignment algorithm was designed to incorporate all the considerations of randomness and representativeness. In brief, the block

Table 2-3. 1200-VEHICLE SAMPLE

Make - Model	1970	1969	1968	1967	1966	1965	1964	1963	1962	1961	1960-1957	PRD *	ACT **
BUICK	2	3	3	3	3	3	3	2	2	2	9	46	36
Special	1	2	2	2	2	3	3	2	2	1	-	20	20
CADILLAC	2	3	3	3	3	3	3	3	3	2	7	34	35
CHEVROLET	7	8	8	10	13	16	15	13	11	8	44	148	153
Chevelle	4	4	4	4	5	5	4	-	-	-	-	30	30
Corvair	-	-	-	-	1	2	2	3	3	3	2	16	16
Chevy II	3	3	2	1	2	2	3	5	4	-	-	24	25
Camaro	2	4	3	4	-	-	-	-	-	-	-	12	13
CHRYSLER	1	2	2	2	3	2	2	2	1	-	3	19	20
DODGE	3	4	5	3	4	3	3	2	2	1	5	34	35
Dart	2	2	2	2	2	3	3	3	1	1	-	20	21
FORD	7	7	7	7	8	8	8	7	6	5	27	93	97
Falcon	1	1	1	2	2	2	3	3	4	5	4	27	28
Fairlane	2	2	3	2	2	2	2	3	2	-	-	20	20
T-Bird	1	1	1	1	1	1	2	2	2	1	1	14	14
Mustang	4	5	5	8	10	12	-	-	-	-	-	42	44
IMPERIAL	-	-	1	-	-	1	-	-	1	-	-	3	3
LINCOLN	-	1	1	1	1	1	1	1	1	1	1	9	10
MERCURY	1	2	1	1	2	2	1	1	1	1	4	17	17
Comet	1	1	1	1	1	1	2	2	3	2	1	15	16
Cougar	1	2	2	3	-	-	-	-	-	-	-	8	8
OLDSMOBILE	2	3	2	2	3	3	3	3	3	2	8	33	34
F-85	2	2	3	3	2	2	2	2	1	1	-	20	20
PLYMOUTH	4	4	4	3	3	3	2	2	1	1	10	36	37
Valiant	1	1	2	2	2	3	3	2	1	1	1	18	19
PONTIAC	2	3	3	3	4	4	5	4	3	2	8	40	41
Temptest	2	3	3	4	4	3	3	1	2	1	-	24	26
Firebird	1	1	2	2	-	-	-	-	-	-	-	5	6
AMERICAN MOTORS	2	2	3	2	2	4	6	6	5	3	6	39	41
OTHER DOMESTIC	-	-	-	-	1	-	1	1	1	1	8	13	13
IMPORT P/C-7	-	-	-	-	-	-	-	-	-	-	-	34	-
VOLKSWAGEN	14	13	12	9	9	9	7	6	5	4	13	91	101
STATION WAGONS	13	17	13	11	12	13	14	13	11	8	28	152	153
P/C-6*													
Toyota	11	10	4	4	2	-	-	-	-	-	-		31
Datsun	6	5	3	2	1	-	-	-	-	-	-		17
TOTALS	105	121	111	107	110	116	106	95	82	57	190	1202	1200

*Number Predicted by Strict Proportion
**Number in Test Sample

Table 2-4. IMPORTED VEHICLES IN CLASS P/C-7

Alfa Romeo	Ferrari	Morgan
Arnault Bristol	Humber	Porche
Aston Martin	Jaguar	Rolls-Royce
Austin Healey	Lancia	Rover
Bentley	Mercedes	Singer
BMW	Moretti	Triumph
Citroen	Maserati	Volvo

Table 2-5. TEST VARIABLE UNDER OBSERVATION

Variable	Dimensions	Classifications
Exhaust controls	2	Controlled, uncontrolled
Vehicle age	14	Model years, 1970 through 1957
Vehicle size	6	Foreign, compact, specialty, medium, large, station wagon
Test Regime	5	Certificate of Compliance, Idle Test, Key-Mode Test, Diagnostic Test, and AAMP
Test period	4	1st, 2nd, 3rd, 4th quarter

design assures that: (1) an equal number of vehicles is exposed to each test type; (2) a representative cross section of vehicles based on age, make, and model is processed through each test regime; and (3) the testing is internally structured and scheduled to minimize or eliminate the effects of random error, learning curves, instrumentation drift, and other time-dependent sources of error. This approach is known formally as the Latin Square procedure.

2.3.2.2 Test Scheduling - There are several time-dependent phenomena attendant to implementing an experiment involving various personnel, instrumentation, and test procedures. One procedure often used in statistics to account for such effects, Latin Squares, tests all possible combinations of the variable types in a random order. In other words, the pattern developed assures that vehicle testing by test regimes is not ordered such that a repeated cycle is followed that might introduce bias into the test data.

The vehicle test and service schedule assures that a random assignment of test regime and maintenance center occurs to minimize or eliminate inherent variability or bias errors. Two other considerations were investigated before the 1200-vehicle test program was implemented, both of which were deviations from the initial test philosophy proposed by the Air Resources Board. The first was the random assignment of service vehicles to maintenance centers to evaluate and/or identify significant differences among the three types. The second exception was the inclusion of a test control group of vehicles to determine the repeatability and statistical fluctuations inherent in the primary inspection system as implemented for baseline measurements. These alterations are discussed below.

2.3.3 Random Assignment of Service Vehicles

The experiment design was structured to allow evaluation of individual maintenance center service, performance, and technical capability (along with attendant costs) in responding to vehicle emission inspection results. Initially, it was assumed that as vehicle service was desired, the test schedule and service assignment algorithm would identify the randomly selected service facility. This was immediately unacceptable since the ARB provided equipment for Idle Tests sufficient for only six facilities. Thus, either the facilities having the equipments would be unvarying or the instruments would necessarily be housed at Northrop and transported to the selected facility on an individual-case basis.

There were two arguments against the latter solution. First, the Idle Test instrumentation is not designed for mobility. Second, if the instruments were transferred between facilities, this would necessitate that all participating facilities be trained in the proper utilization of the instruments.

During the initial months of the vehicle testing program, 120 selected vehicles, based on the 1200-vehicle sample, were processed and comprised the learning phase. Immediately prior to initiating this significant phase, which is completely documented in Northrop Report No. 71Y15, Learning Phase Final Report, dated 22 January 1971, for the State of California Air Resources Board, a brief indoctrination and training program was conducted for pertinent personnel representing the participating service facilities.

These sessions were scheduled and devised to inform and educate only those personnel concerned with a given test philosophy. It would have simplified matters considerably if personnel were equally qualified in all five test philosophies. A valid evaluation and comparison of individual performance among the five test concepts and among the different types of facilities (independent garages, service stations, and franchised dealers) could have been accomplished. Then it would have been possible to recommend a specific type of service facility for a given test regime. However, several questions had to be answered before such a decision could be rendered with any degree of confidence. These questions were:

a. What constitutes a representative service facility of the types being considered?

b. How many of each type is required in the sample to have statistically valid information?

c. What established criteria can confidently determine whether the performance by a service facility is satisfactory or not?

2.3.3.1 Representative Service Facility - Prior to evaluating and comparing the independent garages, franchised dealers, and service stations, it should be assured that a valid sample is being investigated. The question that first arises is "What is a representative service facility?" To answer this, certain factors should be considered. A service facility comprises personnel, instrumentation, policies, and procedures. Each of these should be evaluated to identify those salient characteristics that determine true representativeness.

Technical personnel complements differ among the service types considered and even within a given group. Qualifications and special training requirements are not standardized to the point where distinct classes of skill levels exist and are agreed upon by the general automotive service industry. Likewise, there are dissimilarities among the service facilities as to what constitutes an acceptable minimum level of instrumentation and equipments for a typical facility type.

There could very well be commonalities among the service outlets for a specific oil company, but are these prevalent throughout all the oil companies? Which oil company service facility is most representative of all the oil companies service facilities? Realize, of course, that these same questions apply equally to the independent garages and franchised dealers.

Policies and procedures are established by facility management and, in part, by the general automotive service industry. Experience, education, and training become an integral part of a technical personnel staff. As such, many things are done according to personal preference. However, many functions are dictated by management. Personnel motivation and pride in work accomplished is inherent, but it also can be induced through incentives or punishment.

It is reasonable to assume that policies and procedures instituted in a specific franchised oil company station would be similar for all representatives. However, it is doubtful that policies and procedures are the same for all independent garages. By the very nature of their being in business, it is most likely that management thinking would differ considerably when considering personnel salaries, benefits, and other motivational aspects.

2.3.3.2 Service Facilities Sample Size - If it were possible to identify a representative service facility of each desired type, then it is conceivable that two of each type would have been sufficient to provide the necessary service for the anticipated work load (assuming a daily inspection rate of ten vehicles and 50 percent rejection). However, because of the above factors, the selection of representative service facilities becomes rather difficult.

To circumvent the problem, 25 service facilities were selected with Certificate of Compliance assigned seven and six each to the other test regimes. The complement of six was comprised of one service station, two independent garages, and three dealers. The Certificate of Compliance was assigned an extra dealer to accommodate the many different emission control systems that are installed. The breakdown reflects the assumption that approximately 50 percent of automotive repair work in the State is performed by authorized franchised dealers, 33 percent by independent garages, and 17 percent by service stations.

There were several factors that contributed to limiting the number of service facilities to 25. One of the primary considerations was previously mentioned. This was the fact that the Air Resources Board provided only six sets of Idle Test equipments, thereby limiting that test regime's complement of service facilities. Other factors are the training required to assure a uniform level of information for the participating facilities personnel and the logistics costs of transferring test vehicles within a large geographic area.

2.3.3.3 Maintenance Service Performance Criteria - The contention is that there are differences in performance and service among the three types of facilities. What is required is a method and criteria that may be used to evaluate and compare the alternatives. The method would be to distribute the required maintenance service among the facilities on a random basis, as previously determined in the experiment design. From the theoretical viewpoint, this is highly desirable; from the practical viewpoint, this is not indicative of real-world conditions.

Very early in the learning phase it became evident that most dealers were reluctant to work on any make of car other than that sold by their establishment. This was also true for dealers of major manufacturers such as the big three. Almost universally, service facilities would not accept foreign cars unless they were dealer vehicles or the facility specialized in foreign cars. As noted in the table of vehicle samples, only the top three foreign vehicles (in terms of registrations) were actually processed (Volkswagen, Toyota, and Datsun). Consequently, these vehicle types were restricted to a few centers.

Based on the short-cycle tests results, the vehicles were processed to receive required corrective maintenance and/or adjustments. If emissions reduction is established as a measure of performance, then the service facilities could be compared for effectiveness. However, it must be recognized that a multitude of combinations of engine malfunctions and maladjustments contribute to emission changes. Because a service facility performed its function with resulting emission changes does not necessarily indicate satisfactory or unsatisfactory performance. Unless each class of maintenance facility is exposed to the same total spectrum of repair and adjustment operations, an objective comparison among them is difficult.

By the end of the testing, 1095 vehicles were processed, of which approximately 600 were serviced. Each maintenance center processed 25 vehicles, again discounting the fact that foreign vehicles were already constrained. Given that each facility serviced 25 vehicles, it is highly doubtful that the facility was exposed to the total spectrum of repair and adjustment options. It is also questionable that a comparison of 25 service centers can be used to project over a statewide program with any degree of confidence, when the factors of representativeness, sample size, and performance criteria are fully considered.

2.3.4 Test Vehicles Control Group

A vital part of any experiment is the isolation and quantification of the variables under observation. The structured experiment lacked a method of separating the emission reduction attributable to vehicle maintenance from that due strictly to statistical fluctuations in the inspection and measurement system. In essence, the experiment had no control group or no way of separating emission reductions achieved by service from those due to weather or other random effects. It might be argued that since it is the relative effectiveness of the five test regimes that is being evaluated, the effects of system variability would apply equally to all tests. However, the possibility exists that the system error might be significant enough that true emission reductions would be far below (or above) that calculated. If such effects are not considered, then any analytical predictions or projections of effective reductions would be suspect.

Following the completion of the 120-vehicle pilot study learning phase, the Air Resources Board advised Northrop to incorporate a control group. The results are discussed in the following paragraph.

2.4 OPERATIONAL PROCEDURES AND DATA ANALYSIS

A learning phase was conducted at the initial stage of the vehicle testing and maintenance study. During this phase, 120 vehicles, selected and based on a 10:1 proportional reduction of the main test phase of the 1200-vehicle sample, were tested and serviced as required by four test regimes. The results of the learning phase were documented by Northrop and reviewed by the Air Resources Board in January 1971. Based on their evaluation of that report, the Air Resources Board approved continuation of the testing program into the main test phase.

In the following paragraphs, the vehicle emission testing and maintenance service procedures are discussed. An analysis was performed on the data available on serviced vehicles that considers the effects of marginal measurements, revised limits, and maintenance repair technicians. Areas of improvement in each of the test regimes are discussed as a result of the analysis.

Statistical analyses of the operational data are then described. Various standard mathematical tests of the vehicle emission data are performed. The results of the first and second quarter vehicle testing are used to generate the effectiveness data for each of the test regimes. These data are summarized, tabulated, and discussed in preparation for input into the effectiveness equation described in Section 4.

2.4.1 Vehicle Emission Testing and Maintenance Procedures

The 120-vehicle learning phase was instituted to provide a means of familiarizing pertinent personnel with the study objectives and program implementation, to uncover and resolve unforeseen problems, and to establish firm testing, maintenance, administration, and management policies and procedures as they would affect the main test phase. It provided the Air Resources Board with the opportunity to monitor the activities, recommend policy changes, and evaluate the results before granting approval to proceed with the 1200-vehicle testing phase. In the following paragraphs a brief description of the various facets of the total vehicle testing program is presented.

2.4.1.1 Initial Training and Indoctrination - Two types of orientation and familiarization programs were instituted to inform and train the affected personnel. Orientation sessions were conducted at Northrop for service managers and technicians as selected by the participating maintenance centers. Tentative procedures for the appropriate test types were distributed and discussed. Each session lasted between 2 and 3 hours.

Personnel assigned to the Diagnostic Test attended training classes conducted at the Joe DeGiorgio Automotive Evaluation Center in Long Beach. The program consisted of five 8-hour sessions of lecture, demonstration, individual and group participation in the theory and practice of automotive engine diagnosis, exhaust emission diagnosis, and the appropriate methods for emission reduction. Attendees included representatives from Northrop, Olson Laboratories, and the Air Resources Board.

2.4.1.2 General Test Procedures - All vehicles in the program were initially given a hot-start seven-mode test at the Northrop-Olson Laboratories inspection facility, which is completely equipped and staffed to perform each of the five test types. This seven-mode test data was filed and served as the pre-service emission baseline. Certificate of Compliance vehicles were dispatched to selected maintenance facilities, based on assignments specified by the applicable algorithm. Similarly, those vehicles designated for AAMP tests were transferred to those facilities receiving the ARB-provided HC/CO analyzers.

The Idle Test, Key-Mode Test, and the Diagnostic Test were conducted at the Northrop facility. Vehicles requiring further service were then dispatched to the appropriate service centers.

All serviced vehicles were retested at the Northrop facility following return from the maintenance facilities. In all cases, regardless of test regime, the seven-mode hot-start retest was used to qualify a serviced vehicle. Those failing to qualify were sent to their respective service facilities for further action.

2.4.1.3 Emission Limits - The experiment was designed to fail 50 percent of the vehicles tested in each of the test regimes, but Certificate of Compliance and AAMP required that all vehicles be processed by maintenance facilities. For the other three regimes, emission limits were used to identify vehicles requiring service. Basic guidelines for establishing the limits were provided by the RFP and also by the Air Resources Board. Additionally, the Clayton Manufacturing Company provided some guidance for the Key-Mode Test, based on their New Jersey program data.

Due to the relatively small sample size (30 vehicles) for each test regime during the learning phase, it was first necessary to test all vehicles within a test regime, analyze the emission data as related to HC and CO, and then determine the limits that would provide a 50 percent rejection. The results of previous studies by the Air Resources Board and Clayton provided the range of values. The empirically derived data provided clearly defined limits for each test regime.

The established limits were selected to reject half of the vehicles processed to obtain maximum information on costs and service benefits. As such, separate limits were set for both controlled and uncontrolled vehicles within each test regime. Based on the learning phase results, the limits were slightly modified for use during the main test phase of 1200 vehicles. See Table 2-6 for emission test limits.

2.4.1.4 Maintenance Service Procedures - All vehicles assigned to the Certificate of Compliance test regime were dispatched to qualified Class A certification stations. During the training program, these service facilities were directed to comply with the established California Highway Patrol inspection procedures. Additionally, the facilities were instructed to perform basic idle adjustments on uncontrolled vehicles. See Appendix A for a description of the additional instructions.

For those vehicles identified for the Idle Test procedures, the established HC and CO limits were consulted after the vehicles were subjected to the hot-start seven-mode tests. Those exceeding the limit(s) were then dispatched to the designated Idle Test service facility. Using the appropriate equipments, the facilities performed the indicated maintenance and adjustments. Appendix C describes the Idle Test procedures conducted at the service facilities.

The Key-Mode Test was conducted by Olson Laboratories personnel at the inspection facility at Northrop. Procedures followed were those generated by Clayton Manufacturing, designers of the Key-Mode Test. Vehicles exceeding limits in HC and/or CO in either of the three modes of idle, low cruise, or high cruise were then

Table 2-6. EMISSION TEST LIMITS

1. Idle Test Limits:					
a. Controlled	HC (ppm)	CO (%)			
EM	350	5			
AI	250	4			
b. Uncontrolled	700	6			
2. Key-Mode Test Limits:	Idle		Cruise		
a. Controlled	AI	EM	Low	High	
CO (%)	4.0	5.0	2.5	2.5	
HC (ppm)	300	400	300	300	
b. Uncontrolled					
CO (%)	7.0		4.5	3.5	
HC (ppm)	800		550	550	
3. Diagnostic Test Limits:	Idle				
a. Controlled	AI	EM	60/Loaded	50/8-hp	Decel
CO (%)	4.0	5.0	-	2.5	-
HC (ppm)	300	400	250	250	2000
b. Uncontrolled					
CO (%)	7.0		-	3.5	-
HC (ppm)	700		400	550	9000

NOTE: AI = Air Injection
EM = Engine Modification

sent to the appropriate maintenance facility. At these facilities, the procedures were as outlined by the truth charts shown in Appendix D.

The Diagnostic Test concept was such that the detailed analysis conducted at the inspection facility resulted in specific recommendations for maintenance and adjustments when vehicles exceed the specified emission limits. Consequently, the maintenance facilities that received these vehicles were provided with detailed instructions. Appendix E contains an example of the instruction sheet.

2.4.1.5 Post-Maintenance Testing - All serviced vehicles were returned to the primary inspection facility at Northrop to receive post-maintenance testing to establish the post-service emissions baseline. These emission measurements were compared with the test limits to determine adequacy of maintenance and adjustments. If satisfactory, the vehicle was processed and released; otherwise, the vehicle was rerouted through the service facility for further corrective action. Vehicles requiring major expenditures to realize possible emission reductions were evaluated on an individual basis to determine whether or not to proceed with additional service. In a majority of cases, the Air Resources Board was consulted prior to rendering a decision. The remaining cases were resolved where the data indicated what the results of further maintenance activity would accomplish, either based on similar vehicle emission profiles or age/mileage characteristics.

For those vehicles that were serviced and released, a very basic questionnaire was sent to the registered owner requesting performance appraisal. Results of these returns are discussed in Section 4.

SECTION 3

TEST STATION REQUIREMENTS ANALYSIS

3.1 TEST FUNCTION ANALYSIS

Station and equipment complements are a function of the times required for each necessary function to be completed. The following sketch is a generalized time-line analysis of these required functions. The lengths of each time period are dictated by the capabilities of personnel and the characteristics of the respective equipment, including automobile and inspection procedures. It was assumed that personnel would have the required technical skills and training to complete tasks within the limit of instrument capability. It was also assumed that technical and operational characteristics reported by equipment suppliers were correct as stated in the equipment survey.

Pre-Test	Test Performance	Data Analysis	Post-Test	Pre-Test (for Next Test)
t_p	t_i	t_d	t_c	t_p

Pre-test, t_p, includes those operations performed prior to actual emission testing, and includes vehicle placement in the test lane, test equipment connections, and other preparatory activities. The pre-test tasks are segmented into two parts: vehicle description data and test data recording, and visual inspection equipment/safety. Fifty seconds are assigned to the vehicle description and test data recording. The task elements involve those functions required to receive the vehicle into the station and record the vehicle description data on the selected format. It is envisioned that certain conversation between the vehicle driver and test technician concerning vehicle condition and testing requirements will be conducted during that period. Results of this discussion may qualify the testing in some manner; recording of these qualifications will also be necessary. Once the data management functions are completed, the test technician inspects the vehicle to ascertain its acceptability for testing. The engine and under-hood areas are inspected for obvious component failures and safety hazards. The exhaust system is inspected to determine its suitability for subsequent emission measurement. If the vehicle is found unacceptable for testing, the driver must be provided with the reasons and rescheduled for retest when he has corrected the discrepancies. Forty seconds are allowed for the visual inspection period. The pre-test and post-test time estimates, although fairly short in cases where vehicle difficulties exist, would most likely be more than adequate when the vehicle arriving for inspection is in good condition.

Test performance time, t_i, is a function of the test procedures, vehicle and driver responses, and equipment and instrument characteristics. Data analysis time, t_d, may vary from negligible to a significant amount, depending on the type of testing, the data displays incorporated in the facility, and the degree of automation in the data system. This time period also includes the time required to record any essential information for the vehicle owner's use.

Post-test times include driver consultation and removal of the vehicle from inspection areas. Driver consultation time is devoted to discussing inspection and test results with the vehicle owner or his representative. During this period, any further action required, as determined by the testing, would be explained to the responsible party.

The time-line analysis establishes each test task element against a time base. The time required to accomplish these tasks was determined and then utilized to evaluate personnel and instrumentation complements. First, a given minimum instrumentation configuration was established that would provide sufficient technical capability to perform the necessary testing and emission analysis. Second, a minimum personnel complement (one or more technicians) was determined. Typical task times were then determined and a vehicle throughput rate was calculated for this minimum configuration. The personnel complement was then increased by one, new task times were developed, and a new throughput rate was calculated. This process was repeated until the limiting factor became maximum equipment utilization. When this occurred, additional equipment was added; the personnel staffing was again set at a minimum (two or more technicians) and the process was repeated. The time-line analysis was conducted for each inspection test mode and included detailed study of the inspection tasks to determine appropriate time allocations and equipment utilization schedules. Test times were determined for the pre-test, test, and post-test functions. Initially, the test flow of a single vehicle was studied. Then, additional personnel were considered to be available to assist in testing operations. With the additional personnel complement, task time-sharing was studied to determine its effect on total test times and subsequent throughput rate improvements. Invariably, when multiple personnel were used in the test of a single vehicle, time gaps developed. These gaps resulted from particular task activities that require the attention of a single technician. In these cases, when additional assistance does not improve task efficiency or vehicle throughput, the excess personnel then become available for time assignment to other vehicles.

Test hardware utilization gaps also become apparent. When a single vehicle test flow is being considered, the test hardware becomes available for possible cross-utilization during vehicle pre-test and post-test activities. This hardware availability provides the opportunity to enter additional vehicles into the time-line analysis. This iterative process is then continued until personnel and test hardware utilization is determined, which will effect maximum vehicle throughput rate with a single set of test hardware. This throughput rate will serve as the expression of single lane facility test capability.

3.2 TEST STATION FUNCTIONAL FLOW ANALYSIS

A facility functional flow and test capability analysis was conducted to arrive at estimates of facility testing capabilities with single and double lane equipment and personnel complements. Test time data, which were calculated during the preceding time analysis, provided the basis of functional flow assessments. Station functional flow charts were developed (Figures 3-1, 3-2, 3-3, 3-4, and 3-5) which display the testing activities against a time base. However, in this case, the individual testing elements have been assembled into three time blocks. The time blocks represent the total time required for pre-test, testing, and post-test functions. Station functional flow analyses of Idle, Key-Mode, Certificate of Compliance and AAMP are relatively straightforward, with station testing capability being expanded as personnel complement is increased. However, in the case of the Diagnostic type station, station functional flows become more involved as alternate vehicle pass/fail rates are considered. On each functional flow chart, a summary table is provided. These summary tables identify station testing capabilities with various personnel and equipment configurations. Vehicles per hour, vehicles per minute, and the average man-minutes expended per vehicle are listed for single and double lane configurations with minimum to maximum test crew complements. Pre-test and post-test times also are summarized for an individual vehicle test.

The analysis methodology was applied to a modularized concept of a complete single lane inspection facility able to process one vehicle at a time. Any larger throughput capability can be determined by appropriate combinations of the single and double lane configurations. Since the equipment and personnel requirements of a double lane are not necessarily twice that of the sincle lane configuration, each test regime has been analyzed for both cases. By evaluating the time-line analysis, cross-utilization of both hardware and personnel can be shown to occur, resulting in more efficient application of the test system elements in double lane stations than in single lane stations. No further cross-utilization was feasible in stations larger than two lanes.

The single lane configuration is comprised of the minimum equipment and systems required to conduct a particular test cycle, and of the minimum personnel staff necessary to realize maximum utilization of the hardware employed. Determination of minimum hardware requirements was aided by the analysis of past studies, by communications with field personnel, by consultation with Air Resources Board personnel, and by the above engineering analysis. Maximum utilization of equipment was determined by the previously mentioned operational and time-line analyses. Once the single lane configuration was designed (after many iterative changes), the two lane configuration was designed. The basic inspection facility requirements were determined for the different station configurations. Facility size recommendations were based on vehicle flow, equipments and system placement, driver waiting areas, utilities areas, and station access. The major elements leading to a detailed station design were determined with the aid of Industrial Engineering personnel at Northrop.

3.2.1 Certificate of Compliance Station Flow Analysis

Certificate of Compliance functional flow is represented by Figure 3-1. Time-line analysis of the compliance test function has not revealed any clear advantage in equipment cross-utilization concepts; therefore, additional flow diagramming of station functional operations was not necessary. Testing capability for a single lane involves the tasks as performed by a single technician. Double lane capability is achieved by adding another man and equipment set. Facility testing capability depends upon the engine adjustment policy. If engines are to be adjusted during the inspection process, the facility throughput rate for single lane is 4.6 vehicles per hour. If adjustment is deferred and assigned to the repair level, throughput improves to 7.7 vehicles per hour.

3.2.2 Idle Inspection Station Flow Analysis

Idle facility functional flow is described in Figure 3-2. Single lane functional flows with one- and two-man test crews were studied. Further hardware cross-utilization is not seen as practical, and double lane station requirements are essentially twice the single lane personnel and equipment requirement. Maximum testing capability of a two-man, single lane facility is 34 vehicles per hour. Output capability increases proportionally, and a double lane station with four men has a capability of 68 vehicles per hour.

3.2.3 Key-Mode Station Flow Analysis

Key-Mode station functional flow is described in Figure 3-3. Single lane functional flows with one- and two-man crews were studied. Further hardware cross-utilization is not practical, and double lane test equipment requirements are essentially twice that of single lane. Maximum testing capability for a single lane two-man operation is 21 vehicles per hour; when expanded to double lane, a 43-vehicle-per-hour throughput rate can be realized.

3.2.4 Diagnostic Inspection Station Flow Analysis

Diagnostic inspection station functional flow analysis was conducted for various crew sizes. Full utilization of the equipment in a single lane station occurs with a four-man crew when average test times from the Test and Diagnostic function analyses are used and 50 percent of the vehicles fail the initial inspection. Multiple lane stations require a complete equipment complement for inspection and a complete diagnostic equipment complement to supply each diagnostician. A complete double lane configuration includes the equipment and personnel complement of two single lane stations and can process twice as many cars. No extra benefit in personnel or inspection/diagnostic equipment can be realized from their cross-utilization between lanes in multiple lane stations.

The station capability in vehicles/hour/lane, assuming average test times and a 50 percent vehicle inspection failure rate, is 12.6 for a four-man station, 9.4 for a three-man station, 6.3 for a two-man station, and 3.15 for a one-man station. Average test time is 15 minutes. The station functional flow analysis for a four-man crew is shown in Figure 3-4.

3.2.5 Annual Adjustment and Maintenance Procedure Station Flow Analysis

The AAMP functional flow time line is shown in Figure 3-5. Time-line analysis of the AAMP test function has not revealed any clear advantages in equipment cross-utilization concepts; therefore, additional flow diagramming of station functional operations was not necessary. Testing capability for a single lane involves the tasks performed by a single technician, similar to the Certificate of Compliance test. Double lane capability is achieved by adding another man and equipment set. As is seen in the test station function flow diagram, the test time (even though there are some different functions) is identical to the Certificate of Compliance test. The test time with adjustments is 13 minutes per vehicle or 4.6 vehicles per hour per lane.

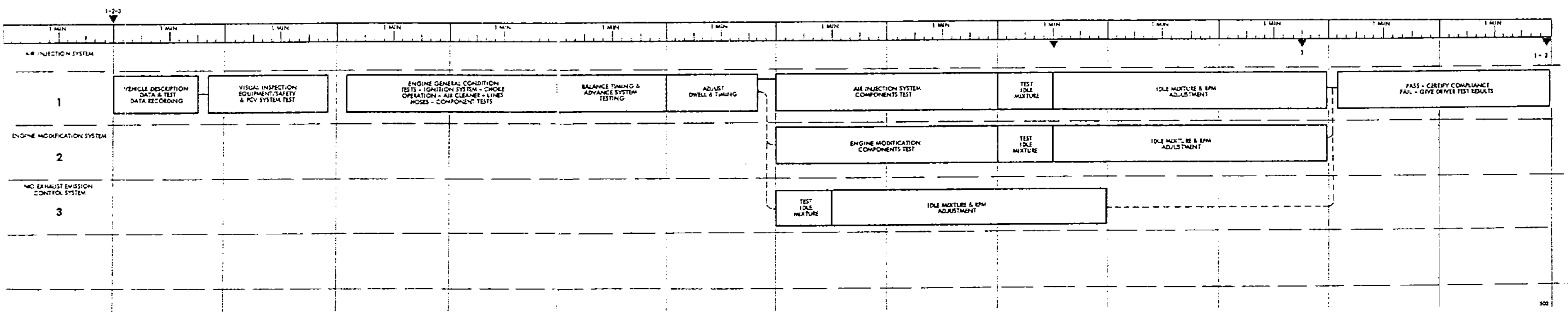
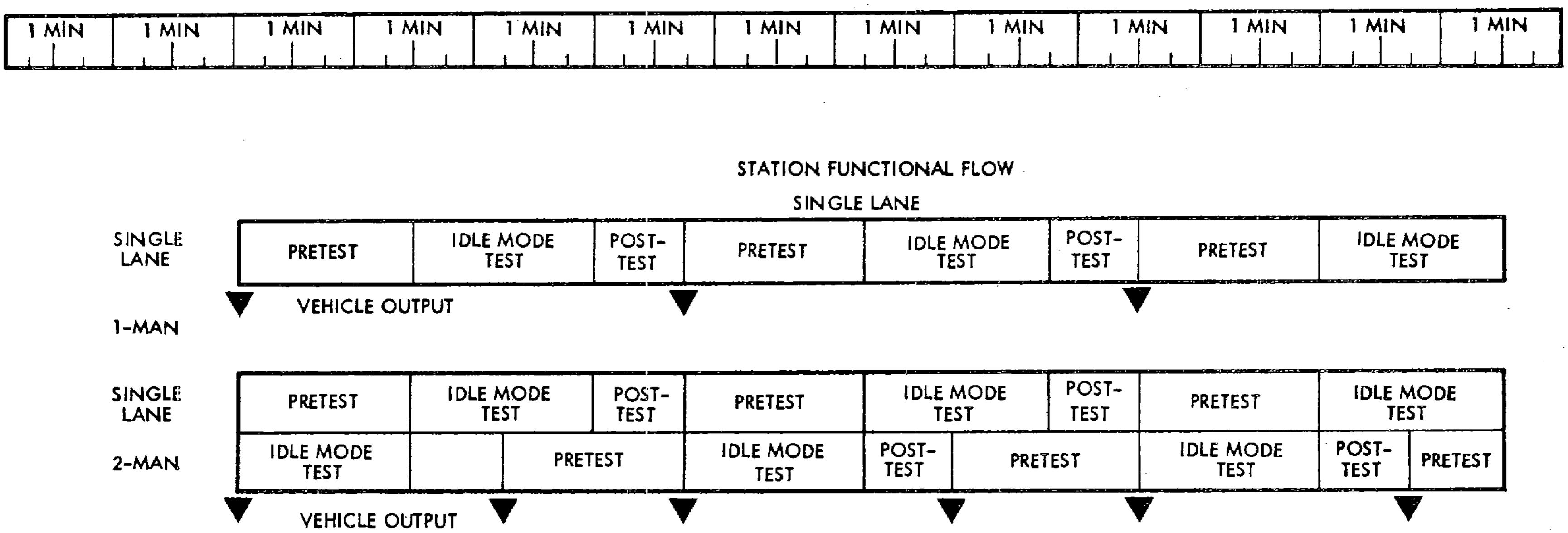


Figure 3-1. CERTIFICATE OF COMPLIANCE
SINGLE LANE TEST FUNCTION FLOW



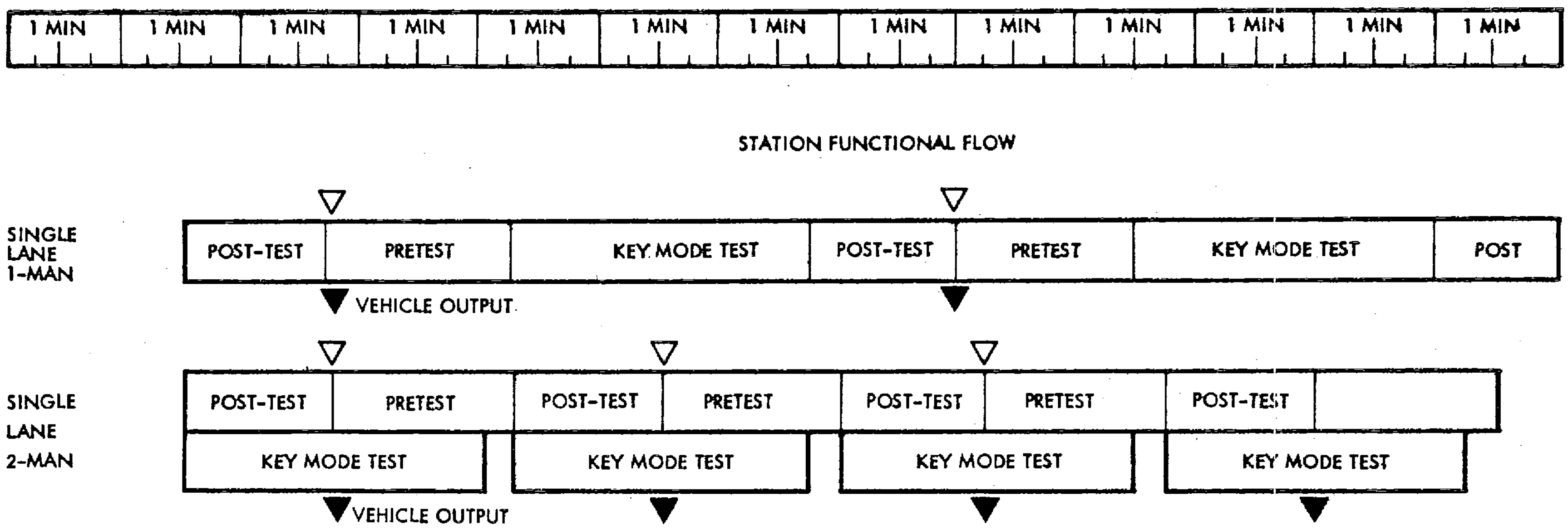
STATION FUNCTION FLOW SUMMARY TABLE

	SINGLE LANE		DOUBLE LANE	
VEHICLES PER HOUR	17	34	51	68
AVG TIME PER VEHICLE (MIN)	3.75	1.8	1.25	.9
SLACK TIME PER HOUR	0	0	0	0
TEST CREW SIZE	1	2	3	4

PRETEST TIME	1.5
TEST TIME	1.5
POST-TEST TIME (PASS)	.25
POST-TEST TIME (FAIL)	1.25
POST-TEST TIME (AVERAGE)	.75

502

Figure 3-2. IDLE TEST STATION FUNCTIONAL FLOW

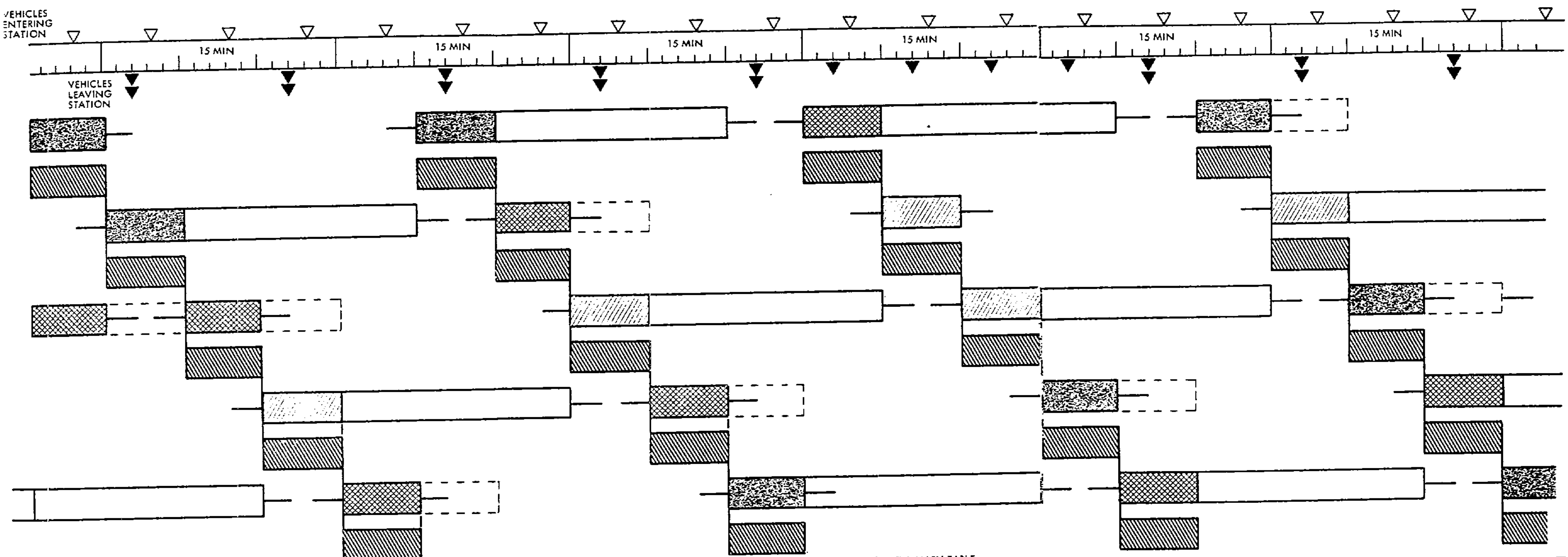


FUNCTIONAL FLOW SUMMARY TABLE	SINGLE LANE		DOUBLE LANE	
VEHICLES PER HOUR	11.4	21.8	33.2	43.6
AVG TIME PER VEHICLE	5.25	2.75	1.8	1.37
SLACK TIME PER HR	0	5.5	0	11
TEST CREW SIZE	1	2	3	4

PRETEST TIME	1.5
TEST TIME	2.5
POST-TEST TIME (PASS)	.5
POST-TEST TIME (FAIL)	2.0
POST-TEST TIME (AVERAGE)	1.25

502

Figure 3-3. KEY-MODE SINGLE LANE STATION FUNCTIONAL FLOW



DYNAMOMETER TEST | DIAGNOSE EMISSION | DIAGNOSE VEHICLE IGNITION/FUEL/MECH SYS

FUNCTIONAL FLOW SUMMARY TABLE

VEHICLES PER HOUR 50% FAILURE RATE	12.6	9.4	6.3	3.15
AVERAGE TEST TIME/VEHICLE (MIN)	4.7	6.3	9.5	19
TEST CREW SIZE	4 MEN	3 MEN	2 MEN	1 MAN

PRETEST TIME (MIN)	2	POST-TEST PASS (MIN)	.5
TEST TIME PASS (MIN)	5	POST-TEST FAIL (MIN)	3.5
TEST TIME FAIL (MIN	25	POST-TEST AVERAGE (MIN)	2
AVERAGE TEST TIME (MIN)	15	AVERAGE MAN-MINUTES PER VEH	19

502

Figure 3-4. DIAGNOSTIC SINGLE LANE TEST STATION FUNCTIONAL FLOW

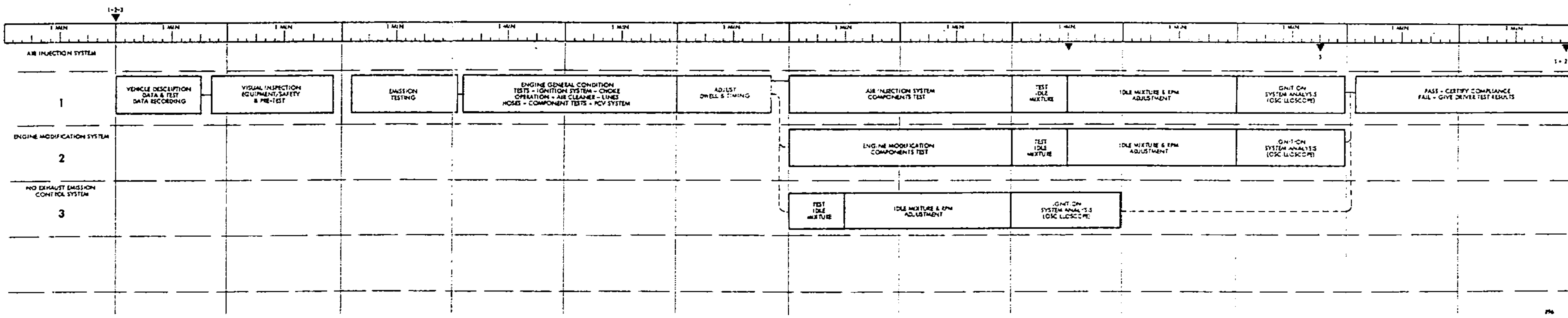


Figure 3-5. ANNUAL ADJUSTMENT AND MAINTENANCE PROCEDURES SINGLE LANE TEST FUNCTIONAL FLOW

3.2.6 Comparison of Test Regime Throughput Rates

The previous paragraphs document the results of the time-line analysis for each of the test regimes evaluated. The Idle Test is capable of processing the most vehicles per hour (17) with the AAMP and Certificate of Compliance the least (4.6). A summary comparison of the throughput rates for each test regime is shown in Table 3-1. These rates are used in the subsequent analysis.

Table 3-1. SUMMARY COMPARISON OF THROUGHPUT RATES FOR EACH TEST REGIME

	Test Regime				
Throughput Rate	Certificate of Compliance	Idle	Key-Mode	Diagnostic	AAMP
Vehicles per hour processed	4.6	34	21	9.4	4.6

3.3 FACILITIES

In determining the facility configuration and size, engineering analyses of the functions and assistance from industrial engineering personnel was required. A floor plan and artist's conception of the exterior for each double lane configuration was developed (Figures 3-6, 3-7, and 3-8). Each facility was designed with durable, but attractive and inexpensive, construction to provide the necessary enclosure for the equipments and personnel. Industrial engineering personnel recommended that the facilities be constructed of wood frame, 10-foot stucco and plasterboard walls, with 90-pound felt hot-mopped roofs. Two 10- by 10-foot aluminum overhead garage doors were provided for each inspection lane. The estimates included interior walls and doors for utility and office spaces, and concrete slab floors with a 6-foot-deep concrete-lined inspection pit. The inspection pit was provided with a sump pump and access stairs, and was covered with expanded metal grating. Fire suppression sprinklers, compressed air (110 psi), and electrical convenience outlets were provided throughout the working areas. Each facility had one restroom containing one toilet and one wash basin. The exterior yard was asphalt with painted aisles and parking stalls. Each dynamometer was provided with a concrete-lined pit ready for installation. Each dynamometer and engine diagnosis stall was provided with a 2500-cfm exhaust recovery system using 6-inch flexible hose. The exhaust gases were routed through floor ducts and up side walls for discharge above the building roof. Each single or double lane diagnostic station was equipped with an additional restroom.

3.3.1 Mobile Facilities

Each mobile inspection facility was equipped with the required equipments for a single lane of the respective regime. In addition, the mobile facility required a van of sufficient size to transport inspection personnel, equipment, and 110-vac power supply, and, where applicable, a dynamometer mounted on a trailer.

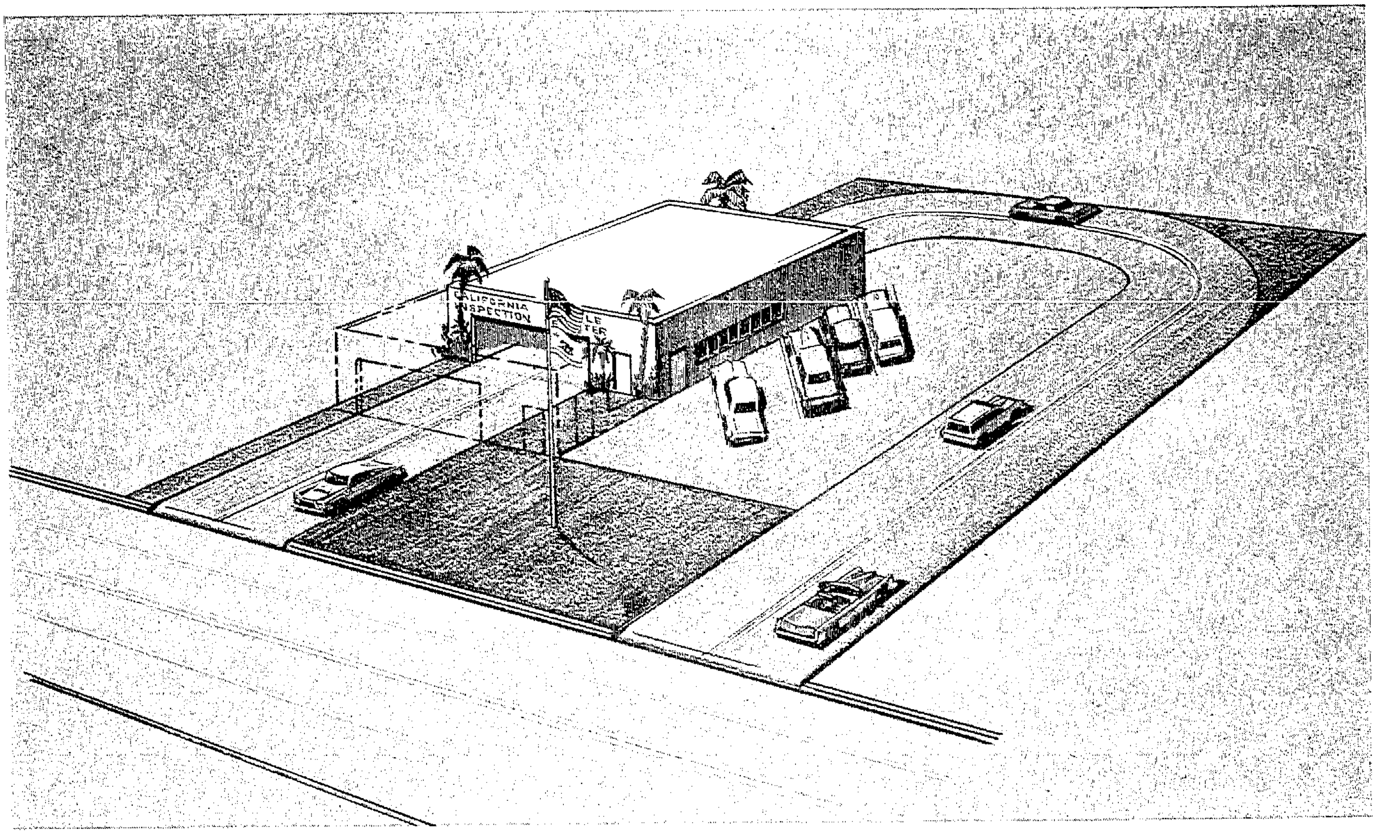


Figure 3-6. ARTIST'S CONCEPTION OF IDLE INSPECTION STATION

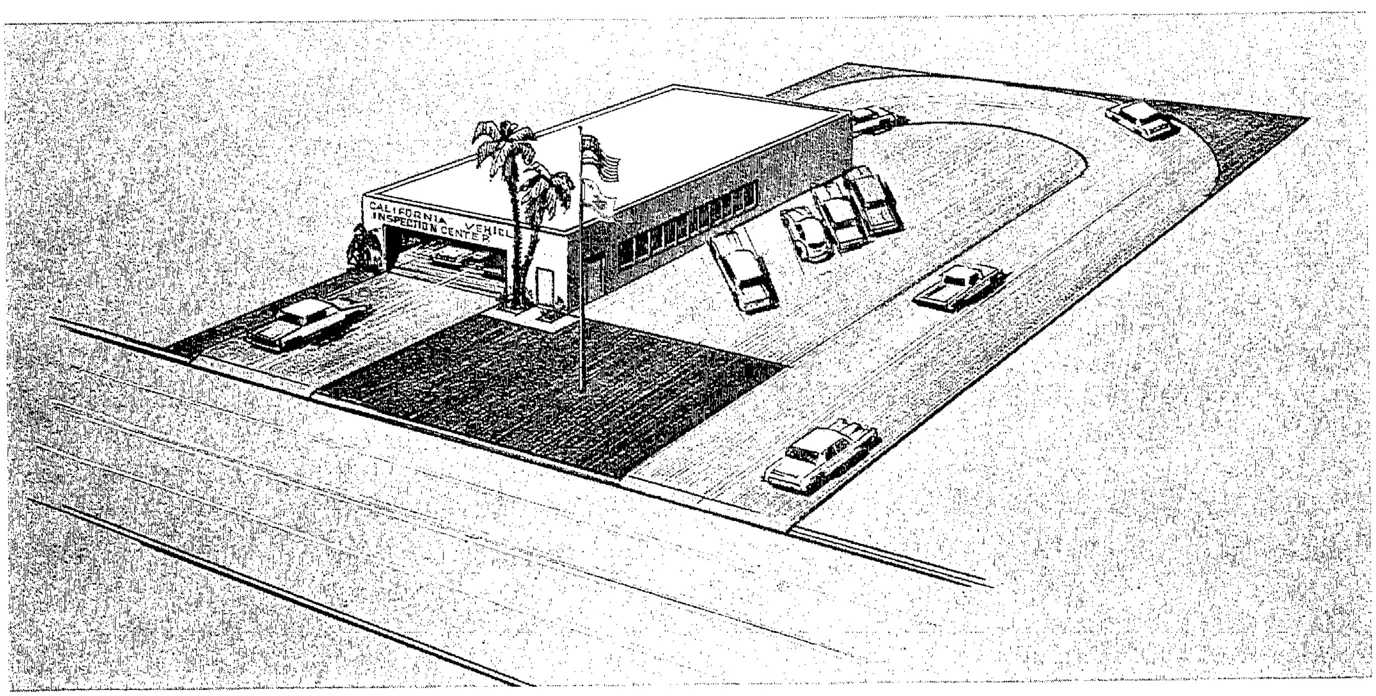


Figure 3-7. ARTIST's CONCEPTION OF KEY-MODE INSPECTION STATION

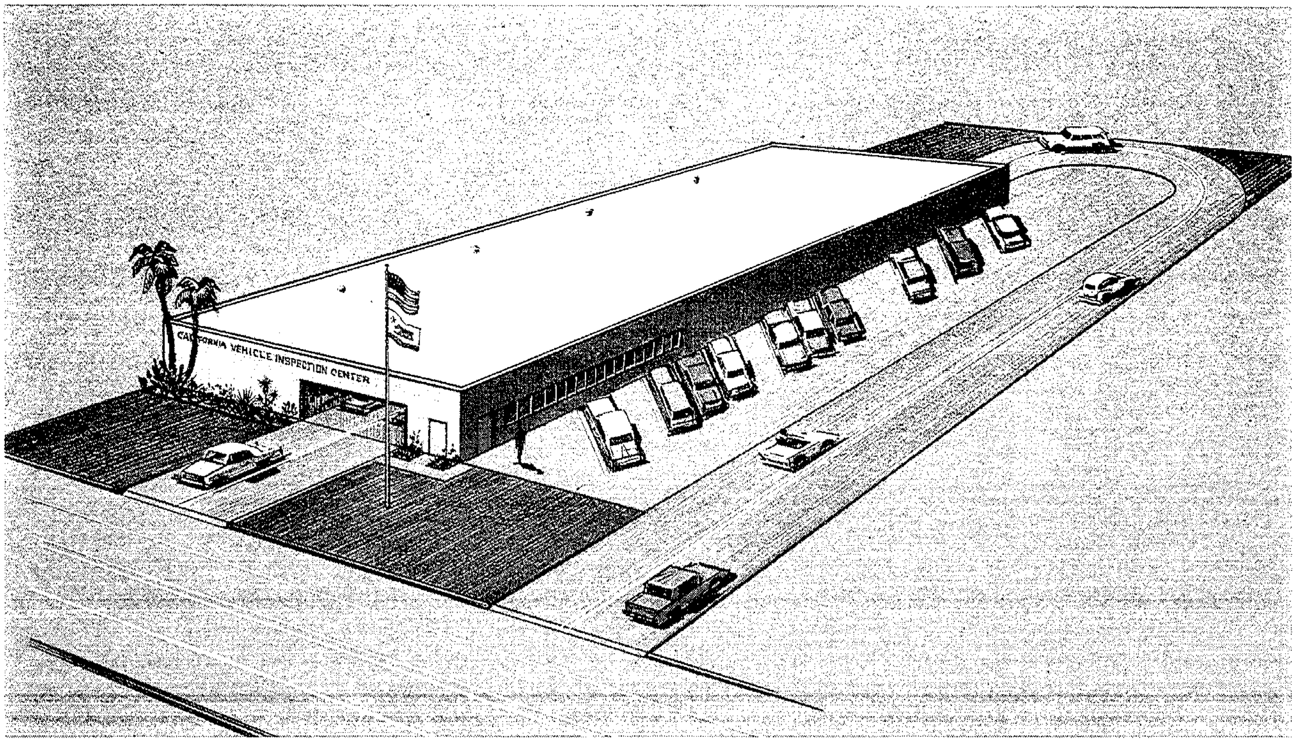


Figure 3-8. ARTIST'S CONCEPTION OF DIAGNOSTIC INSPECTION STATION

3.4 EQUIPMENT

Equipment and area requirements were identified for single and double lane station configurations of each test regime. Specific instrument requirements are identified in the instrumentation review of Section 3, Volume III. Vehicle inspection test equipment requirements were developed for each regime. The instruments and other equipment were grouped in their generic groups and assigned to each regime's station configurations of from one to seven lanes. Seven lanes were arbitrarily chosen as the maximum station size. Driver waiting areas, utilities, and office spaces were designated. The test facility size requirements were generated by analysis (minimum size) and refined by industrial engineering personnel (recommended size). The two-lane station floor plans resulting from the analysis are shown in Figure 3-9.

3.4.1 Equipment Types and Generic Groups

The equipment is described as inspection equipment, inspection support equipment, and administrative support equipment. The inspection equipment includes the following five groups: (1) the dynamometer system, including dynamometer, controls, readouts, and cooling fan, (2) the exhaust emission inspection test system for HC, CO, NO, and O_2, including the sample system and gas analyzers, (3) engine diagnostic equipment including scope, meters, and probes, (4) the exhaust emission analysis system for HC and CO for engine diagnosis and the Certificate of Compliance test, and (5) the data processor/recorder system.

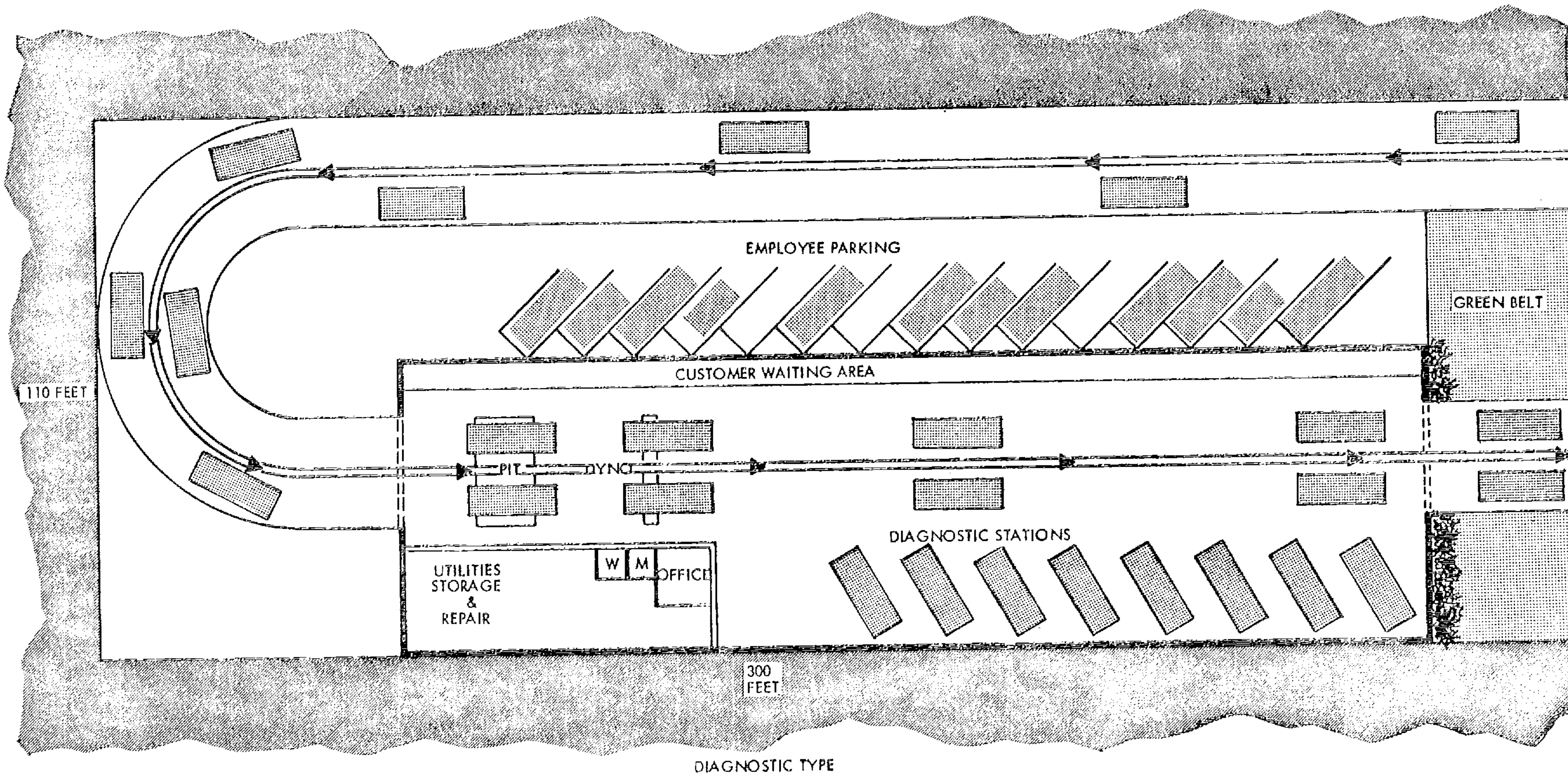


Figure 3-9. TWO-LANE STATION FLOOR PLANS (Sheet 1 of 3)

01001

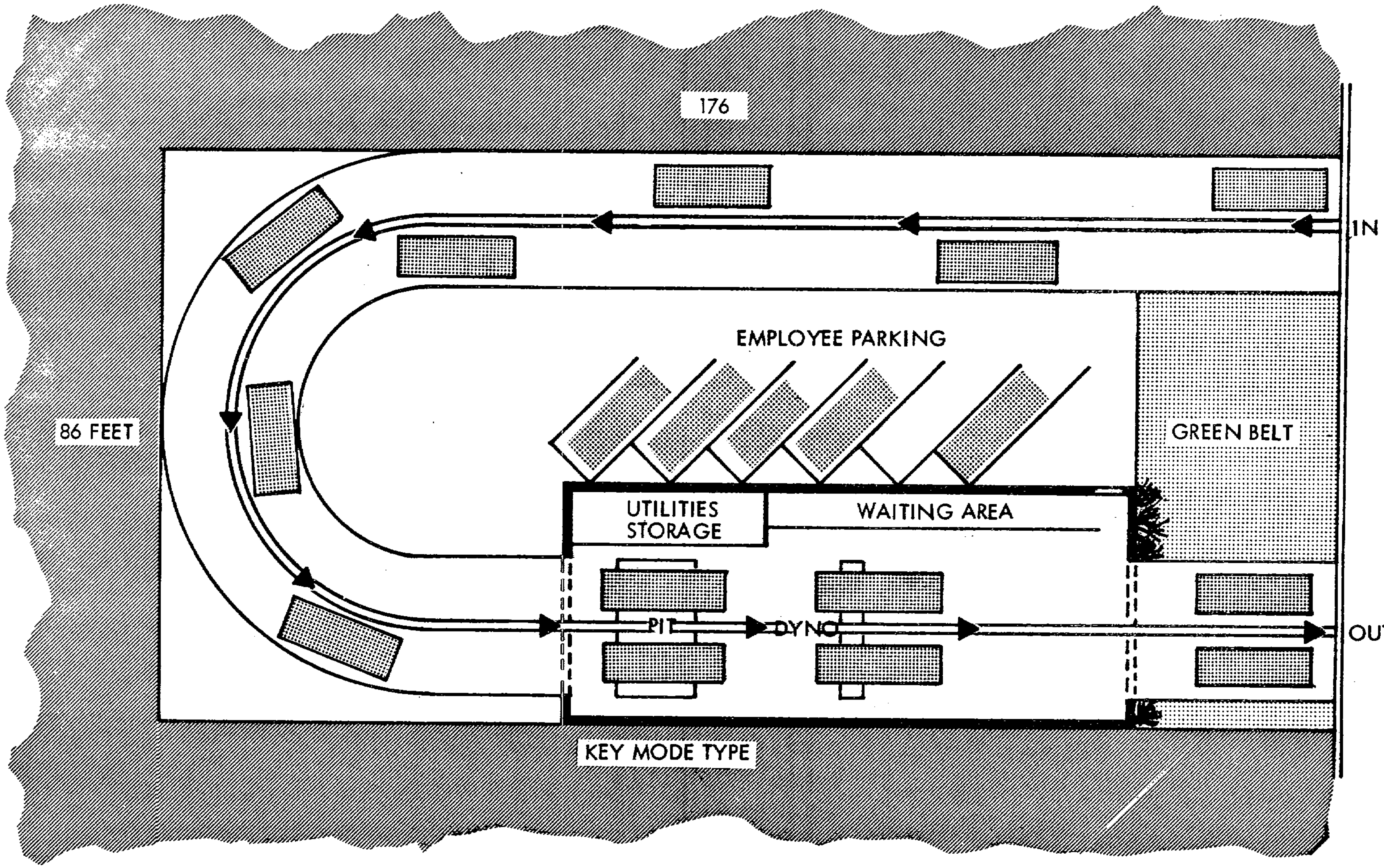


Figure 3-9. TWO-LANE STATION FLOOR PLANS (Sheet 2 of 3)

0100 2

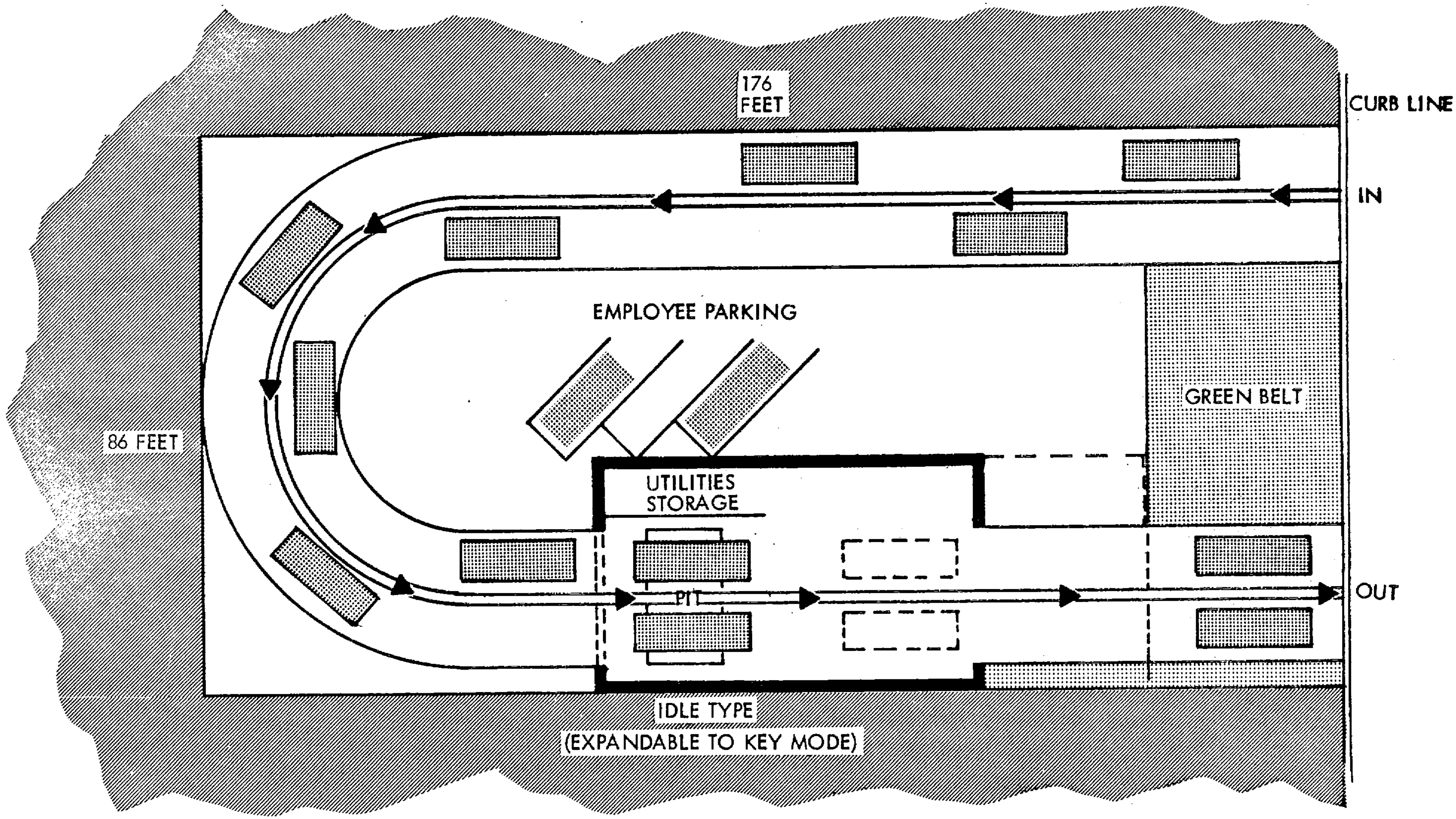


Figure 3-9. TWO-LANE STATION FLOOR PLANS (Sheet 3 of 3)

During the analysis, the exhaust emission inspection test system and the data processor/recorder functions were combined into a single instrument package. This package was assigned to each lane of all the test regimes, except Certificate of Compliance which was assigned only the exhaust emission analysis system (numbered 4). This distinction was considered most realistic in terms of the level of emission measurement sophistication required. The HC and CO analyzers (4) have 5 percent accuracy; the HC, CO, and NO analyzers (2) have 1 percent accuracy.

The inspection support equipment includes equipment and supplies required to calibrate and maintain the inspection equipment, including expendable items such as sample probes, filters, and belts. The administrative support equipment includes office equipment, fixtures, and public facilities required to maintain and operate the facility and conduct the necessary routine administrative functions.

3.5 PERSONNEL REQUIREMENTS

The following paragraphs outline the personnel requirements for operating the emission inspection station. The required staff and skill levels are defined. The training requirements, including curriculum, facilities, and instructor training, conclude the discussion. The following statements summarize the manpower requirements to staff and operate an emission inspection station:

a. <u>Skill Levels</u> - Inspection station personnel skill levels are based on auto technician skill levels currently available from the industry. Level III requires 5 years experience and some formal education in the auto tuneup and diagnostic field. Level II requires 3 years tuneup and diagnostic experience with some formal education. Level I requires some tuneup experience and vocational auto or trade school education.

b. <u>Inspection Station Staff</u> - The Diagnostic inspection regime requires the highest skill levels to operate the lanes. Two Level III inspectors and one each of Levels II and I inspectors will be required to operate one Diagnostic lane. The Key-Mode and Idle inspection regimes require one inspector at Level II and one at Level I to operate one inspection lane. The Certificate of Compliance and AAMP regimes require one man at Level I to operate one lane.

c. <u>Data Processing</u> - The inspector in charge of the inspection station must issue pass or fail certificates. A written diagnosis outlining the emission problems would be a major contribution to any inspection regime.

d. <u>Equipment Maintenance</u> - Inspection station personnel will be required to conduct instrument calibrations, perform routine maintenance, and repair minor mechanical failures. Equipment manufacturers or program management will service equipment when internal or major repairs are required.

e. <u>Training Requirement</u> - To assure the successful implementation of the selected inspection regime, effective training for station inspectors is obviously mandatory. Some recommendations are in order for a manpower development program which can be offered to inspection personnel and instructors. Existing public education facilities can be utilized to implement statewide inspector training programs.

f. Curriculum - The recommended curriculum is quite similar for all five inspection regimes. It features classroom instruction, laboratory demonstrations, and on-the-job training (OJT). The distribution of training hours is shown in Figure 3-10. Laboratory demonstrations and OJT account for 59 to 76 percent of the total training effort for all test regimes. The Diagnostic training effort is the longest, at 174 hours; and the Idle test is the shortest, at 87 hours. Both the Key-Mode and Diagnostic regimes require dynamometer training.

g. Training Facilities - The training program could be implemented into California's existing public education facilities. School laboratories could be equipped with the applicable inspection station instrument packages. Dynamometer facilities with as many as four dynamometers are currently available through private industry. On-the-job training would be conducted at the inspection station.

h. Training Instructors - Qualified and credentialed teachers would be selected as training instructors, provided they could meet the Level III skill requirements. All instructors would be required to attend the inspection training class prior to their teaching a class. Initial training programs for instructors can be conducted by personnel already involved in the vehicle emission control and emission measurement training programs.

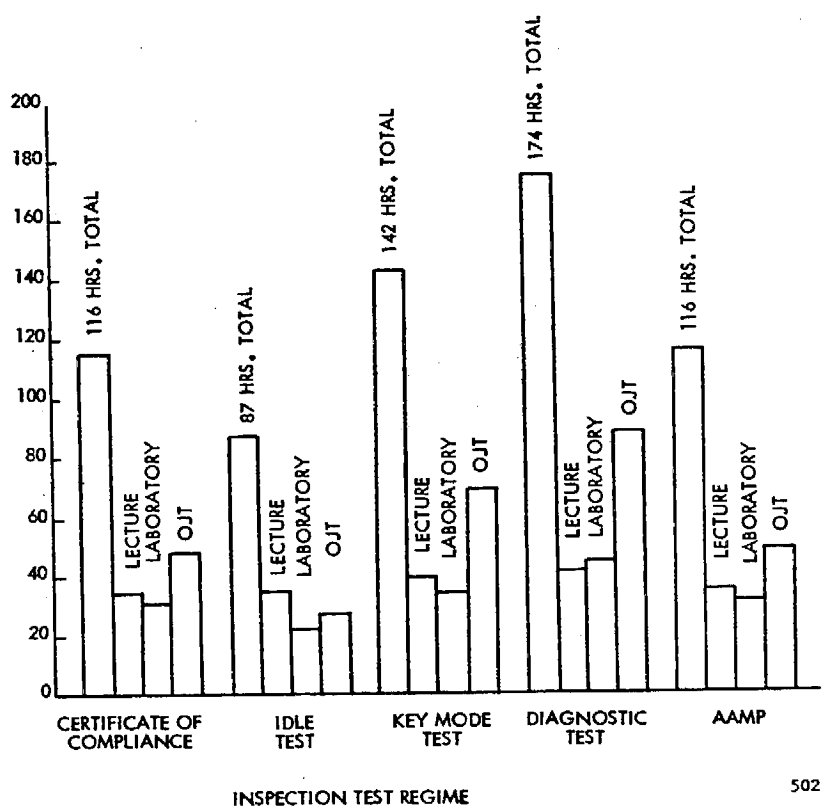


Figure 3-10. TRAINING REQUIREMENT DISTRIBUTION FOR INSPECTION STATION PERSONNEL

3.5.1 Inspection Personnel

To assure the success of any vehicle emission inspection test, it is imperative that the State select and train competent inspectors to operate the stations. Since the inspection involves vehicle emission measurements, the inspector should have a strong automotive background, as well as a good mechanical aptitude. He must thoroughly understand vehicle operation for the various test modes, and must be cognizant of emission control system technology. In addition, he should be able to confront the motorist with a pleasant attitude, regardless of the inspection test results.

3.6 NUMBER AND GEOGRAPHICAL DISTRIBUTION OF INSPECTION STATIONS

To provide cost estimates, it was necessary to determine the size and number of stations required for each inspection regime. Two analyses were conducted to derive this information. First, a station algorithm was developed which calculated the vehicle throughput (number of vehicles per day per lane) for each candidate inspection regime. This model permitted permutation of station operating variables such as effect of failure rate, vehicle arrival times, and personnel complement. The output of this model (vehicles/day/lane) was then applied to a second algorithm which determined the number of lanes of each inspection regime required by localities. This information was used to determine the number and size of stations required by each inspection regime. The results of the station algorithms and the number of lanes for each air basin required for each test regime are presented in Table 3-2.

Table 3-2. SUMMARY LANE ASSIGNMENTS

	Test Type				
	Certificate of Compliance	Idle	Key-Mode	Diagnostic	AAMP
Annual Vehicle Throughput per Lane	7,500	32,000*	25,000*	13,020*	7,500
Air Basin	Total Lane Equivalents Required**				
1. South Coast	635	148	194	368	635
2. San Francisco Bay Area	332	78	94	190	332
3. San Joaquin Valley	112	26	33	61	112
4. Sacramento Valley	86	17	24	47	86
5. San Diego	86	20	29	48	86
6. Southeast Desert	41	10	9	26	41
7. North Central Coast	27	7	10	16	27
8. South Central Coast	27	7	8	16	27
9. North Coast	14	3	4	8	14
10. Northeast Plateau	4	2	2	3	4
11. Great Basin Valley	2	1	1	1	2
Total	1,366	319	398	784	1,366

*Based upon a 50 percent rejection rate.
**One lane equivalent is one stationary lane or the required number of mobile lanes to achieve the throughput of a single stationary lane.

SECTION 4

PROGRAM EVALUATION AND RESULTS

This section discusses the results of a public opinion survey conducted to determine and evaluate the sentiments of the general populace regarding specific facets of an inspection program. The questionnaire, the survey method, and the findings are described.

A program cost analysis that utilizes a computerized life-cycle cost model is discussed. Major cost elements are categorized into initial investment and annual operating expenditures. In addition to the program cost analysis, a vehicle owner cost breakdown is provided to identify the various expenses incurred by the typical motorist as a function of test regime.

The effectiveness of each test regime is quantified by the measure of effectiveness developed to consider the effects of vehicle population, age, miles driven, emission profile, and inspection failure rate. Statistical data relative to test regimes emission reduction and degradation are included. Test regimes effectiveness projected for the next 20 years is facilitated by the calculation of the effectiveness indices which are then graphically plotted by program year. The statistical validity and significance of the test data are discussed in the concluding paragraphs of this section.

4.1 PUBLIC OPINION SURVEY

The purpose of this survey, conducted by Opinion Research of California, was to measure opinions of vehicle owners concerning a motor vehicle emission inspection program. A multistaged, modified probability sample design was utilized to select 1000 owners of private passenger automobiles registered in the State of California. The sample design called for stratification of the State into major population areas, with a systematic selection of 100 primary sample clusters which were each factored into 10 subclusters. Ultimate sampling units consisted of eight vehicle owners, one of whom was randomly selected as the original interviewee. The remaining names were randomly substituted if the original interview could not be completed.

The interviewing was conducted by telephone and two callbacks were made, for a total of three calls, before substitutions were introduced. In those sampling units where no interview could be completed by telephone, the selected respondent was interviewed in person at his place of residence.

A total of 2506 calls were made to complete the 1000 sample. Sixty-two in-home interviews were necessary to meet sample design requirements. Sixty-six percent of the completed sample were original interviewees, while 34 percent were substitutes.

The interviewing was conducted from 13 March 1971 through 22 March 1971. Additionally, an investigation of attitudes about a vehicle emission inspection program was made among a selected group of 50 leaders in California by Opinion Research of California. These 50 select individuals are associated with various business, industrial, legal, governmental, news media, employee, and public organizations. These individuals were interviewed in person during the period from 26 April 1971 to 30 April 1971.

4.1.1 Methodology

Mindful of the purpose of the study and anticipated application of the data obtained, this study was designed to provide a high level of precision and confidence as well as to develop in-depth data. The statistical validity (precision and confidence) of all survey results are primarily dependent on the size and design of the sample.

In survey research, the size of the sample necessary to yield significant results not only relates directly to the number of units (persons) in the universe, but also to the absolute number of cases in the sample. An optimum sample in a survey is one which fulfills the requirements of efficiency, representativeness, reliability, and flexibility. The sample should be large enough to avoid intolerable sample error, and small enough to avoid unnessary expense. It should be large enough, however, to achieve required precision, but not a needlessly high precision.

Applying the above criteria, the survey utilized a sample that yielded a 95 percent degree of certainty and a ±4 percent precision or permissible error. These sample requirements indicate a sample size of 1000 cases distributed throughout the State of California. The statistically selected sample provided for a representative cross-section of California registered vehicle owners.

In addition to the general investigation of motorists' attitudes, the opinions of special interest groups and/or leaders who may have a direct impact upon the overall acceptance or rejection of the program were assessed. Fifty such individuals are included in this select group (i.e., media representatives, legislative advocates, and automobile associations).

4.1.2 Objectives

The primary objectives of the public opinion survey were to ascertain the California motoring public's acceptance of a mandatory vehicle emission inspection and maintenance program. Investigation of public attitudes included the following broad subject areas:

a. The advantages/disadvantages of a vehicle emission inspection and maintenance program

b. The convenience/inconvenience factors, including location of inspection centers, frequency of inspection, and time allocation for inspection

c. The desirable/undesirable aspects of corrective maintenance as it relates to personal convenience, reduction of vehicle emissions, and vehicle safety and operation

d. The acceptance/rejection of cost factors relating to both inspection and corrective maintenance

e. The approval/disapproval of public and/or private operation of the inspection program

f. The acceptance/rejection of punitive measures for nonconformity to the program.

4.1.3 Questionnaire

Opinion Research of California reviewed related research and literature preliminary to drafting the questionnaire document. Questionnaire conferences were held with representatives of the Air Resources Board and Northrop Corporation to assure maximum data acquisition. The questionnaire was pretested and revised accordingly. A copy of the questionnaire is provided in Appendix K, Volume III.

4.1.4 Findings

4.1.4.1 General Discussion - More than three-fourths of the automobile owners and four out of five of the leaders interviewed in the study name the automobile as the major contributor to air pollution in California at this time. Approximately four out of ten owners interviewed have only one car in the family, an almost equal number have two cars, while the remainder have more than two cars. These vehicles virtually run the gamut of makes and models, with Chevrolet and Ford being the front runners. According to the survey, automobile owners have little knowledge about the type of emission tests made on their vehicle, although more than three-fourths of them maintain they have had the pollution control device in the automobile inspected.

4.1.4.2 Current Safety Inspection Program - Slightly more than half of the survey respondents maintain they have had their vehicle checked at some time or another by the California Highway Patrol at one of their side-of-the-road safety inspection points. Overall, the safety inspection program is viewed positively by the majority of those interviewed, with less than one-fourth of the respondents offering negative comments about the inconvenience or ineffectiveness of the program.

More than half of the leaders also view the program favorably. However, one out of five of these individuals maintain the program should be expanded to detect more defective automobiles, and eight of the leaders maintain the program is not as effective as it should be primarily because it is "hit and miss."

4.1.4.3 Mandatory Emission Inspection Program - The survey results indicate that three-fourths of the car owners believe a mandatory vehicle emission inspection program for all vehicles in the State is necessary, while just over half of the leaders agree that such a mandatory program is necessary.

The primary advantages of a mandatory vehicle emission inspection program, in the car owner's opinion, is that it will reduce air pollution, force people to repair their cars, and detect defective automobiles. The leaders also view the advantages of the program as reducing pollution and detecting defective automobiles. Additionally, the leaders believe the program would check the effectiveness of the emission control devices and encourage more technological advances in the area.

The major disadvantages of such a program are the expense and inconvenience, according to the vehicle owner. The leaders see these as disadvantages in addition to the problems of administering a statewide program.

Consistent with other results in the survey, the vast majority of vehicle owners (82 percent) would favor a mandatory vehicle emission inspection program in California. Three out of five of the leaders would also favor such a program. The principal reason for the respondent's favoring the program is that it will reduce air pollution, and the primary reason for opposing the program is the cost.

4.1.4.4 Inspection Facility Ownership and Operation - More than half of the car owners believe the inspection program should be conducted by the State of California rather than private garages or service stations licensed by the State, whereas the reverse is true of the leaders; more than half of these individuals believe the inspections should be conducted by private facilities.

Among the vehicle owners who believe the inspection should be made by the State of California, the main reason is they do not have trust in the private garages and service stations. The main reason the private garage is selected by those who do so is because of the convenience factor.

The leaders who believe the inspections should be conducted by the State are likewise concerned about potential abuses and dishonesty of the private garages, but the main reason for selecting the private garage or station is because of the cost to the State to develop and run the inspection centers.

4.1.4.5 Inspection Time, Costs, and Related Factors - More than three-fourths of the automobile owners believe that motor vehicles should be checked at least once a year for emissions; three-fifths of the leaders concur with this frequency.

The majority of the automobile owners interviewed would continue to favor the program if the inspection took 30 minutes or less, if the inspection fee were $1.00 or less, if they had to drive 10 miles or less to an inspection center, and if the average repair costs were $10.00 or less. When the time limit, driving distance, and costs exceed those described above, a majority of the respondents would oppose the mandatory vehicle inspection program.

Just over half of the owners interviewed and just less than half of the leaders believe 15 days is a sufficient length of time to repair a car if it does not pass the vehicle emission inspection. Among those who believe 15 days is not a sufficient length of time, the majority maintain 30 days is the minimum number necessary to have a deficient car repaired.

4.1.4.6 Inspection Enforcement - A significant division of opinion exists among both vehicle owners and leaders on the question of enforcement provisions in the inspection program. Forty-seven percent of the owners approve and an equal number disapprove of an enforcement provision which would require the owner to repair his vehicle within a specified time limit or surrender his license plates and registration papers. Nineteen of the leaders approve, and 23 disapprove of the same proposal; the remainder are undecided on the issue. Among those who disapprove, approximately half believe there should be some fine imposed, but there is no concensus as to the amount of the fine.

4.1.4.7 Program Acceptability - A final question asked of the vehicle owners was, "Now that you know more about the mandatory vehicle emissions inspection program, in general, do you approve or disapprove of spending the necessary time and money to reduce vehicle emissions and lessen air pollution in California?" Eighty-six percent of all respondents maintain they would approve of such expenditures of time and money.

4.2 PROGRAM COST ANALYSIS

This paragraph provides a summary of costs involved in implementing each of the five test regimes in the configurations described in Section 3. A detailed cost analysis model was developed that provides a framework for evaluating the program costs associated with each of the five test regimes. This life-cycle cost model categorizes cost elements into major submodels of research and development, initial acquisition and investment, and annual operations and maintenance. Results of exercising the model for each of the test regimes are then presented.

4.2.1 Economics of Emission Reduction

The economic evaluation of any regulatory and mandatory program that is implemented and maintained for the public benefit involves far more than the application of statistical methods to the study of cost-related data. As mentioned previously in this report, vehicle emissions are a major contributor to air pollution, especially in terms of NO and CO. Each of these pollutants has its own characteristics and each community affected faces different meteorological, topographical, and economic conditions. As such, the effects and benefits derivable from an inspection program would not be equally applicable to the total populace. To justify the institution of a statewide testing concept, the benefits derived must be balanced against the costs incurred to achieve these advantages. The task, then, is to identify and quantify these costs.

4.2.2 Cost Analysis Model

Each of the five candidate test regimes under evaluation involves an extremely large number of fixed and variable cost items. Personnel wages, building costs, maintenance, and equipment and installation costs must all be systematically evaluated for each regime if the total cost of each of these five testing concepts is to be accurately assessed. To facilitate fixed and parametric cost comparisons, among the five candidate regimes, a linear life-cycle program cost model was developed. This cost model identifies and quantifies the various program cost elements involved for each of the five regimes in their various configurations, and provides a convenient means for parametric and sensitivity analyses.

This cost model was designed to provide expected aggregate cost magnitudes for the various program areas throughout the desired program lifetime for each regime considered. Since the five regimes may vary widely both in cost and expected methods of implementation and administration, this cost model does not provide a cost accounting treatment of required program expenditures; it is simply a tool that allows cost items to be readily identified and analyzed.

The following paragraphs describe the cost model exercised for each of the five test regimes. This description is intended to present only the costing categories and concepts upon which the model was conceived; no numerical analyses are presented.

4.2.2.1 General Description - The framework around which this cost analysis model was designed was the concept of life-cycle cost. Life-cycle costing is a technique that assures that required resources are systematically considered, assists in the analytical process, facilitates data acquisition and mathematical computation, and indicates areas of critical resource requirements. The life-cycle cost (LCC) model used in subsequent analyses is composed of three major submodels corresponding to three major program phases: research and development, initial acquisition and investment, and annual operation and maintenance.

The research and development category includes all costs necessary to conceive, design, develop, and document a total program capable of satisfying the identified goals and objectives. For each of the test regimes evaluated, this cost category identifies and quantifies the expenditures necessary to finalize the concept to the point of implementation. Specific equipment, personnel, facilities, support management procedures, and all the other considerations are costed to assure complete coverage of resources. Deficiencies in equipment must be noted, and further research and development in technology must be funded either by industry, by the State, or by both. Such costs are part of this category.

The initial acquisition and investment category includes all the resources and costs incurred in the process of initial program implementation. The resource elements include facilities and instrumentation, and functional elements include indoctrination, initial training, and certification. This category includes those expenditures of a non-R&D and non-recurring nature associated with the initial acquisition and start up of the program.

The annual operation and maintenance category includes all expenditures necessary to operate and maintain the inspection facility. Cost elements are expenses such as personnel wages and salaries, facilities upkeep, and sustaining or replacement training. This category includes all recurring expenditures for the total program.

Using the above three cost categories, the total program LCC for each test regime is calculated by manipulating the generalized, first-level-cost model delineated in equation (1).

$$LCC = \sum_{n=1}^{Y} \left\{ \left(C_{RD_n} + C_{INV_n} + Ke_n C_{OP_n} \right) \right\} \qquad (1)$$

where:

LCC = total program cost for expected duration

C_{RD} = program research and development expenditures, in dollars

C_{INV} = initial acquisition and investment expenditures, in dollars

C_{OP} = operation and maintenance expenditures, in dollars

n = index of years in life-cycle duration

Ke_n = escalation factor applied for year n

Y = expected number of years in life cycle.

In the following paragraphs, each of the major categories are further defined by identifying the contributing cost elements as applicable to the test regimes and total program.

4.2.2.2 Program Research and Development Costs (C_{RD}) - For each test regime, various research and development costs may be required before initial implementation. If present instrumentation cannot satisfy facility requirements, the cost to modify, upgrade, or develop the necessary equipments may be borne, in part, by the program. Additions or modifications to current methodology or technology must also be considered under this category, wherever essential advancements are necessary, before any selected implementation is instituted. After program implementation, any required R&D effort becomes part of program management costs as listed and described under annual operation and maintenance costs. A discussion of R&D costs applicable to all regimes is presented in Volume III, Section 6, of this report.

4.2.2.3 Facility Acquisition and Investment Costs (C_{INV}) - This cost category will include those resources and functional costs that are related to initial acquisition and implementation. They are nonrecurring expenditures necessary to initiate the program and are differentiated from the research and development costs which were necessary prior to initial implementation. Described below are the general areas of interest.

a. Site Acquisition - Based on the physical locations selected for the inspection facilities, the land area required for station placement must be acquired, either purchased or leased, if not already owned. This will be a cost element regardless of whether the State or private industry runs the program.

b. Facility Plans and Bids - All necessary site plans and construction drawings must be completed so that interested and qualified contractors may submit bids for consideration. The submitted bids must be evaluated, qualifications of contractors certified, and contracts drawn for the selected parties. Modifications to existing facilities would be handled somewhat differently; however, the cost elements would remain basically the same.

c. Facility Construction and Acceptance - New facilities must be constructed to comply with the facilities plans and drawings. In the case of older, established facilities, necessary modifications must be accomplished to accommodate any new equipments and space allocation requirements. Completed facilities are then inspected and certified for acceptance.

d. Equipment Acquisition and Installation - Equipments selected and recommended for the particular test regime must be purchased and installed. Acceptance tests must be conducted before the facility may be certified as an approved inspection facility. The test documentation would probably be supplied by the program management office. Additionally, it may be advisable for a team of qualified and trained technical inspectors to be available for guidance.

e. Personnel Indoctrination and Training - Depending on the test regime chosen for implementation, selected personnel may be required to receive the necessary program indoctrination and training to perform satisfactory vehicle inspection. Many of the test equipments and procedures may be unfamiliar to the affected technicians. Additionally, administrative, facility, and management personnel may be called upon to explain vehicle test program objectives and results. The training program may be developed and administered by the program office or by the facility owner using material provided by the program office. Identifiable cost elements would be the development of the training program, any equipments and documents essential to the training course, the required training of instructors if none are available, pay and travel allowances for instructors and students while receiving training, and apportioned costs for training facilities.

f. Station Qualification and Certification - After the facility is completely equipped and staffed, and prior to receiving the first vehicle to be inspected, the total facility must be qualified and certified. It was previously stated that equipments are accepted and certified after installation. These tests conducted now would be for the total system of equipments, personnel, procedures, and documentation to assure uniformity on a statewide basis. Cost elements would be any special test procedures and certification duties and the facility personnel apportioned pay. Until the facility is certified, it is not operational.

The mathematical relationships which were used to quantify investment costs are presented in Volume III, paragraph 6.6.

4.2.2.4 Operation and Maintenance Costs (C_{OP}) - The functions and cost elements of an inspection facility are described below in terms of anticipated operating and maintenance activities. Personnel salaries, wages, and benefits would be the largest cost element required for an inspection facility annual expenditure. Sustaining personnel training and upgrading programs may be instituted to assure continuing satisfactory operation. The maintenance of primary inspection equipment is of paramount importance, with secondary emphasis on supporting equipments, tools, and supplies. Administrative equipments and supplies also incur annual upkeep expenses. Additionally, the facility itself requires grounds and building maintenance. The functions performed by the program management office include vehicle scheduling, records administration, emission limits establishment and review, equipments requirement evaluation, and station qualification and certification. Other administrative functions common to any program management office are equally applicable. The contributing cost elements to this category are discussed in ensuing paragraphs.

4.2.2.4.1 Personnel Salaries, Wages, and Benefits - Based on the personnel requirements analysis conducted for each of the applicable test regime configurations, a complement of technical and administrative personnel is identified. The cost to staff the individual facilities would consist of all salaries, wages, and benefits required.

4.2.2.4.2 Personnel Training and Upgrading - New personnel added to the program subsequent to the initial start date may require indoctrination and training, depending on the test regime incorporated. In addition, current members of the inspection and administrative personnel staff would require periodic upgrading programs. The program management office may utilize the initial training facilities and materials to provide sustaining training, depending on the scope of the task. Anticipating that this function would not be of major proportions, perhaps the individual facility may incorporate program-directed training policies and procedures. The method of determining this training operation would be similar to that involved during the initial training phase.

4.2.2.4.3 Inspection-Oriented Equipments, Tools, and Supplies - The inspection-oriented equipments will require periodic preventive maintenance and some corrective maintenance activities. In most cases, various tools and supplies would be necessary to accomplish the tasks. Repair documents and replacement parts would be required in some instances to restore satisfactory operation of equipment. The expendable and consumable parts and supplies are part of operation and maintenance costs, whereas tools and documentation are part of the initial investment.

4.2.2.4.4 <u>Support-Oriented Equipments, Tools, and Supplies</u> - These cost items are required to support the maintenance, calibration, and testing of the primary equipments and are not for items directly utilized during the emission analysis of vehicles. Included would be calibration gases, test equipments maintenance, and general-purpose tool replacements required for supporting activities.

4.2.2.4.5 <u>Administrative Support Equipments and Supplies</u> - There may be administrative support equipments included in the inspection facility to prepare inspection forms, to record inspection data, and, where required, to record receipt of inspection fees. Incidental office supplies would also be required to satisfy the facility administrative office requirements.

4.2.2.4.6 <u>Inspection Facility Upkeep</u> - Included in the cost of ownership would be the operations and maintenance expenditures for the facility itself. Grounds and building maintenance, all utilities required for operation and upkeep, and other incidental expenses such as property taxes and income taxes must be considered under this category.

4.2.2.4.7 <u>Program Management and Administration Costs</u> - Total management costs include salaries, wages, and benefits of administrative personnel; related office space and equipments; and clerical supplies. Depending on the type of management program implemented, there may be several levels of authority, ranging from a department or agency level down to a regional district level. Each level of management would involve similar types of expenses. Any required surveillance or certification program would require supporting technical inspectors in addition to administrative personnel.

Prior to initial testing and inspection, vehicle scheduling must be planned and completed. Appropriate vehicle owners must be notified of the applicable inspection period and the facility location. Proper forms and information pamphlets must be developed that would inform the public of program objectives and inspection policies and procedures. A program scheduling and monitoring concept must be developed and implemented to assure achieving the desired effects and benefits.

4.2.3 <u>Comparative Cost Summary</u>

The investment and operating costs described in the previous paragraphs are compared in the following paragraphs according to the five inspection regimes. The costs have been estimated subject to specified assumptions. However, cost elements have been presented in such detail that the reader should be able to construct cost estimates based on different assumptions from the data contained in this section.

For example, the cost of a test procedure employing different equipment could be determined by adding the new equipment cost to the other existing investment costs and the operating costs. A modified Idle inspection program using the instruments assigned to the Certificate of Compliance would have an equipment acquisition cost of $18,000,000 rather than $50,000,000. If only exhaust emission measurement equipment is required, the additional equipment cost would be $8,000,000.

4.2.3.1 Investment Cost - The following comparative discussion of investment costs of the five test regimes is supplemented by Figure 4-1 and Table 4-1. All costs discussed are based on the State-owned, State-operated configuration of each regime. Readily apparent from either Figure 4-1 or Table 4-1 is the relative ranking of investment costs of each of the five test regimes. Least costly is Idle Test, at $12,084,000, followed by Key-Mode Test, Certificate of Compliance (C of C), Diagnostic Test, and AAMP at $19,830,000, $30,263,000, $88,776,000, and $34,458,000, respectively.

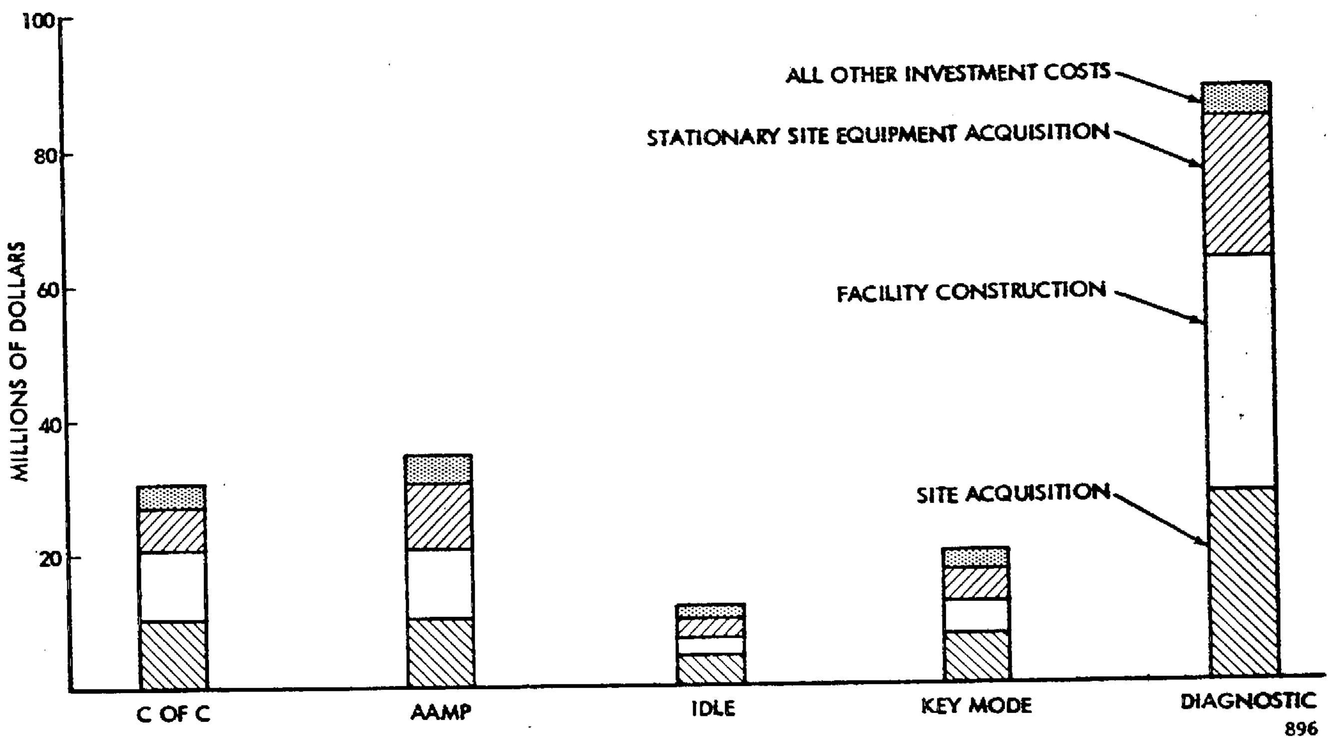


Figure 4-1. COMPARISON OF INVESTMENT COSTS FOR FIVE TEST REGIMES

4.2.3.2 Operating Costs - Graphic and tabular summary results of the comparative operating costs of the five test regimes for 1972 are presented in Figure 4-2 and Table 4-2. The following discussion references these two presentations.

For each of the five test regimes, the two largest portions of this total investment cost are site acquisition and facility construction. The proportional costs for site acquisition range from a low of 32 percent for Diagnostic to a high of 38 percent for Idle, with Certificate of Compliance and AAMP at 35 percent, and Key-Mode at 37 percent. Facility construction takes another large portion of initial investment cost, from a low of 25 percent for Idle, to a high of 40 percent for Diagnostic, with Certificate of Compliance and AAMP at 35 percent, and Key-Mode at 37 percent. These two cost elements comprise at least 59 percent of the total investment cost of each test regime.

Table 4-1. INVESTMENT COSTS BY TEST TYPE
(THOUSANDS OF DOLLARS)

Cost Element	C of C	Idle	Key-Mode	Diagnostic	AAMP
Site Acquisition	10,609	4,566	7,315	28,097	10,609
Facility Construction	10,256	2,551	5,130	35,208	10,256
Stationary Site Inspection Equipment	6,365	3,040	5,096	21,060	9,405
Mobile Inspection Equipment	1,490	1,000	594	1,690	2,490
Equipment Installation	-	58	590	501	58
Training Costs	703	97	173	1,176	800
Facility Plans and Bids	15	15	20	25	15
Qualification and Certification					
Salaries of Field Personnel	199	178	323	396	199
Program Administrative Costs	626	576	589	623	626
Total Investment Cost	30,263	12,084	19,830	88,776	34,458

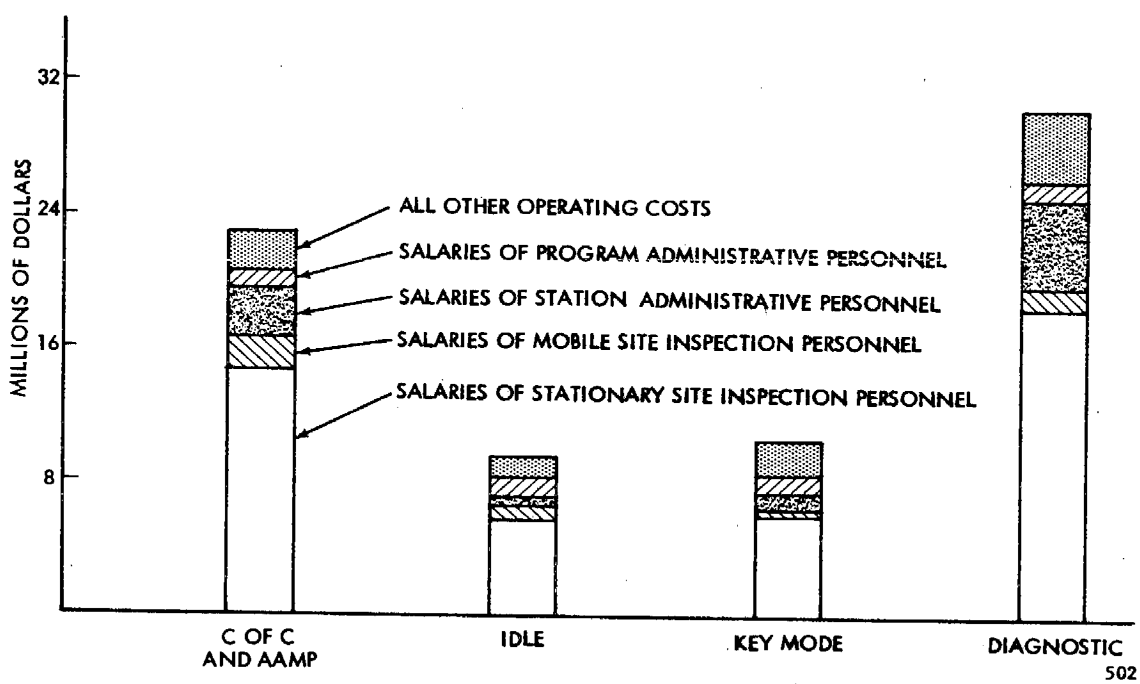


Figure 4-2. COMPARISON OF 1972 OPERATING COSTS FOR FIVE TEST REGIMES

Table 4-2. ANNUAL OPERATING COSTS BY TEST TYPE (THOUSANDS OF DOLLARS)

Cost Element	C of C or AAMP	Idle	Key-Mode	Diagnostic
Salaries of Stationary Facility Personnel	14,737 (64)*	5,893 (62)	6,131 (59)	18,677 (61)
Salaries of Mobile Facility Personnel	1,749 (8)	742 (8)	517 (5)	1,505 (5)
Salaries of Station Administrative Personnel	2,782 (12)	631 (7)	981 (9)	5,209 (17)
Equipment Maintenance	768 (3)	406 (4)	515 (5)	212 (0.5)
Equipment Depreciation	768 (3)	406 (4)	515 (5)	212 (0.5)
Stationary Inspection Facility Maintenance	511 (2)	128 (1)	258 (2)	1,759 (6)
Inspection Facility Depreciation	511 (2)	128 (1)	258 (2)	1,759 (6)
Salaries of Program Administrative Personnel	1,099 (5)	1,055 (11)	1,103 (11)	1,167 (4)
All other Administrative Operating Costs	186 (1)	187 (2)	198 (2)	188 (1)
Total	23,110	9,576	10,476	30,688

*Percentage of Total

Idle and Key-Mode test regimes require smaller initial investments primarily because fewer lanes are required to accommodate the anticipated vehicle population. Diagnostic facilities require a significantly larger land area and facilities for each site due to its lower throughput rates and greater space allocation requirements to accommodate vehicle queing and diagnostic equipments.

Another significant investment cost element is inspection equipment acquisition which includes both stationary and mobile sites. This cost item contributes to the total investment cost from a low of 26 percent each for Certificate of Compliance, AAMP, and Diagnostic, to 29 percent for Key-Mode and 33 percent for Idle.

The equipment installation category applies only to the Idle, Key-Mode, and Diagnostic regimes, as only they involve nontrivial installation procedures. Of the three regimes, Key-Mode equipment installation represents the greatest portion of investment cost, at 3 percent. Idle and Diagnostic equipment installation costs represent less than 1 percent of the total investment cost of their respective regimes.

Training costs are nominal at 1 percent of investment cost each for Idle, Key-Mode, and Diagnostic Tests, and 2 percent for Certificate of Compliance.

The qualification and certification cost category consists of the salaries of field personnel, who would inspect and certify inspection stations, and program administrative costs during the preoperational period of qualification and certification that, in turn, consist of salaries of program administrative personnel and all other program administrative costs incurred during this period. These costs are nominal for all regimes, varying from a low of 1 percent for Diagnostic to a high of 5 percent for Idle. These varying percentages, but essentially equivalent absolute magnitudes, are merely indicative of the essentially invariant cost of administering a comprehensive program of mandatory periodic vehicle inspection.

By far the largest percentage of operating costs of any of these regimes is for inspection facility personnel. Ranging from a high of 72 percent for Certificate of Compliance and AAMP to a low of 64 percent for Key-Mode, with Idle and Diagnostic between at 70 percent and 66 percent, respectively, inspection facility inspection personnel salaries clearly dominate the operating cost category. Inspection station administrative personnel salaries vary from 12 percent of the total 1972 operating cost, in the case of Certificate of Compliance and AAMP, to a low of 7 percent for Idle. This variation is indicative of the significant difference in vehicle throughput per lane that exists between Certificate of Compliance (and AAMP) and Idle tests, the former requiring a much larger number of multilane facilities, and, consequently, a significantly larger number of station administrative personnel. Equipment maintenance and equipment depreciation (10 years, straight-line method) each represent a nominal portion of the total projected 1972 operating cost for each regime, varying from 1/2 of 1 percent for Diagnostic, to a high of 3 percent for Key-Mode.

Program administrative personnel salaries reflect again in operating costs (as they did in the qualification and certification category of investment costs) the comparable cost required to administer any of these five test regimes. Although their individual percentage representations within a given regime vary from 4 to 11 percent of operating cost for Diagnostic and Idle tests, respectively, their absolute magnitudes vary from $1,055,000 for Idle to $1,167,000 for Diagnostic.

To facilitate the analytical process, it was assumed that equipments would have a fixed life span of between 5 and 10 years, and a straight-line depreciation would be appropriate. The diagnostic consoles, dynamometers, and other heavy equipments were depreciated on a 10-year lifetime, and the gas analyzers and automated data processing equipments used a 5-year lifetime.

Table 4-3 shows the annual operating costs for each of the test regimes as a function of program calendar year. In all cases, operating costs, as denoted in Table 4-2, are escalated 5 percent annually to arrive at the costs shown for the program duration.

Table 4-4 presents approximate inspection fees that would be expected from each motorist. The fees were determined by dividing the 1972 operating costs by the total number of vehicles to be tested. It does not consider vehicle retest fees, if retesting is required as part of the program. This calculation procedure applies only to: (1) State-owned and State-operated facilities, and (2) privately owned and operated facilities regulated by the State. For State-licensed private facilities, the fee was based on estimated labor time and known labor rates (see Volume III, Section 6).

Table 4-3. OPERATING COSTS FOR FIVE TEST REGIMES (THOUSANDS OF DOLLARS)

Calendar Year	C of C or AAMP	Idle	Key-Mode	Diagnostic
1972	23,477	9,978	10,919	33,122
1973	24,651	10,477	11,465	34,778
1974	25,883	11,001	12,038	36,517
1975	27,178	11,551	12,640	38,343
1976	28,536	12,128	13,272	40,260
1977	34,353	17,858	19,950	58,030
1978	31,404	13,347	14,607	44,307
1979	32,974	14,014	15,337	46,522
1980	34,623	14,715	16,104	48,848
1981	36,354	15,406	16,909	51,291
1982	49,131	22,045	26,328	99,905
1983	38,201	16,262	17,948	56,436
1984	40,111	17,075	18,845	59,258
1985	42,117	17,929	19,788	62,221
1986	44,222	18,825	20,777	65,332
1987	53,568	26,830	27,322	80,572
1988	48,669	19,395	22,907	72,018
1989	51,102	20,365	24,052	75,619
1990	53,658	21,383	25,255	79,400

Table 4-4. APPROXIMATE INSPECTION FEES

Configuration	C of C or AAMP	Idle	Key-Mode	Diagnostic
State Owned and Operated	$2.31	$ .96	$1.05	$ 3.07
Privately Owned and Operated, State Regulated	2.94	1.22	1.33	3.90
State Licensed	9.00	6.00	6.00	12.00

4.2.4 Vehicle Owner's Cost Analysis

In addition to the periodic vehicle inspection fee, the owner of a vehicle that fails to satisfy the emission requirements will be faced with the service and repair costs to bring the emission levels to an acceptable value. Discussed below are the anticipated service and repair costs as a function of test regime and emission-controlled and uncontrolled vehicles.

Based on the service performed on all of the 1095 vehicles tested, cost averages were obtained for each of the test regimes. The cost was segregated into two categories: parts (not including sales taxes), and labor. Table 4-5 shows the average cost for all services vehicles, regardless of test regime. As expected, the uncontrolled vehicles as a class incurred more costs to achieve a specified emissions level as did the relatively newer controlled vehicles. It should be noted that the data reflects total service performed and includes reserviced vehicle data. The earlier analysis reported in Volume III, Section 6, illustrated that less cost to the typical motorist would be expected if service was not required beyond the initial service. Differences between average initial and average multiple (reservice reservice required) service did not affect the relative ranking of the alternative test regimes. Hence, all data in this analysis will report multiple servicing as a worst case, in the event the State may impose a reservicing requirement.

Table 4-5. AVERAGE SERVICE AND REPAIR COSTS

Vehicle Group	Average Costs
Controlled (246)*	$20.70
Uncontrolled (438)	28.70
All Vehicles (684)	25.90

*Represents vehicle quantity serviced

4.2.4.1 Certificate of Compliance Repair Costs - The cost of the Certificate of Compliance service to the car owner represents, for controlled cars, the prevailing rate of cost for this test throughout the State. This cost of inspection is, in most cases, indistinguishable from the adjustment performed. The cost for performing the Certificate of Compliance inspection is higher than normal for uncontrolled cars because of modifications imposed by the Air Resources Board for the current study, which required that uncontrolled cars be subjected to essentially the same test and adjustments as controlled cars.

By intent, there were no failure limits; all cars were sent to Official Motor Vehicle Pollution Controls Stations for certification. The costs incurred for this certification did not vary significantly from the controlled set to the uncontrolled set, as shown in Table 4-6.

Based on the vehicles serviced, the vehicle owner would expect to pay, on the average, $8.65 for the Certificate of Compliance on controlled vehicles and $8.40 for the modified Certificate of Compliance for uncontrolled vehicles, or a composite average of $8.53. Note that these costs include any required reservicing. Since the Certificate of Compliance does not impose an emission limit, very few vehicles were returned for additional servicing. In these isolated cases, the baseline tests indicated that an obvious problem existed.

Table 4-6. CERTIFICATE OF COMPLIANCE REPAIR COSTS

Vehicle Group	Average Costs
Controlled (78)*	$ 8.65
Uncontrolled (95)	8.40
All Vehicles (173)	8.53
*Represents vehicle quantity serviced	

4.2.4.2 Idle Test Repair Cost - The ground rules for repairs to cars in the Idle Test regime were to simply perform any repairs necessary to bring the CO and HC for the car being tested within prescribed limits. A set of adjustments was first performed in an attempt to lower the emission levels. When these adjustments were found to be insufficient, additional appropriate repairs were authorized. In actuality, the garages had essentially complete freedom to perform any repairs they deemed necessary. However, if repair costs would exceed $75 for a given vehicle, the repair men were required to contact study personnel for permission to proceed.

Decision to proceed with repairs expected to exceed $75 was based on the individual vehicle and the emission characteristics. Where the analysis indicated that additional service data was required to supplement existing data, then the repairs were authorized. However, if the specific vehicle characteristics (model year, mileage, or emission measurements) were similar to a previously serviced vehicle, then no new information was expected and the vehicle was rejected from the program.

Table 4-7 presents a summary of the average costs incurred by serviced vehicles. Recall that service costs are averaged overall repairs required (initial and re-service) to satisfy the emission limits.

Table 4-7. IDLE TEST REPAIR COSTS

Vehicle Group	Average Costs
Controlled (43)*	$36.00
Uncontrolled (92)	33.40
All Vehicles (135)	34.20
*Represents vehicle quantity serviced	

4.2.4.3 Key-Mode Test Repair Cost - Repairs performed on cars exceeding the Key-Mode emission test limits were to follow the procedures presented in the Clayton Manufacturing Company's Key-Mode Truth Chart Manual. All participating garages were briefed on how to interpret these truth charts and were given copies of the manual. Each car dispatched for service was accompanied by a Key-Mode "report card" stating the emission test results with rejected modes indicated.

Table 4-8 shows the average costs incurred by the serviced vehicles. As in the previous discussions, the average service cost reflects all required repairs (initial and reservice) to achieve emission values to meet established limits.

Table 4-8. KEY-MODE TEST REPAIR COSTS

Vehicle Group	Average Costs
Controlled (43)*	$26.70
Uncontrolled (111)	32.10
All Vehicles (154)	30.00
*Represents vehicle quantity serviced	

4.2.4.4 Diagnostic Test Repair Cost - Vehicles requiring service were diagnosed by technicians using the diagnostic consoles and a dynamometer. Based on the experience, training, and judgment of these diagnosticians, various service adjustments and parts replacements were recommended. The actual maintenance was performed by selected garages.

Table 4-9 presents the average costs incurred to obtain desired emission levels for the serviced vehicles. The average costs include the effects of initial and reservice expenditures for both controlled and uncontrolled vehicles.

Table 4-9. DIAGNOSTIC TEST REPAIR COSTS

Vehicle Group	Average Costs
Controlled (31)*	$27.20
Uncontrolled (66)	53.30
All Vehicles (94)	41.00
*Represents vehicle quantity serviced	

4.2.4.5 Annual Adjustment and Maintenance Procedure Repair Cost - The repairs performed on those vehicles processed by the AAMP test regime were determined by engine diagnosis using an oscilloscope and with the vehicle idling. All vehicles in this test regime were subjected to the prescribed adjustment and repair procedure in an attempt to achieve the minimum pollution capability of each individual vehicle.

Table 4-10 lists the average repair cost for all vehicles processed by the AAMP method. Since there were no rejection limits for emission, all vehicles received the necessary adjustments and any required repairs during the initial service.

Table 4-10. AAMP TEST REPAIR COSTS

Vehicle Group	Average Costs
Controlled (51)*	$17.10
Uncontrolled (74)	22.00
All Vehicles (125)	19.20
*Represents vehicle quantity serviced	

4.2.4.6 Comparison of Vehicle Owner Cost by Test Regime - Table 4-11 summarizes the average service costs for ease of comparison. For controlled vehicles, the cost ranges from a low of $8.65 for Certificate of Compliance to $36.00 for a vehicle serviced by the Idle Test regime. With respect to the uncontrolled vehicles, the cost ranges from a low of $8.40 for Certificate of Compliance to $53.30 for Diagnostic Test.

As a matter of record, these costs reflect both initial and any reservice costs for the Idle, Key-Mode, and Diagnostic Test regimes. For Certificate of Compliance and AAMP, there were no established emission limits; thus, all vehicles received essentially initial service only. The desirability of imposing reservice as a method of assuring emission cutoff limits was discussed in Volume III as not being cost effective in view of vehicle owner's cost and inconvenience weighed against the marginal additional improvement in emissions.

4.3 TEST REGIMES EFFECTIVENESS

The program effectiveness of the five test regimes is evaluated in the following paragraphs. An effectiveness index was developed in Volume III, Section 5, that considers the effects of exhaust emissions, vehicle population, model-year distribution, average vehicle miles driven, and anticipated inspection failure rates. Results of the initial vehicle testing and maintenance phase involving 523 vehicles also were discussed in Volume III. Discussed below are the results of the total test program involving 1095 vehicles.

Table 4-11. REPAIR COST SUMMARY

Test Regime	Vehicles		
	Controlled	Uncontrolled	All
C of C	\$ 8.65	\$ 8.40	\$ 8.53
Idle Test	36.00	33.40	34.20
Key-Mode Test	26.70	32.10	30.00
Diagnostic Test	27.20	53.30	41.00
AAMP	17.10	22.00	19.20

4.3.1 Effectiveness Index

Measures of effectiveness are used to evaluate how well a particular concept satisfies identified objectives. For this analysis, the effectiveness index for each test regime is related to the amount of vehicle emission reduction achieved. Equation (1) is the mathematical expression for the measure of effectiveness. The factors are discussed in subsequent paragraphs.

$$MOE = \sum_{i=1}^{20} \sum_{n=1}^{3} F \cdot P_i \cdot D \cdot M \cdot K_n \cdot W_n(Y) \cdot C \qquad (1)$$

where:

- MOE = measure of effectiveness, in tons of pollutants
- F = expected inspection failure rate, in percent
- P_i = vehicle population for ith year
- D = vehicle distribution by model year, in percent
- M = vehicle average miles driven per year
- K_n = proportional pollutant weighting to program objective
- $W_n(Y)$ = magnitude of pollutant change as a function of model year, grams per mile
- Y = model-year vehicle
- C = conversion factor, grams to tons
- n = index of pollutants, 1 = HC, 2 = CO, 3 = NO_x
- i = index of program calendar years.

4.3.1.1 Inspection Failure Rate (F) - To derive the operational data necessary to perform a cost and effectiveness analysis of the test regime, the Air Resources Board required that approximately half of the inspected vehicles be serviced.

Emission limits were selected to satisfy this requirement. The factor F was inserted in the MOE equation to reflect the inspection failure rate anticipated during program implementation. For this study, a fixed rejection rate of 50 percent was applied to each test regime.

4.3.1.2 Vehicle Population (P_i) and Distribution (D) Projections - The vehicle population estimated projection for future program years, as used in this analysis, is based on a projected increase of 3.6 percent annually. As reported in Volume III, previous attempts to obtain projections of motor vehicle registration from sources such as the California Division of Motor Vehicles, R. H. Donnelly, Inc., and the California Air Resources Board were unsuccessful. Using data from the annual statistical issue of Automotive Industries, which included U.S. motor registrations for the period 1900-1970, an average percentage rate increase was calculated. The statistical data period was limited to the years 1956 through 1970, which exhibited relative stability in passenger vehicle registrations. California registrations do not necessarily follow the national average; however, since the estimated projections are common to all test regimes, any lack in accuracy does not affect the relative rankings achieved.

Table 4-12 shows the California Vehicle Distribution by model year, as referenced and used in Volume III, for any given calendar year. For purposes of this analysis, it has been assumed that this proportional distribution would be constant and applicable throughout the duration of the program.

Table 4-12. VEHICLE DISTRIBUTION BY MODEL YEAR

Vehicle Age in Years	Percent of Total Vehicle Population
Under 1	7.8
1-2	9.5
2-3	8.8
3-4	9.6
4-5	9.8
5-6	9.1
6-7	8.2
7-8	6.7
8-9	6.6
9-10	5.3
10-11	3.3
11-12	3.6
12-13	3.0
13-14	3.0
14-15	1.5
15 and over	4.2

4.3.1.3 Vehicle Average Miles Driven (M) - The amount of emission pollutants precluded from entering the atmosphere would be dependent on the model-year vehicles and the associated vehicle utility or miles driven. Based on data provided by the Air Resources Board, Table 4-13 shows the average miles driven annually for each vehicle age category.

Table 4-13. AVERAGE MILES DRIVEN ANNUALLY

Vehicle Age in Years	Average Miles Driven Annually
Under 1	13,200
1-2	12,000
2-3	11,000
3-4	9,600
4-5	9,400
5-6	8,700
6-7	8,600
7-8	8,100
8-9	7,300
9-10	7,000
10-11	5,700
11-12	4,900
12-13	4,300
13-14	4,300
14-15	4,300
15 and over	4,300

4.3.1.4 Program Weighting of Emission Pollutants (K_n) - Overall program effectiveness should be related to total air pollution reduction. This could be determinted if a satisfactory reaction model existed that was acceptable to all interested parties and organizations. Then the total effects of reducing any, all, or portions of the pollutants could be determined.

The pollutants, and the atmospheric reaction products, have adverse effects to varying degrees on different objects. That is, under a given set of environmental and meteorological conditions, the primary pollutants and the resulting products affect the exposed animal and human life, vegetation, and manufactured products to various degrees and extents.

In Volume III, Section 5, the effects of HC, CO, and NO_x as emitted into the atmosphere were discussed. It was concluded that presently available data and reports do not provide sufficient confidence in any cause-effect relationship to justify weighting one pollutant over another. Consequently, during the initial submittal based on 523 vehicles inspected and serviced, weighting was derived using the California Emission Standards for 1966, 1971, and 1974. In addition, an equal weighting scheme was used. It was shown that regardless of the weighting scheme pursued, the relative ranking among the candidate test regimes remained constant. No further analysis of the effects of using different weighting is deemed necessary on the additional fleet data. Should this be required at a later date, the MOE may be easily determined since the computer program as used during the initial submittal is available.

4.3.1.5 Pollutant Change, $W_n(Y)$, as a Function of Model-Year - This factor is included to account for the differences in emission pollutant changes resulting from servicing the various model-year vehicles. Paragraph 4.3.4 contains a breakdown by model-year for each test regime considered. This is presented in tabular format to be compatible with tables previously presented.

4.3.2 Fleet Statistics Before and After Service

Table 4-14 shows the average vehicle emission profile before and after service. The data presented is for controlled vehicles as a function of test regime. Numbers in parentheses identify the quantity of vehicles processed through a specific test regime. The "before service" column reflects the statistical mean for all vehicles processed within the specific test regime.

Table 4-14. EMISSION CONTROLLED VEHICLES BEFORE AND AFTER SERVICE

Test Regime	HC (Grams/Mile)		CO (Grams/Mile)		NO_x (Grams/Mile)	
	Before	After	Before	After	Before	After
C of C (Mean) (78)	3.35	2.62	34.0	32.1	4.92	5.15
Standard Deviation	4.80	1.20	27.8	33.2	2.39	2.47
Idle Test (Mean) (128)	2.99	2.47	37.7	27.9	4.94	5.16
Standard Deviation	2.20	0.96	26.1	15.0	2.30	2.21
Key-Mode Test (Mean) (122)	3.45	2.49	35.0	24.3	4.86	5.05
Standard Deviation	4.81	0.96	27.0	14.8	2.39	2.22
Diagnostic Test (Mean) (89)	3.10	2.59	34.7	26.7	4.88	5.10
Standard Deviation	3.20	0.99	22.7	14.6	2.03	2.03
AAMP (Mean) (51)	3.77	2.88	39.2	34.3	4.62	4.68
Standard Deviation	4.44	1.35	22.7	22.6	1.95	2.08
Controlled Vehicles (468)	3.22	2.53	35.6	27.4	4.90	5.11

The "after service" column reflects the statistical mean of all vehicles; those initially passing, combined with those serviced. There exists a certain commonality among the test regimes. On a fleetwide basis, each test regime shows a decrease in

HC and CO, and an increase in NO_x. This similarity is reflected in the total controlled vehicles statistical mean for HC, CO, and NO_x.

4.3.2.1 Uncontrolled Vehicles Fleet Statistics - Table 4-15 shows the before and after service data for all uncontrolled vehicles. Numbers in parentheses indicate the quantity of vehicles processed within the specific test regime. As previously discussed, the "before" column is the statistical mean for all vehicles, whereas the "after" column combines the emission data of both passed and serviced vehicles to derive a fleet reading.

Table 4-15. UNCONTROLLED VEHICLES BEFORE AND AFTER SERVICE

Test Regime	HC (Grams/Mile)		CO (Grams/Mile)		NO_x (Grams/Mile)	
	Before	After	Before	After	Before	After
C of C (Mean) (95)	6.56	5.93	61.5	58.1	3.77	3.91
Standard Deviation	6.01	4.51	38.0	31.6	2.01	2.06
Idle Test (Mean) (172)	7.54	5.35	71.2	56.4	3.54	3.74
Standard Deviation	6.68	2.32	41.7	35.0	1.95	1.95
Key-Mode Test (Mean) (178)	7.49	5.24	77.8	49.4	3.34	4.12
Standard Deviation	6.62	2.86	43.4	25.7	1.94	1.96
Diagnostic Test (Mean) (108)	7.84	4.97	69.4	52.1	3.63	4.02
Standard Deviation	7.02	1.96	43.6	33.0	2.23	2.20
AAMP (Mean) (74)	8.93	5.94	78.8	63.1	3.46	3.41
Standard Deviation	8.81	2.81	44.0	32.3	1.86	1.91
Uncontrolled Vehicles (627)	7.41	5.34	71.3	53.6	3.53	3.94

The fleet statistics for the uncontrolled vehicles show that regardless of test regime, reductions in HC and CO are realized. However, in the case of NO_x only AAMP shows a slight decrease in statistical mean, whereas all other test regimes exhibit increases.

Table 4-16 lists the statistical means for the total fleet of controlled and uncontrolled vehicles for the three pollutants without relating to test regimes.

4.3.2.2 Emission Profile Changes - Table 4-17 shows the percent change between the fleet statistical means before and after service as a function of test regime and emission pollutant. For the controlled vehicles, the Key-Mode Test method achieved the greatest reduction in HC (27.8 percent) and CO (33.4 percent). In

Table 4-16. STATISTICAL MEANS FOR TOTAL FLEET BEFORE AND AFTER SERVICE

Vehicles	HC (Grams/Mile)		CO (Grams/Mile)		NO_x (Grams/Mile)	
	Before	After	Before	After	Before	After
Controlled (468)	3.22	2.53	35.6	27.4	4.90	5.11
Uncontrolled (627)	7.41	5.34	71.3	53.6	3.53	3.94
Total Fleet (1095)	5.61	4.13	56.0	42.3	4.12	4.45

Table 4-17. EMISSION PROFILE CHANGES FOR TOTAL FLEET

Test Regime	HC (Percent)	CO (Percent)	NO_x (Percent)
Controlled Vehicles (468)	-21.4	-23.0	+ 4.29
C of C (78)	-21.8	- 5.6	+ 4.68
Idle Test (128)	-17.0	-26.0	+ 4.45
Key-Mode Test (122)	-27.8	-33.4	+ 3.92
Diagnostic Test (89)	-16.4	-23.0	+ 4.53
AAMP (51)	-23.6	-12.5	+ 1.30
Uncontrolled Vehicles (627)	-28.0	-24.8	+11.6
C of C (95)	- 9.6	- 5.53	+ 3.72
Idle Test (172)	-29.0	-20.8	+ 5.65
Key-Mode Test (178)	-30.0	-36.6	+23.4
Diagnostic Test (108)	-36.6	-24.9	+10.7
AAMP (74)	-33.5	-19.9	- 1.45

terms of NO_x emission, none of the test regimes reduced the fleet statistical mean. It should be noted that Table 4-17 data are derived from previous fleet statistics. As such, the percent change is for the total vehicle population, and does not indicate the relative change for a typical serviced vehicle. The relative percent change for a typical serviced vehicle is discussed in paragraph 4.3.3.

For the uncontrolled vehicles, the Diagnostic Test method achieved the greatest reduction in HC (36.6 percent) whereas the Key Mode experienced the greatest reduction in CO (36.6 percent). The NO_x readings show that all test regimes except AAMP realized an increase with Key-Mode showing the largest (23.4 percent). AAMP shows a slight decrease of 1.45 percent when considering the total fleet comprised of passed and serviced vehicles.

4.3.3 Serviced Vehicles Emission Reductions

Table 4-18 shows the statistical data for serviced controlled vehicles only. The data presented in the "before" column represents the statistical mean and standard deviation for all emission controlled vehicles identified as exceeding the specified limits. Data in the "after" column presents the same type of information, except they reflect post-service emission measurements.

The numbers in parentheses signify the corresponding vehicle quantity processed by the test regime. For each test regime, the statistical means indicate the following: HC and CO are decreased while NO_x is increased as a result of vehicle service and repair.

Table 4-18. EMISSION PROFILE OF SERVICED CONTROLLED VEHICLES

Test Regime	HC (Grams/Mile)		CO (Grams/Mile)		NO_x (Grams/Mile)	
	Before	After	Before	After	Before	After
C of C (Mean) (78)	3.35	2.62	34.0	32.1	4.92	5.15
Standard Deviation	4.80	1.20	27.8	33.2	2.39	2.47
Idle Test (Mean) (43)	4.38	2.83	60.1	31.1	4.40	5.04
Standard Deviation	3.21	1.10	30.8	18.4	2.48	2.32
Key-Mode Test (Mean) (43)	5.50	2.76	54.8	24.4	4.06	4.62
Standard Deviation	7.66	1.10	32.5	14.6	2.42	2.07
Diagnostic Test (Mean) (31)	4.09	2.60	50.4	27.6	3.99	4.62
Standard Deviation	5.16	0.95	26.4	14.2	1.82	2.05
AAMP (Mean) (51)	3.77	2.88	39.2	34.3	4.62	4.68
Standard Deviation	4.44	1.35	22.7	22.6	1.95	2.08
Serviced Controlled Vehicles (246)	4.17	2.70	47.0	29.4	4.47	4.93

4.3.3.1 <u>Serviced Uncontrolled Vehicles</u> - Table 4-19 shows the statistical data for the serviced uncontrolled vehicles. Data in the "before" and "after" columns correspond to the statistical mean of all emission measurements of those uncontrolled vehicles prior to and after service and repair activities.

Table 4-19. EMISSION PROFILE OF SERVICED UNCONTROLLED VEHICLES

Test Regime	HC (Grams/Mile)		CO (Grams/Mile)		NO_x (Grams/Mile)	
	Before	After	Before	After	Before	After
C of C (Mean) (95)	6.56	5.93	61.5	58.1	3.77	3.91
Standard Deviation	6.01	4.51	38.0	31.6	2.01	2.06
Idle Test (Mean) (92)	9.66	5.56	85.1	57.4	3.06	3.43
Standard Deviation	8.38	2.45	41.4	34.2	1.89	1.96
Key-Mode Test (Mean) (111)	9.22	5.61	94.1	48.7	2.72	3.97
Standard Deviation	7.82	3.38	44.6	27.0	1.60	1.92
Diagnostic Test (Mean) (66)	9.90	5.20	85.0	56.6	3.01	3.64
Standard Deviation	8.17	1.76	44.9	35.5	1.86	1.97
AAMP (Mean) (74)	8.93	5.94	78.8	63.1	3.46	3.41
Standard Deviation	8.81	2.81	44.0	32.3	1.86	1.91
Serviced Uncontrolled Vehicles (438)	8.76	5.61	81.7	55.8	3.13	3.76

Table 4-20 lists the statistical means for the controlled and uncontrolled vehicles along with those for the total fleet of serviced vehicles.

4.3.3.2 <u>Emission Profile Changes for Serviced Vehicles</u> - Table 4-21 shows the percent change in emission characteristics for serviced controlled and uncontrolled vehicles. The data indicate that the typical controlled vehicle would realize the greatest reduction in HC (49.7 percent) and CO (55.5 percent) by being inspected and serviced using Key-Mode Test procedures. All test regimes increased NO_x readings of serviced vehicles.

Table 4-20. STATISTICAL MEANS FOR ALL SERVICE VEHICLES

Serviced Vehicles	HC (Grams/Mile)		CO (Grams/Mile)		NO_x (Grams/Mile)	
	Before	After	Before	After	Before	After
Controlled (246)	4.17	2.70	47.0	29.4	4.47	4.93
Uncontrolled (438)	8.76	5.61	81.7	55.8	3.13	3.76
All (684)	7.16	4.59	69.6	46.0	3.60	4.16

Table 4-21. EMISSION PROFILE CHANGES FOR SERVICED VEHICLES

Test Regimes	HC (Percent)	CO (Percent)	NO_x (Percent)
Controlled Vehicles (246)	-35.2	-37.5	+10.3
C of C (78)	-21.8	- 5.6	+ 4.68
Idle Test (43)	-35.4	-48.2	+14.5
Key-Mode Test (43)	-49.7	-55.5	+13.8
Diagnostic Test (31)	-36.5	-45.3	+18.3
AAMP (51)	-23.6	-12.5	+ 1.3
Uncontrolled Vehicles (438)	-35.9	-31.7	+20.1
C of C (95)	- 9.6	- 5.53	+ 3.72
Idle Test (92)	-42.5	-32.5	+12.1
Key-Mode Test (111)	-39.1	-48.2	+46.0
Diagnostic Test (66)	-47.4	-33.4	+21.0
AAMP (74)	-33.5	-19.9	- 1.44

For the uncontrolled vehicles, the largest reduction in HC (47.4 percent) was achieved using the Diagnostic Test procedure, whereas the Key-Mode Test showed the largest reduction in CO (48.2 percent).

4.3.4 Emission Reduction by Model Year

Table 4-22 reflects the emission reductions achieved as a function of test regime and vehicle model year. The data is in grams-per-mile mass measurement and applies only to those model-year vehicles tested and serviced as part of the Air Resources Board study.

Revised 12/10/71

Table 4-22. EMISSION REDUCTION AS A FUNCTION OF MODEL YEAR

Model Year	C of C			Idle Test			Key-Mode Test			Diagnostic Test			AAMP		
	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
1957 and Older	1.14	5.28	0.28	13.62	23.8	-0.19	8.50	23.2	-0.71	6.70	19.5	-0.40	1.16	8.93	0.95
1958	-0.93	9.70	-1.16	8.34	15.3	-1.43	8.50	23.2	-0.71	6.70	19.5	-0.40	1.16	8.93	0.95
1959	-0.93	9.70	-1.16	8.34	15.3	-1.43	5.54	68.8	-1.95	9.30	25.1	-0.65	1.16	8.93	0.95
1960	-0.81	1.21	-1.40	3.20	- 8.43	0.68	4.94	47.0	-1.23	3.19	22.7	-1.35	1.16	8.93	0.95
1961	-1.35	-9.75	-0.29	0.58	19.7	-0.51	2.50	43.2	-1.41	10.7	8.18	-0.67	3.46	- 1.37	0.14
1962	0.85	1.08	-0.28	3.53	27.8	0.07	2.48	42.3	-1.15	7.64	16.4	0.07	3.8	57.8	-1.87
1963	2.38	14.5	-0.17	3.37	38.8	-0.54	3.15	43.5	-1.17	4.60	38.6	-0.85	1.95	12.5	0.00
1964	0.51	1.16	0.18	4.64	32.1	-0.30	3.23	45.1	-1.08	2.63	43.7	-1.17	1.87	7.0	0.59
1965	1.24	5.56	-0.25	2.39	38.0	-0.75	1.53	53.3	-2.02	2.95	35.0	-0.44	2.52	22.8	0.21
1966	0.14	-3.41	0.31	2.87	29.4	-1.38	5.65	32.8	-0.67	3.68	18.0	-0.30	0.54	0.49	0.35
1967	0.53	3.78	-0.64	1.62	32.1	-1.17	1.31	15.8	-0.26	0.22	21.9	-0.82	2.43	2.61	0.22
1968	0.06	7.09	0.03	1.18	28.45	0.04	0.99	48.7	-1.37	0.79	19.2	-0.27	0.39	7.34	0.10
1969	2.26	-1.21	-0.08	0.48	28.7	-0.35	0.56	26.7	-0.08	0.28	39.1	-1.65	0.85	15.8	0.07
1970	-0.08	2.31	-0.20	0.90	23.9	0.04	5.62	21.9	0.00	0.47	11.76	-0.13	-0.14	4.72	-0.56

Notes:
1. All reductions are in units of grams/mile
2. Minus value denotes increases

In the majority of cases, a sufficient number of vehicles representing a given model year were serviced. However, in several isolated cases, as few as one or two vehicles were available for testing, noticeably in the pre-1960 vintages. Where less than four were serviced for a given year within a test regime, two or more consecutive model years were combined. Examples are model years 1958-1959 for Certificate of Compliance and Idle Test, 1957-1958 for Key-Mode Test and Diagnostic Test, and 1957-1960 for AAMP.

The 1966 and 1967 model-year vehicles presented another case of data combinations, although of a different nature. For each test regime, there were sufficient vehicles for each model year. The problem was that there were both controlled and uncontrolled types within each model year. This was unique to 1966 and 1967 because of the California standards (1966) leading the Federal standards (1968) by two years. Consequently, vehicles sold initially outside of California during 1966-1967 and later registering here did not require emission control systems.

For these vintage vehicles, the statistical mean emission reductions were combined within a given year to develop the value representing that year. This then precluded the necessity to decide which of two emission reductions to use for a given year, what proportion of 1966 and 1967 vehicles are controlled and uncontrolled, and how the proportion changes during program duration. As a matter of interest, for the serviced 1967 vehicles, there were 39 controlled and 21 uncontrolled; and for the 1966 serviced vehicles, there were 45 controlled and 18 uncontrolled. These proportions may or may not be representative of the total California registration of 1966 and 1967 passenger vehicles.

The values from Table 4-22 are the ones used to calculate the measure of effectiveness (MOE) expressed in equation (1) of paragraph 4.3.1. Calculations and plots are discussed in paragraph 4.3.6.

4.3.4.1 Projection of Emission Reductions - To determine the effectiveness of implementing a statewide program for the next 20 years, some measure of emission reduction on 1971 through 1991 model-year vehicles must be predicted. This estimate can be made by extrapolating the ability of the various test regimes to detect and isolate engine malfunction and maladjustment. The following assumptions were involved during the calculation procedure.

a. The average future vehicle that fails the appropriate test will exceed its applicable year's standard by the same percentage as the average vehicle for the model years 1966-1970 exceeded their standard.

b. The emission control systems of the future will continue to require maintenance, adjustment, or replacement of components.

c. The effectiveness of existing test regimes as evidenced during this study will not change significantly during the program duration.

As emission control systems become more effective, each of the candidate test regimes may require slight modifications to reflect new engineering solutions. Since information relative to these future control systems is not available, the effectiveness of the test regimes in altering emissions of the failed vehicles is assumed to remain constant.

To derive the projected emission reductions for model years 1971 through 1991, the fleet of serviced vehicles for years 1966 through 1970 serve as a baseline. These vehicles are emission controlled as related to HC and CO. NO_x control was not required until model-year 1971 vehicles, which were not serviced during this study. Consequently, no attempt has been made to estimate what effects service and repair will have on NO_x readings for model years beyond 1970.

The simplified equation for calculating emission reduction on future vehicles is shown below:

$$ER = UE - SE$$

where:

ER = average vehicle emission reduction
UE = average emission of failed, unserviced vehicle
SE = average emission of post-service vehicle

Using the 1966-1970 controlled vehicles emission profile as a baseline, it is noted that UE, the average emission of failed vehicles, may be expressed as:

$$UE = \beta \cdot STD$$

where:

β = ratio of failed vehicle emission to the applicable standard (measured failed emission/emission standard)

STD = emission standard for a given model-year

Thus, for the controlled vehicles, 1966-1970 era, the value β is as shown in Table 4-23. A sample calculation (Idle Test - all failed controlled vehicles) is given below:

a. HC = 4.38 grams/mile (see Table 4-18)

1966-1969 HC standard = 3.35 grams/mile

$$\beta_{HC} = \frac{4.38}{3.35} = 1.31$$

Table 4-23. CALCULATED VALUES FOR β

Test Regime	β_{HC}	β_{CO}
C of C	1.00	0.99
Idle Test	1.31	1.76
Key-Mode Test	1.64	1.61
Diagnostic Test	1.22	1.48
AAMP	1.12	1.15

b. CO = 60.1 grams/mile (see Table 4-18)

1966-1969 CO standard = 34 grams/mile

$$\beta_{CO} = \frac{60.1}{34} = 1.76$$

Similarly, the serviced vehicle emissions may be calculated and projected using the 1966-1970 vehicle data. Expressing the serviced emissions, SE, in terms of the applicable standard, the following is achieved.

$$SE = \alpha \cdot STD$$

where:

α = ratio of serviced vehicle emission to the applicable standard (measured serviced emission/emission standard)

STD = emission standard for the model year

A sample calculation (Idle Test - all serviced controlled vehicles) is given below. The other values are shown in Table 4-24.

a. HC = 2.83 grams/mile (see Table 4-18)

1966-1969 HC standard = 3.35 grams/mile

$$\alpha_{HC} = \frac{2.83}{3.35} = 0.85$$

b. CO = 31.1 grams/mile (see Table 4-18)

1966-1969 CO standards = 34 grams/mile

$$\alpha_{CO} = \frac{31.1}{34} = 0.91$$

Using these new expressions for UE and SE, the following equation reflects the method of deriving the projected emission reductions based on future standards.

$$ER = \beta \cdot STD - \alpha \cdot STD$$

$$ER = (\beta - \alpha) \cdot STD$$

As an example, consider the 1975 proposed emission standards for HC = 0.5 grams/mile and CO = 12 grams/mile. Then, for the Idle Test regime,

$$\text{Emission reduction in HC} = (\beta_{HC} - \alpha_{HC})\ (0.5)$$

$$ER_{HC} = (1.31-0.85)\ (0.5)$$

$$= 0.23 \text{ grams/mile}$$

Emission reduction in CO $= (\beta_{CO} - \alpha_{CO})\ (12)$

$ER_{CO} = (1.76-0.91)\ (12)$

$= 10.2$ grams/mile

Table 4-24. CALCULATED VALUES FOR α

Test Regime	α_{HC}	α_{CO}
C of C	0.78	0.94
Idle Test	0.85	0.91
Key-Mode Test	0.82	0.72
Diagnostic Test	0.78	0.81
AAMP	0.86	1.01

Table 4-25 includes the calculated emission reductions projected for model-year 1971-1991 vehicles. Note that NO_x predictions are not included, as explained earlier. The 1971-1979 HC and CO values were calculated using the California standards. The 1980-1991 values used the 1980 Federal standards since there are no published post-1975 California standards.

4.3.5 Calculation of Effectiveness Indices

The effectiveness of each test regime in achieving emissions reduction may be viewed graphically by plotting the calculated measures of effectiveness. By inserting the experimentally derived emission data as a function of vehicle model years, the projected annual and total program effectiveness measures are obtained. For some test regimes, a 50 percent inspection rejection rate was used. Average mileage driven per vehicle was based on data provided by the Air Resources Board, as previously noted.

4.3.5.1 Total Program Effectiveness - Figure 4-3 shows the total effectiveness of the five test regimes as measured by emission reduction. The data plot indicates the expected total emission reduction in gross tonnage per year that is precluded from entering the atmosphere. Each of the three pollutants is equally weighted.

A detailed discussion on the significance of weighting factors to be assigned to the pollutants of concern is included in Volume III, Section 5. Four sets of weighting factors were evaluated, three of which used the California emissions standards as a guide, while the fourth used an arbitrary assignment of equal weighting to each pollutant. The initial analysis, submitted in Volume III, June 1971, showed that the relative ranking among the alternatives did not change as a function of weighting factors assigned.

As shown in the figure, the Key-Mode Test regime is the most effective in achieving emission reduction. Following in order of highest effectiveness are Idle Test, Diagnostic Test, AAMP, and Certificate of Compliance.

Revised 12/10/71

Table 4-25. PROJECTED EMISSION REDUCTION AS A FUNCTION OF MODEL YEAR

Model Year	C of C		Idle Test		Key-Mode Test		Diagnostic Test		AAMP	
	HC	CO	HC	CO	HC	CO	HC	CO	HC	CO
1971	0.48	1.15	1.01	19.6	1.8	20.5	0.97	15.4	0.57	3.22
1972	0.33	1.15	0.69	19.6	1.23	20.5	0.66	15.4	0.39	3.22
1973	0.33	1.15	0.69	19.6	1.23	20.5	0.66	15.4	0.39	3.22
1974	0.33	1.15	0.69	19.6	1.23	20.5	0.66	15.4	0.39	3.22
1975	0.11	0.60	0.23	10.2	0.41	10.7	0.22	8.0	0.13	1.68
1976	0.11	0.60	0.23	10.2	0.41	10.7	0.22	8.0	0.13	1.68
1977	0.11	0.60	0.23	10.2	0.41	10.7	0.22	8.0	0.13	1.68
1978	0.11	0.60	0.23	10.2	0.41	10.7	0.22	8.0	0.13	1.68
1979	0.11	0.60	0.23	10.2	0.41	10.7	0.22	8.0	0.13	1.68
1980	0.06	0.30	0.11	5.1	0.20	5.3	0.11	4.0	0.07	0.84
1981	0.06	0.30	0.11	5.1	0.20	5.3	0.11	4.0	0.07	0.84
1982	0.06	0.30	0.11	5.1	0.20	5.3	0.11	4.0	0.07	0.84
1983	0.06	0.30	0.11	5.1	0.20	5.3	0.11	4.0	0.07	0.84
1984	0.06	0.30	0.11	5.1	0.20	5.3	0.11	4.0	0.07	0.84
1985	0.06	0.30	0.11	5.1	0.20	5.3	0.11	4.0	0.07	0.84
1986	0.06	0.30	0.11	5.1	0.20	5.3	0.11	4.0	0.07	0.84
1987	0.06	0.30	0.11	5.1	0.20	5.3	0.11	4.0	0.07	0.84
1988	0.06	0.30	0.11	5.1	0.20	5.3	0.11	4.0	0.07	0.84
1989	0.06	0.30	0.11	5.1	0.20	5.3	0.11	4.0	0.07	0.84
1990	0.06	0.30	0.11	5.1	0.20	5.3	0.11	4.0	0.07	0.84
1991	0.06	0.30	0.11	5.1	0.20	5.3	0.11	4.0	0.07	0.84

NOTE: All reductions are in units of grams/mile

4.3.5.2 Program Effectiveness - Hydrocarbons - Figure 4-4 shows program effectiveness as a function of vehicle HC precluded from entering the atmosphere. The plot indicates that the Key-Mode Test regime is superior to the other test regimes. AAMP is next, with Idle Test and Diagnostic Test essentially equal and all rank below Key-Mode Test. Following AAMP, Idle Test, and Diagnostic Test is Certificate of Compliance.

4.3.5.3 Program Effectiveness - Carbon Monoxide - Figure 4-5 shows program effectiveness as a function of CO emissions precluded from entering the atmosphere as a function of test regime. Key-Mode Test is the most effective, followed in order by Idle Test, Diagnostic Test, AAMP, and Certificate of Compliance.

4.3.5.4 Program Effectiveness - Oxides of Nitrogen - Figure 4-6 shows the program effectiveness as a function of vehicle NO_x precluded from entering the atmosphere as a function of test regime. None of the test regimes exhibit any significant effect in achieving emission reduction. Note that the y-axis (tons reduction) indicates negative values denoting emission increase. AAMP does realize a slight reduction during the first couple of years, whereas all others show increases in emission. After 1987, all test regimes show no effects. This is due to the absence of NO_x emission projection on post-1970 model-year vehicles, as described earlier. After 1987, practically all model years of 1970 and older will have been removed from service, leaving only post-1970 vehicles on the road. Since no projections can be reasonably made with a high degree of confidence on the future effects on NO_x emission control system operation and maintenance, it was assumed that the post-1970 vehicles NO_x will neither deteriorate nor improve following delivery to owner.

Revised 12/10/71

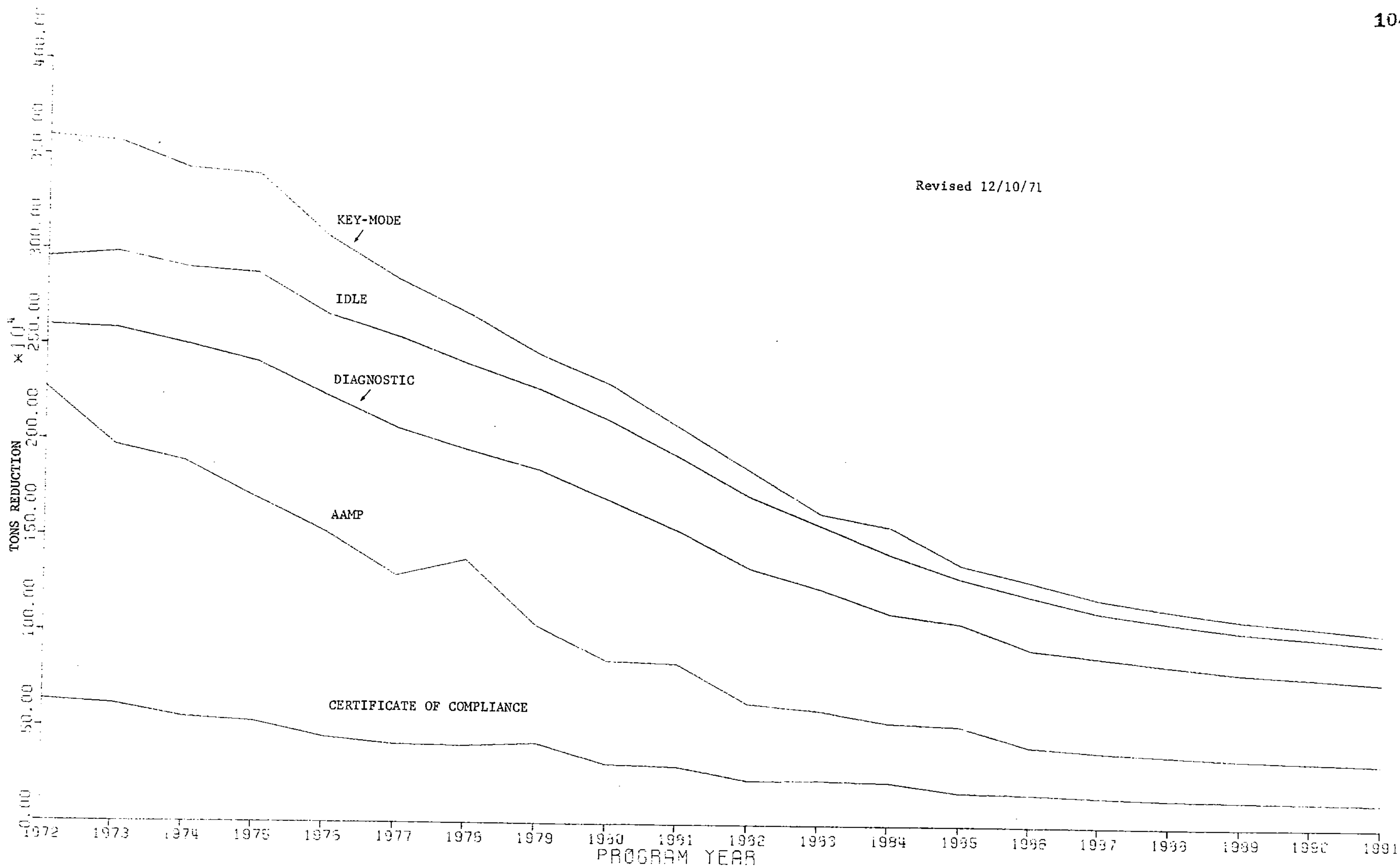


Figure 4-3. TOTAL PROGRAM EFFECTIVENESS - HYDROCARBONS, CARBON MONOXIDE, AND OXIDES OF NITROGEN

Revised 12/10/71

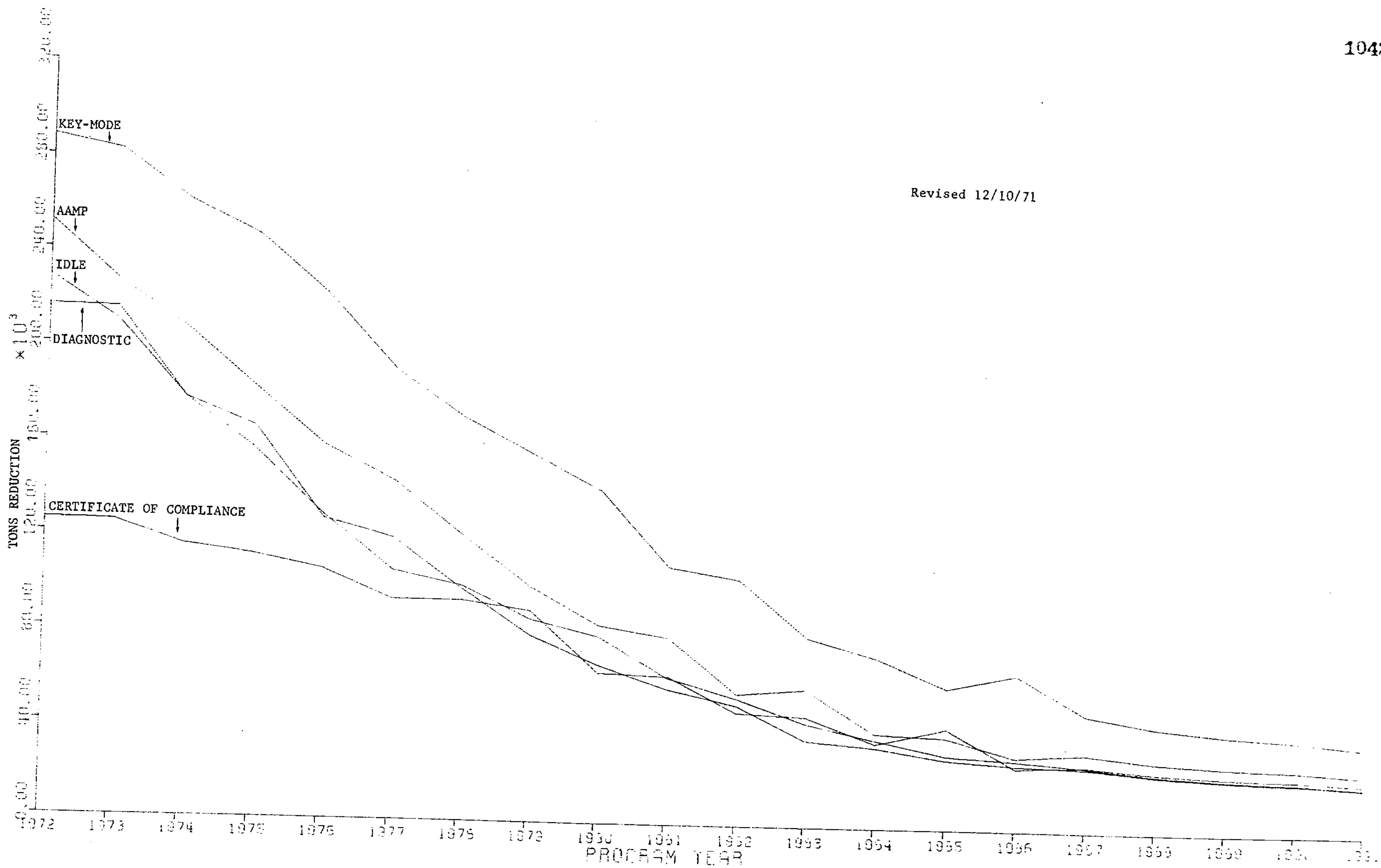


Figure 4-4. PROGRAM EFFECTIVENESS - HYDROCARBONS

Revised 12/10/71

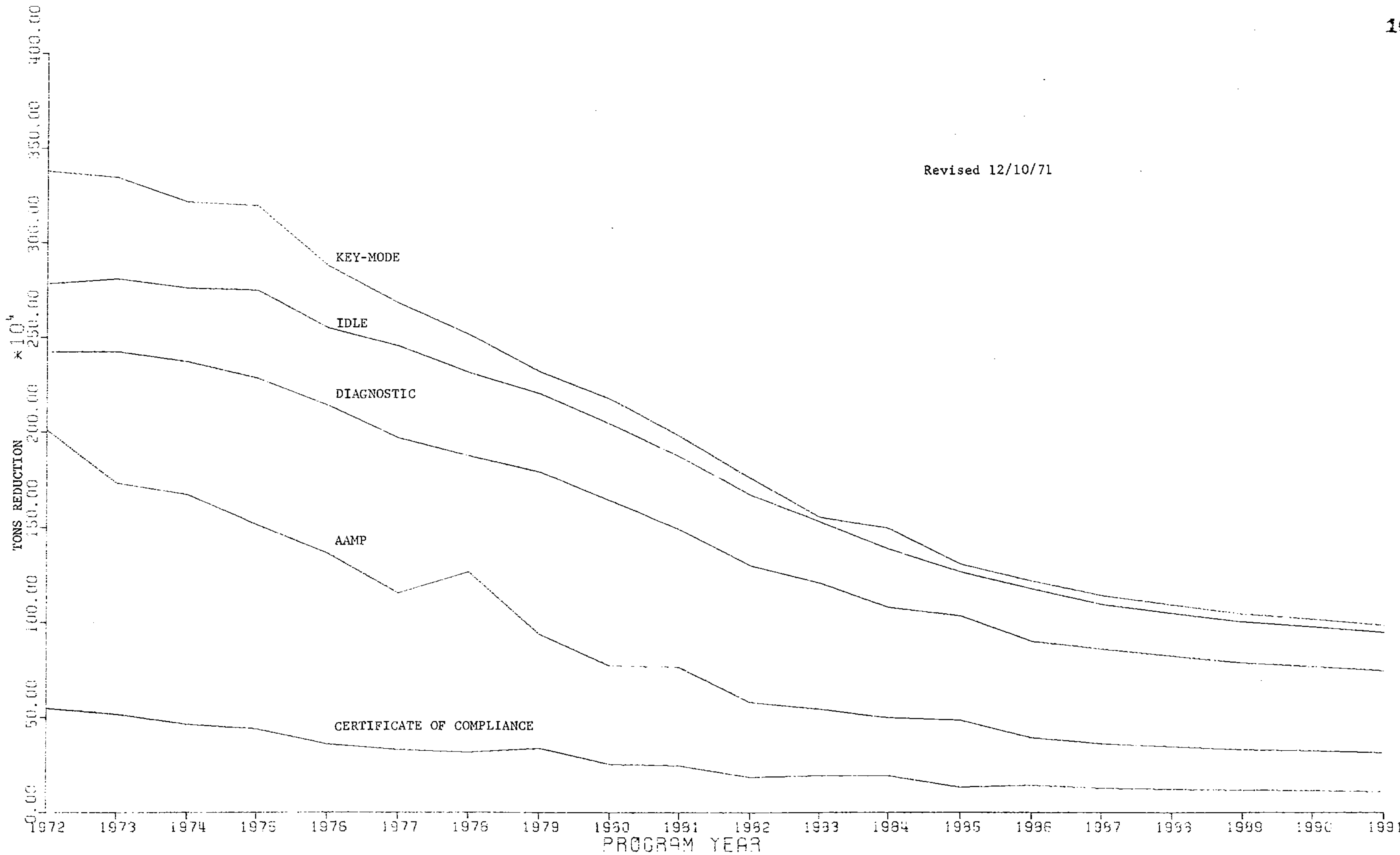


Figure 4-5. PROGRAM EFFECTIVENESS - CARBON MONOXIDE

Revised 12/10/71

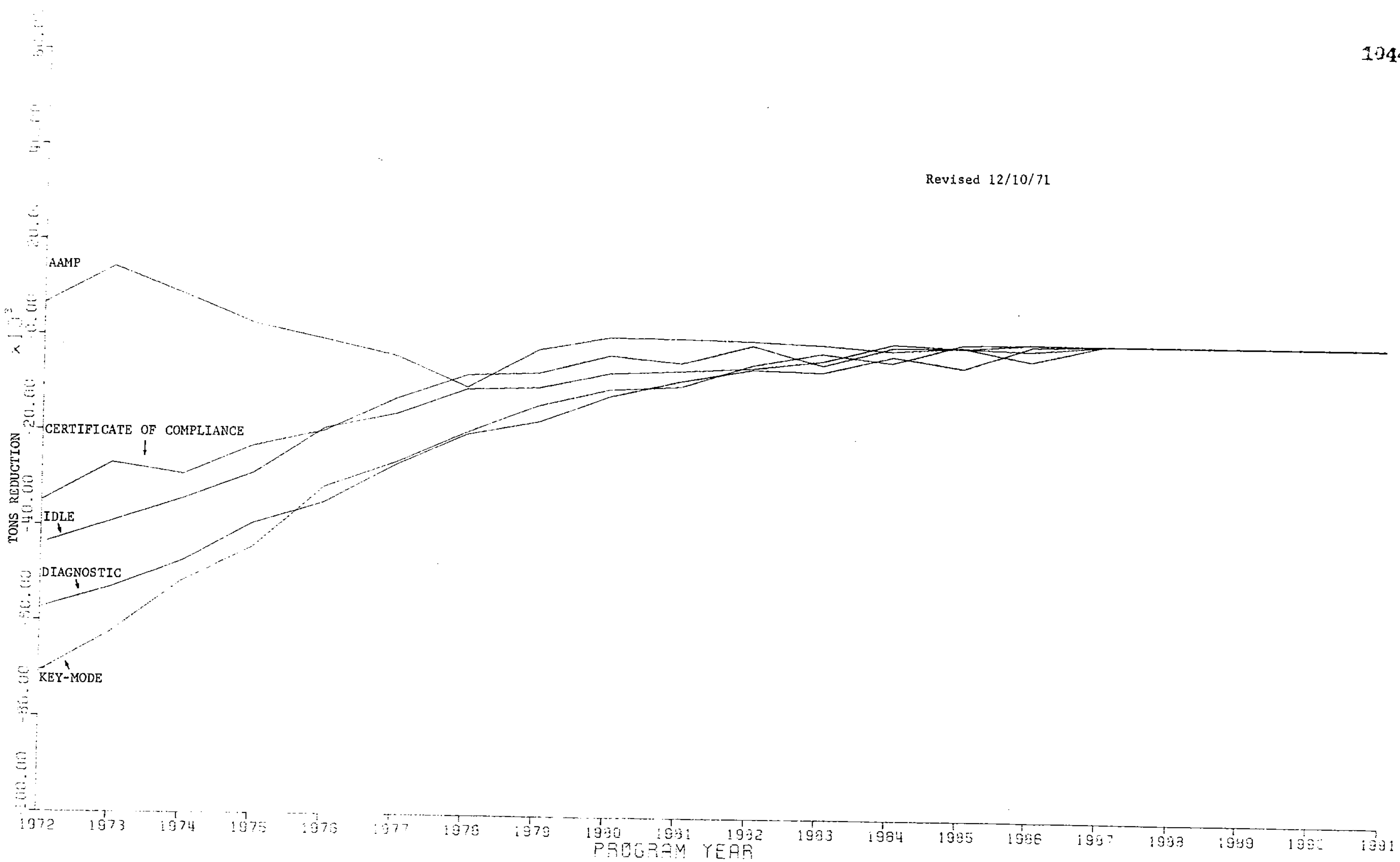


Figure 4-6. PROGRAM EFFECTIVENESS - OXIDES OF NITROGEN

4.3.6 Effectiveness of Periodic Vehicle Inspection

The previous discussions have shown the effectiveness of each test regime in reducing vehicle emissions. The figures displaying calculated effectiveness measures indicate the relative magnitude of the amount of pollutants precluded from entering the atmosphere. What remains is to compare the relative amounts of vehicle emissions with and without periodic vehicle inspection and maintenance for the program years of 1972 - 1991.

4.3.6.1 Vehicle Emission Profile - To determine the effects of a mandatory program, the initial task would be to define the expected emission profile of the vehicle population as it presently exists. Based on this profile, estimates can be made relative to future vehicles. This procedure is similar to that previously used in the calculation of emission reduction for vehicles manufactured during the post-1971 era.

Table 4-26 shows the typical emission profile for the model-year 1970 and older vehicles. The data was derived by calculating the statistical sample mean by model year irrespective of test regime. The average emission reflects the accumulated test measurements on the total fleet of 1095 vehicles using the baseline seven-mode hot-start emission test data recorded prior to any vehicle servicing. As such, the emission profiles should closely approximate the typical vehicles operating today.

Table 4-27 shows the estimated emission profile for the post-1970 model year vehicles. The data for HC and CO was calculated under the assumption that these future emission-controlled vehicles would be similar to present controlled vehicles. By using the 1966-1969 vehicle emission test data along with the 1966 California emission standards, a projection was made relative to the future vehicles. Discussed below are examples for deriving these future emission levels. As noted earlier, the technique is similar to that used to derive the emission reductions anticipated for the post-1970 vehicles.

For the 1966-1969 model-year vehicles, the sample mean HC measurements before service were 3.70 grams per mile, and the CO measurements were 41.7 grams per mile. The corresponding California standards were HC = 3.35 grams per mile and CO = 34 grams per mile (mass equivalent). Then

$$\beta_{HC} = \frac{3.70}{3.35} = 1.11$$

$$\alpha_{CO} = \frac{41.7}{34.0} = 1.26$$

The projected emissions for the 1975 model-year vehicle is then calculated to be as follows, using the 1975 standards of HC = 0.5 grams/mile and CO = 12 grams/mile:

$$\gamma_{HC} = \beta_{HC} \cdot \text{STD (1975)}$$

$$\gamma_{HC} = (1.11)\ (0.5) = 0.55 \text{ grams/mile}$$

$$\delta_{CO} = \alpha_{CO} \cdot \text{STD (1975)}$$

$$\delta_{CO} = (1.26)(12) = 15.1 \text{ grams/mile}$$

Table 4-26. VEHICLE EMISSIONS MEASURED AVERAGE

Vehicle Model Year	Qty Tested	Grams/Mile		
		HC	CO	NO_x
1957 and Older	30	13.75	89.57	3.27
1958	11	7.80	68.19	3.49
1959	30	10.16	75.53	4.67
1960	51	7.32	61.16	3.64
1961	53	7.89	60.53	3.13
1962	64	7.78	73.96	3.58
1963	109	7.52	72.47	3.53
1964	101	6.91	71.74	3.35
1965	122	6.76	80.92	3.48
1966	104	4.79	48.29	4.27
1967	101	4.11	45.79	4.43
1968	104	2.92	38.64	5.01
1969	115	3.04	34.63	5.29
1970	100	2.54	25.27	4.38

Table 4-27. VEHICLE EMISSIONS ESTIMATED AVERAGE

Vehicle Model Year	Grams/Mile		
	HC	CO	NO_x
1971	2.44	29.0	4.0
1972	2.44	29.0	3.0
1973	2.44	29.0	3.0
1974	2.44	29.0	1.3
1975	0.55	15.1	1.0
1976	0.55	15.1	0.9
1977	0.55	15.1	0.9
1978	0.55	15.1	0.9
1979	0.55	15.1	0.9
1980	0.27	7.6	0.5
1981	0.27	7.6	0.5
1982	0.27	7.6	0.5
1983	0.27	7.6	0.5
1984	0.27	7.6	0.5
1985	0.27	7.6	0.5
1986	0.27	7.6	0.5
1987	0.27	7.6	0.5
1988	0.27	7.6	0.5
1989	0.27	7.6	0.5
1990	0.27	7.6	0.5
1991	0.27	7.6	0.5

The experimental data of this study does not include empirical information for post-1970 vehicles. As such, no projections can be confidently made on the effects of NO_x controlled vehicles. Consequently, as was discussed earlier, it will be assumed for this analysis that NO_x readings will neither deteriorate nor improve for these post-1970 vehicles. In effect then, the NO_x measurements would correspond to the applicable standards. For 1971-1979, the California standards were used, and the Federal standards thereafter.

4.3.6.2 Effects on Hydrocarbon Emissions - Figure 4-7 shows the exhaust emission levels of hydrocarbons plotted as a function of program year. The upper curve is the estimated annual tons of HC emitted into the atmosphere based on empirical data projected into the period 1972-1991. The plots indicate that the greatest effectiveness is achieved during the early years. Degradation effects were not included due to the randomness of the test regimes data as discussed earlier.

For example, if Key-Mode is implemented during 1972, the levels of HC emitted would be equivalent to a program without PVI during 1977, or a gain of five years. However, if the same Key-Mode program is implemented beginning in 1974, a delay of 2 years, then the equivalent levels for a program without PVI would be late 1977, or a gain of about 3-1/2 years. It is obvious that as the program start is delayed the effectiveness of implementation is decreased.

In addition, the plots show that the effectiveness of each test regime differs both in the magnitude of the emission reduction and the advancement in program objective (lessening the period to achieve a specified HC level).

4.3.6.3 Effects on Carbon Monoxide - Figure 4-8 shows the exhaust emission levels of carbon monoxide entering the atmosphere as a function of each test regime. As before, the upper curve is that estimated to be the level experienced without a PVI program. The most effective program would be Key-Mode which, if implemented in 1972, would realize a program gain of 8 years relative to one without PVI. As noted earlier, both effectiveness in emission reduction and gains in program years are lessened as implemention date is delayed. Degradation effects were not included in the plots.

4.3.6.4 Effects on NO_x Emissions - Figure 4-9 shows the exhaust emission levels for oxides of nitrogen. The plots illustrate the fact that none of the test regimes are effective in achieving emission reductions. As expected the test regimes emission levels correspond to that without PVI, since a basic assumption during the effectiveness calculations discussed earlier was that post-1970 vehicles would not deteriorate or improve in NO_x emissions after delivery to owner. Degradation or improvement in NO_x was not included in the plots for pre-1970 vehicles.

4.3.6.5 Effects on Total Vehicle Emissions - Figure 4-10 shows the exhaust emission levels of HC, CO, and NO_x as a function of program year. The upper curve is for a program without PVI. The pollutants are equally weighted and no degradation effects were considered in the plot.

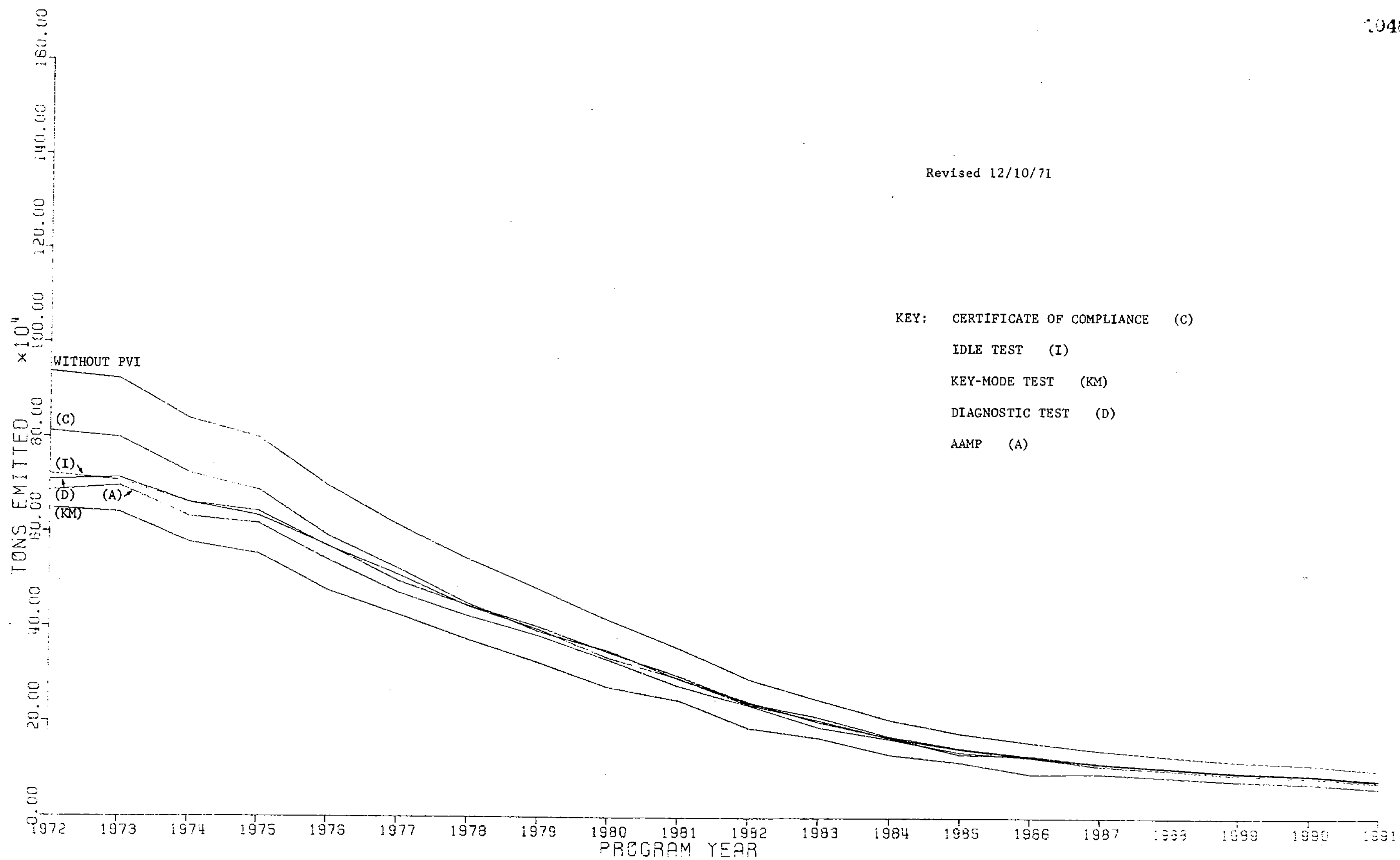


Figure 4-7. EXHAUST EMISSION LEVELS OF HYDROCARBONS

Revised 12/10/71

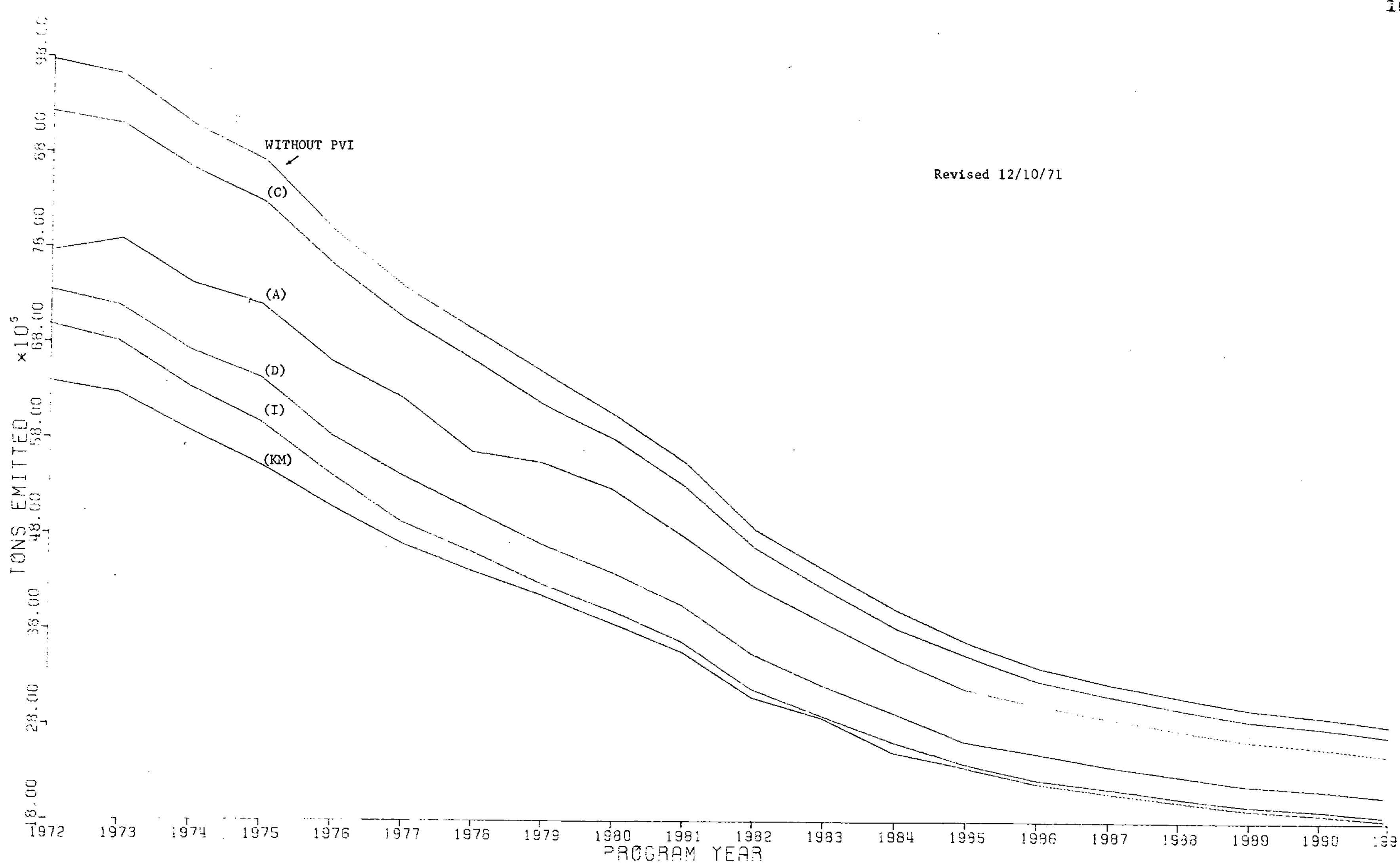


Figure 4-8. EXHAUST EMISSION LEVELS OF CARBON MONOXIDE

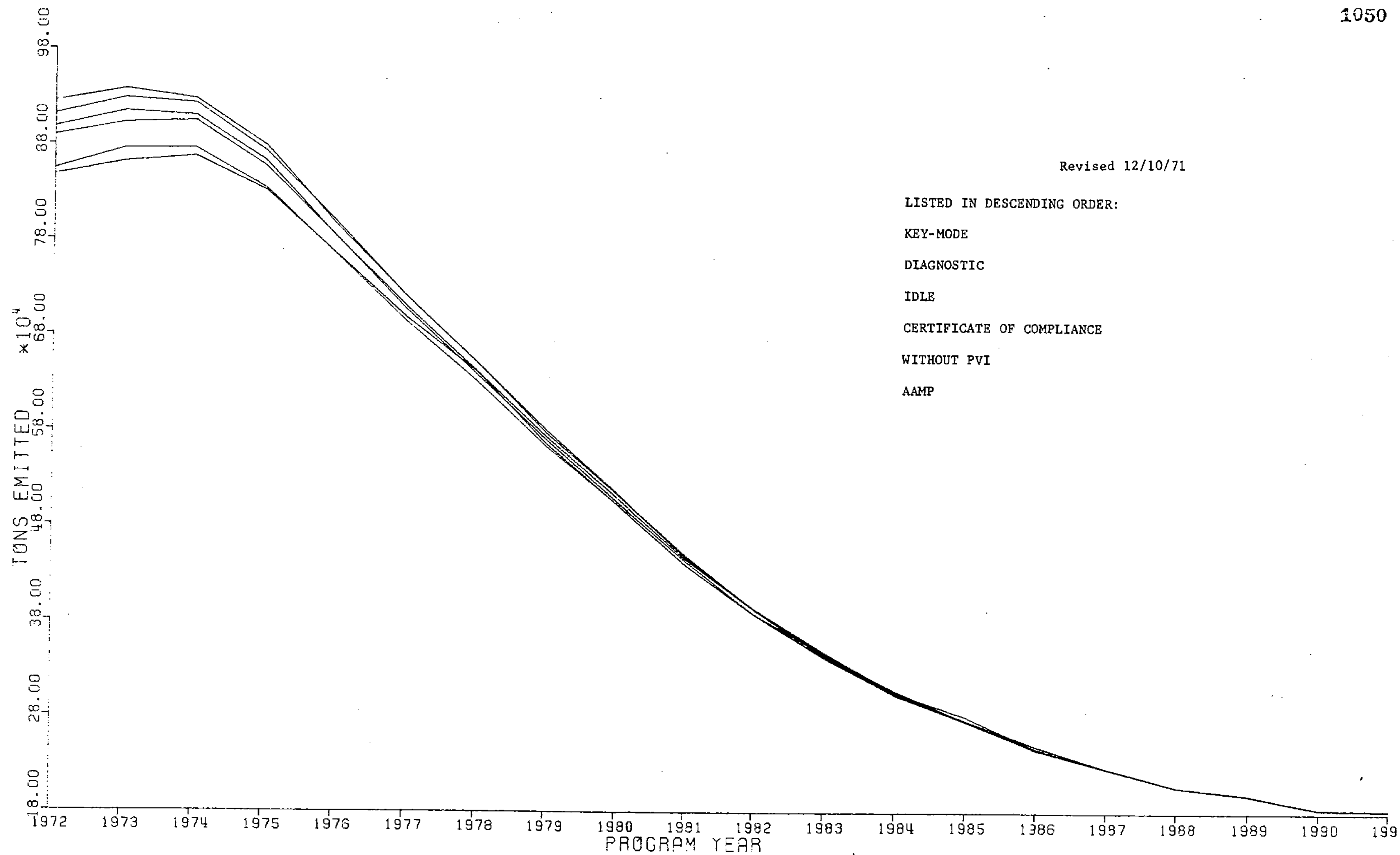


Figure 4-9. EXHAUST EMISSION LEVELS OF OXIDES OF NITROGEN

Revised 12/10/71

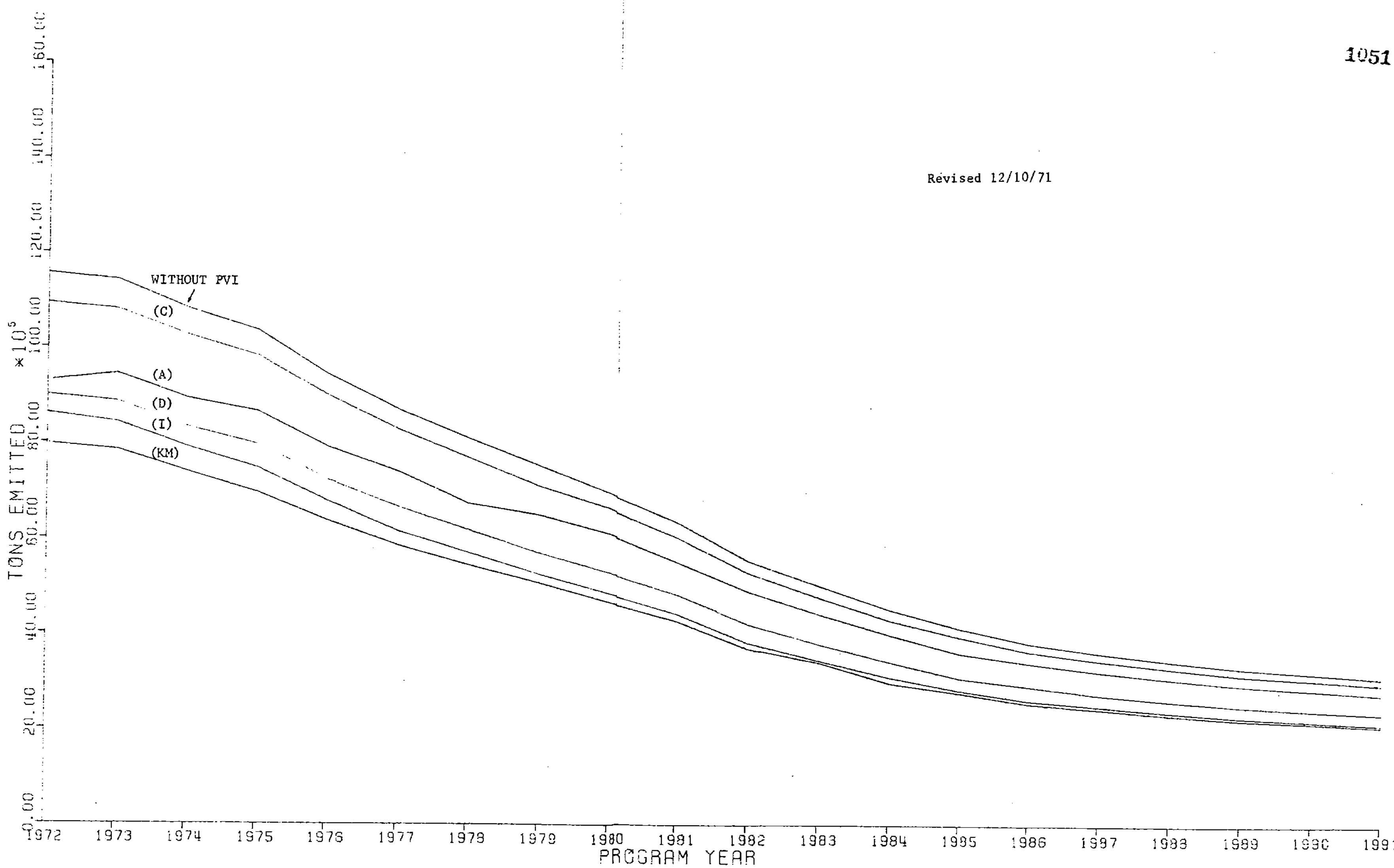


Figure 4-10. EXHAUST EMISSION LEVELS OF HC, CO, AND NO_x