4.8.1.1 The Need for a Simulation Model - Preceding paragraphs have dealt with the requirements for equipment, personnel operations, and support for the four test regimes. These requirements have led to alternative inspection station configurations. Each of the configurations results in a set of time-lines necessary to accomplish the functions to be performed within the inspection stations. These functions are:

a. Pretest inspection

b. Emission testing and pass-fail decision

c. Certification if the vehicle passes

d. Evaluation of test results and instruction to the car owner if failed

e. In addition, for the diagnostic test regime, a detailed diagnosis of the car's engine system to determine the cause of the failure.

Any time-lines developed for accomplishment of the inspection station test functions must be based on one very important premise - that there is a vehicle available to be tested.

The simulation model provides the mechanism for determining throughput of an inspection station by providing vehicles for test in a pattern intended to represent the "real world" arrival of vehicles. The model consists of a set of rules that are used to determine the movement of vehicles through the station, failure of vehicles to pass the emission test, failures of test equipment, and the impact of these happenings on the vehicles waiting to be tested or arriving for test.

Without a simulation model, there would be no assurance that a station designed to service a certain number of vehicles on the average could handle the peak loads that are bound to occur toward the end of a period required for a group of cars to be tested (i.e., a month). It is not economically realistic to design an inspection station to handle peak loads at all times when the real world situation will consist of valleys as well as peaks. These problems - too much demand on a service facility, with a resulting excessive waiting time for service, or too little demand in which case there is too much idle facility time - can be analyzed with the aid of the simulation model.

4.8.1.2 Scope of the Simulation - The simulation is an "if-then operator." If the functions to be performed for a test regime have an assumed mean service time and arrivals occur in a specified manner, then the throughput of the station can be expected to be a deterministic value. This simulation is not an optimization model in the strictest sense. Optimization may be approached through the simulation by making repeated trials to determine the best policy to maximize throughput. No attempt is made by the model to determine the effects of coffee breaks, illness, weather considerations, or differences in vehicle types (such as front wheel drives) or equipment (such as tire chains or studded snow tires) for the test regimes requiring a dynamometer. The test function time-lines take these efficiency reducing factors into account. The program is designed to simulate a fixed facility of one or more test lanes. The possibility of a requirement for mobile stations exists but is not covered here.

The simulation will be used primarily to determine a relative throughput measure of the ability of the various configurations of the four test regimes to service the total passenger vehicle population for the State. This will be accomplished by dividing the annual throughput for each test regime configuration into the number of cars contained in the vehicle population centers identified in paragraph 4.8.2. The simulation is iterative in the sense that configurations can be modified to a minor or major extent and the new configuration run to determine the effect of the changes.

As with any simulation, a number of uncertainties exist for which assumptions must be made. Table 4-10 enumerates the assumptions made for this model. Most of these assumptions are designated as input variables so that they may be changed when more exact information becomes available. This method of allowing for change also facilitates an analysis of the sensitivity of the model to these parameters.

Table 4-10. ASSUMPTIONS USED IN THE INSPECTION STATION SIMULATION MODEL

1. Vehicles arrive randomly with the number of arrivals per time interval described by the Poisson distribution.

2. Service times for the functions to be performed within the inspection station are distributed exponentially with mean service times given for each station configuration.

3. The queue discipline is first-come-first-serviced with a countably infinite waiting line for each test lane. (The maximum finite length of the waiting line will be obtained during the simulation runs.)

4. Arriving vehicles will balk (i.e., not join the waiting queue) if the expected waiting times exceed the times and probabilities given in 5. below.

5. Vehicles that have joined the waiting queue will renege (i.e., leave the queue before testing) with given probability, if waiting times exceed:

   15 minutes with probability of reneging (PREN (1))
   30 minutes with probability of reneging (PREN (2))
   45 minutes with probability of reneging (PREN (3))
   60 minutes with probability of reneging (PREN (4))
   60+ minutes with probability of reneging (PREN (5))

6. There are 250 operating days for the inspection station in a year.

The first two assumptions are well documented in the literature as the "best guess" when a specific arrival or service time distribution is unknown. The assumptions also have been shown to be very good in random arrival situations similar to the vehicle inspection station, such as retail sales store checkout counters, gasoline filling stations, and theatre box offices. The number of arrivals is modified somewhat by a forcing function in the program that requires vehicles that balk or renege return for ultimate testing within the month of first arrival. The probabilities used for balking and reneging were derived from the public opinion survey results. Failed cars must have repair accomplished and return for retest within

20 work days. (This is a program option since retest may not be necessary if effectiveness of first repair has a high confidence level.)

4.8.1.3 Model Description - The basic assumptions used in developing the model are given in the preceding paragraphs. The inputs to the model are listed in Table 4-11 and the outputs are listed in Table 4-12. The primary description of the model is contained in the annotated flow chart shown in Figure 4-21. A few important comments about the flow chart are given below.

Table 4-11. INPUTS TO THE INSPECTION STATION SIMULATION MODEL

Test type
Number of test lanes
Number of test personnel
Number of manned diagnostic stalls
Test station opening time
Time of lunch break or split shift closing
Duration of lunch break or split shift closing
Test station closing time
Mean time for pretest inspection
Mean time to perform emission test
Mean time to perform diagnosis (Diagnostic test only)
Mean time to certify a passed vehicle
Mean time to evaluate a failed vehicle
Mean time between failures for test equipment
Mean time to repair failed test equipment
Availability figure for test equipment
Probability of failing the pretest inspection
Probability of failing the emission test
Probability of failing the retest (when required)
Probability of reneging or balking as a function of time
State vehicle population by air basin and population centers within basins

The arrival distribution, while assumed to be Poisson, is programmed as a subprogram to the main program, and therefore can be changed easily should a more exact distribution be identified. The ability to easily vary the operating hours of the inspection station and periods of closing or reduced work force, such as split shifts or eating periods, will allow the flexibility to test the feasibility of operating only during expected peak periods. A reduced work force during eating periods may result in a decrease in capability and therefore increase service times.

Vehicles will be failed in the pretest inspection or in the emission test with failure probabilities that are input to the model. It is assumed that these failure probabilities will be over the set of all cars and not distinguish between controlled and uncontrolled vehicles or vehicle age. Implicit in this assumption is the setting of different pass-fail limits for subsets of the vehicle population to achieve a constant failure probability. Since the failure probability is an input variable, the effects of different failure rates on throughput can be assessed.

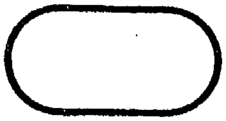
Table 4-12. OUTPUTS FROM THE INSPECTION STATION SIMULATION MODEL

- The values of the input variables
- The number of arrivals generated for a given day
- The times for the arrivals generated for a given day
- The mean arrival rate
- A table of all events occurring on a given day
- The results of the simulation on each arriving vehicle on a given day
- Summaries for a given day, each month, the year
  - Number of arrivals
  - Mean number of arrivals
  - Number of reneges
  - Number of balks
  - Number of vehicles tested
  - Number of vehicles passing initial testing
  - Number of vehicles failing initial test
  - Number of vehicles passing retest (when required)
  - Mean waiting time
  - Mean and maximum length of the waiting queue
  - Mean test time
  - Mean diagnosis time
  - Mean and maximum length of diagnostic queue
  - Mean certification time
  - Mean and maximum length of certification queue
  - Mean evaluation time
  - Mean and maximum length of evaluation queue
  - Number of vehicles returned and/or retested each day
  - Mean time per vehicle in the system
  - Number of test equipment failures
  - Mean time between test equipment failures
  - Total test equipment down time
  - Mean test equipment down time
- Distribution of activity periods
- Total and mean length of inspection station idle periods
- Number of inspection lanes required by air basin and vehicle population centers within the basins.

Test equipment failures and their effect on throughput is included in the model. The equipment availability, mean time between failures, and mean time to repair are input and used by the model to randomly fail and repair the test equipment. Some failures are expected to be repaired rapidly while others may require personnel and/or spares not available at the test station. The effect of these failures on those cars waiting to be tested is reflected in increased waiting times and the resulting higher probability of reneging. Cars already in the test lane are expected to remain unless the repair time exceeds the time for which the probability of reneging is equal to one. In this case, the possibility exists that no vehicles will be available for testing when the test equipment is again working. Periodic maintenance will be performed during slack and/or scheduled periods so as not to affect wait or test times.

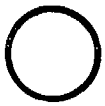
Vehicles passing the pretest inspection and the emission test will receive certification and be exited from the system. Those cars failing the pretest inspection

SYMBOLOGY USED:

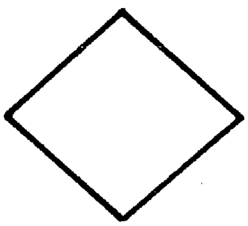


TERMINAL POINT

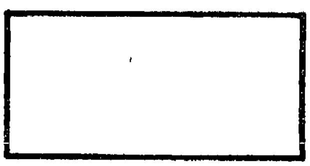
PUNCHED CARD INPUT



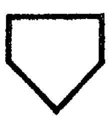
CONNECTOR OR NODE



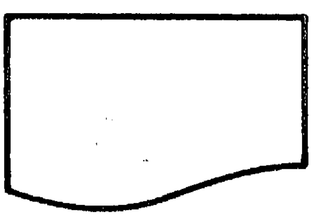
DECISION - ALTERNATE PATH OUTPUT



PROCESS -
* INDICATES A COMMENT



POINTER TO AN OFF-PAGE CONNECTOR



OUTPUT DOCUMENT

CONVENTION: FLOW IS ALWAYS DOWNWARD
UNLESS OTHERWISE INDICATED
BY AN ARROWHEAD

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Figure 4-21. INSPECTION STATION SIMULATION MODEL FLOW CHART (Sheet 1 of 8)

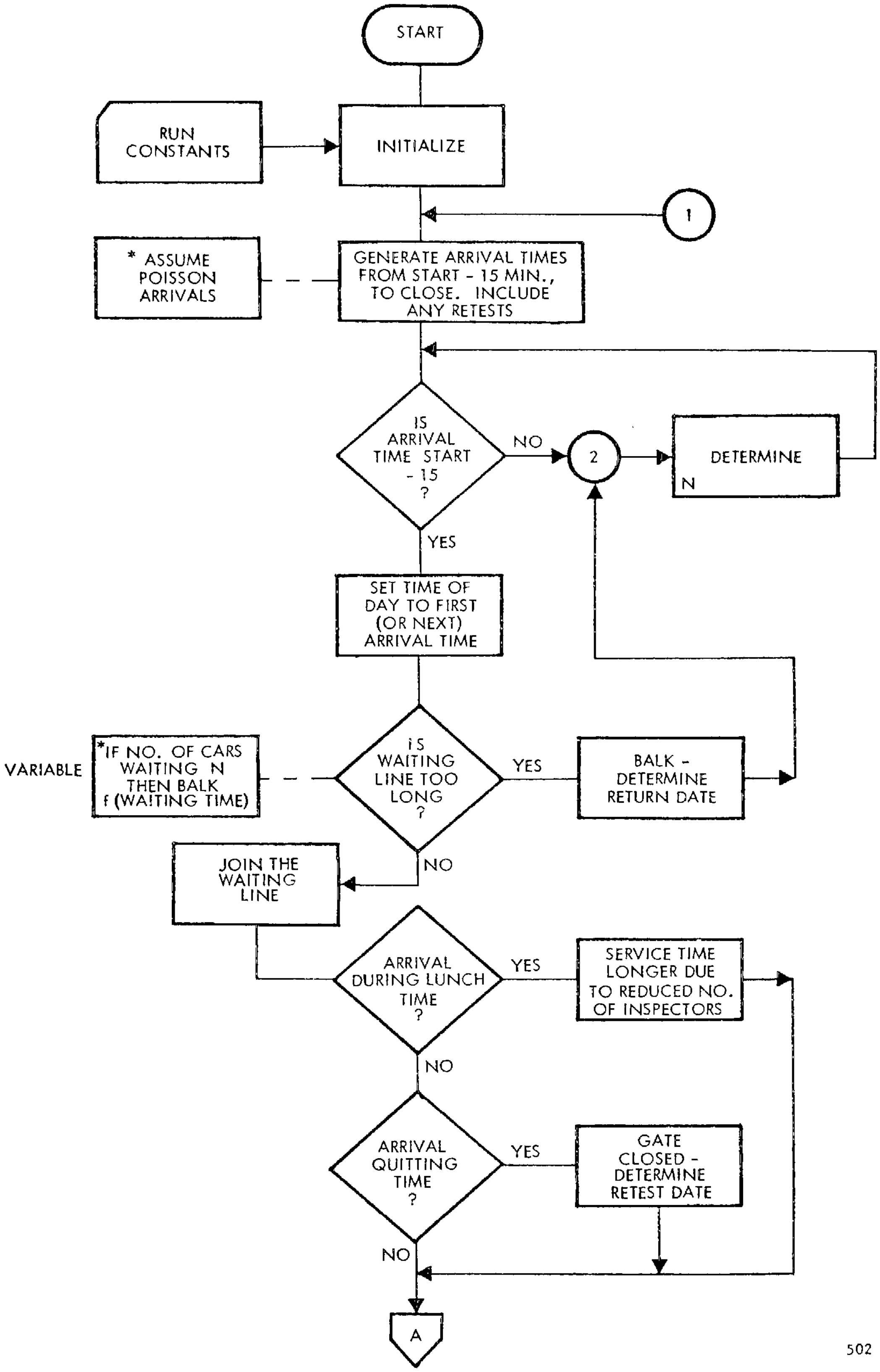

Figure 4-21. INSPECTION STATION SIMULATION MODEL FLOW CHART (Sheet 2 of 8)

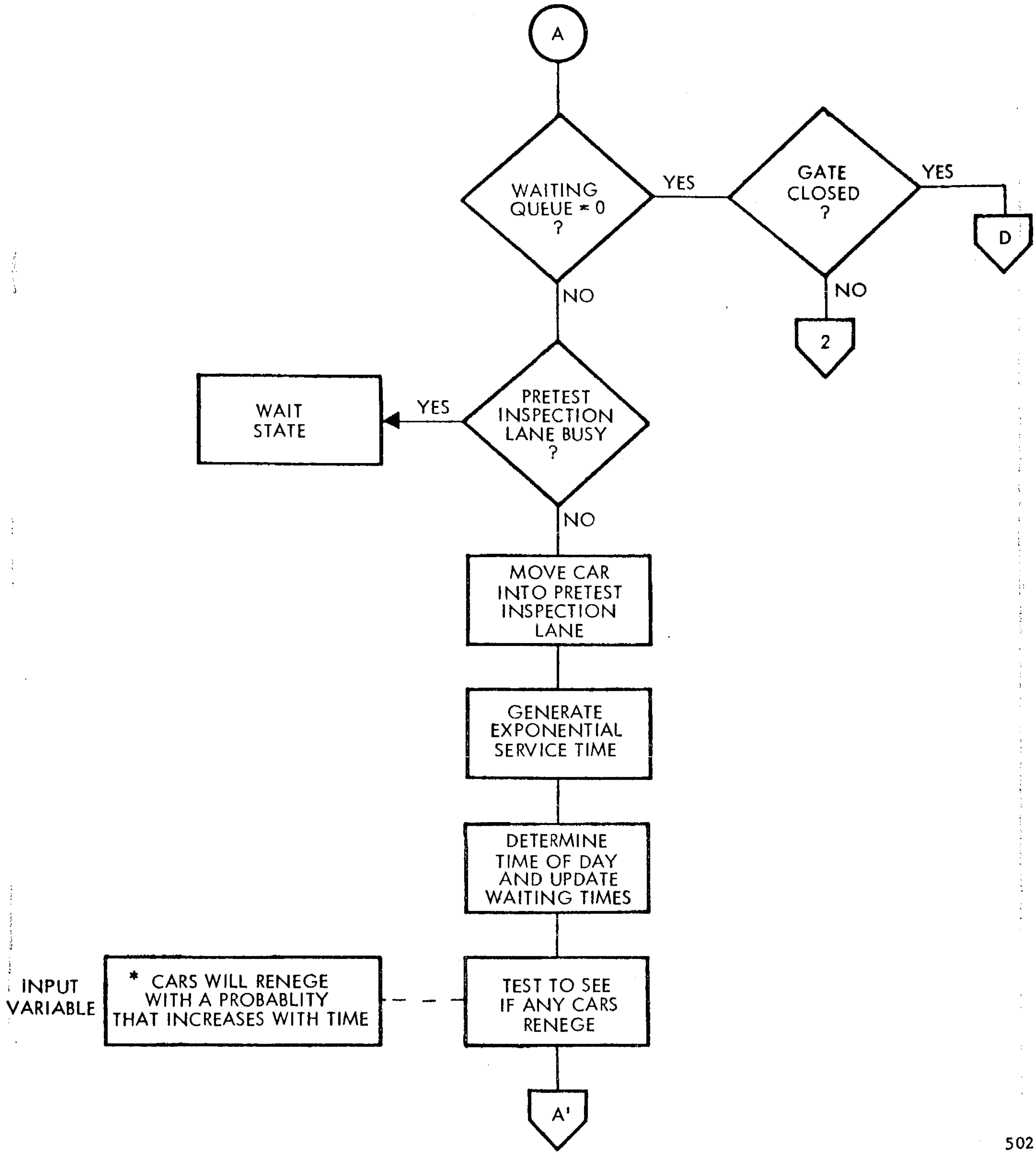

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Figure 4-21. INSPECTION STATION SIMULATION MODEL FLOW CHART (Sheet 3 of 8)

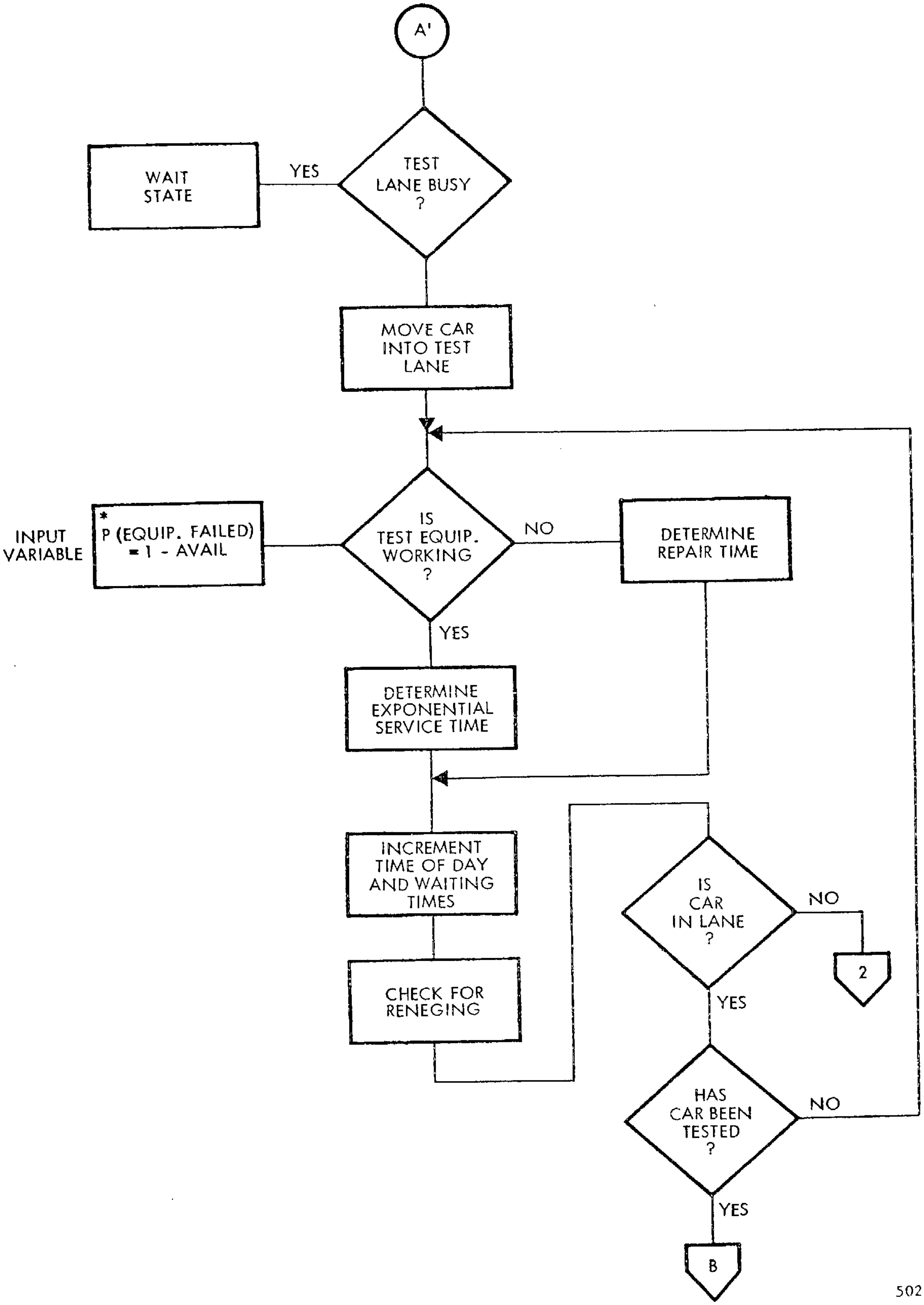

Figure 4-21. INSPECTION STATION SIMULATION MODEL FLOW CHART (Sheet 4 of 8)

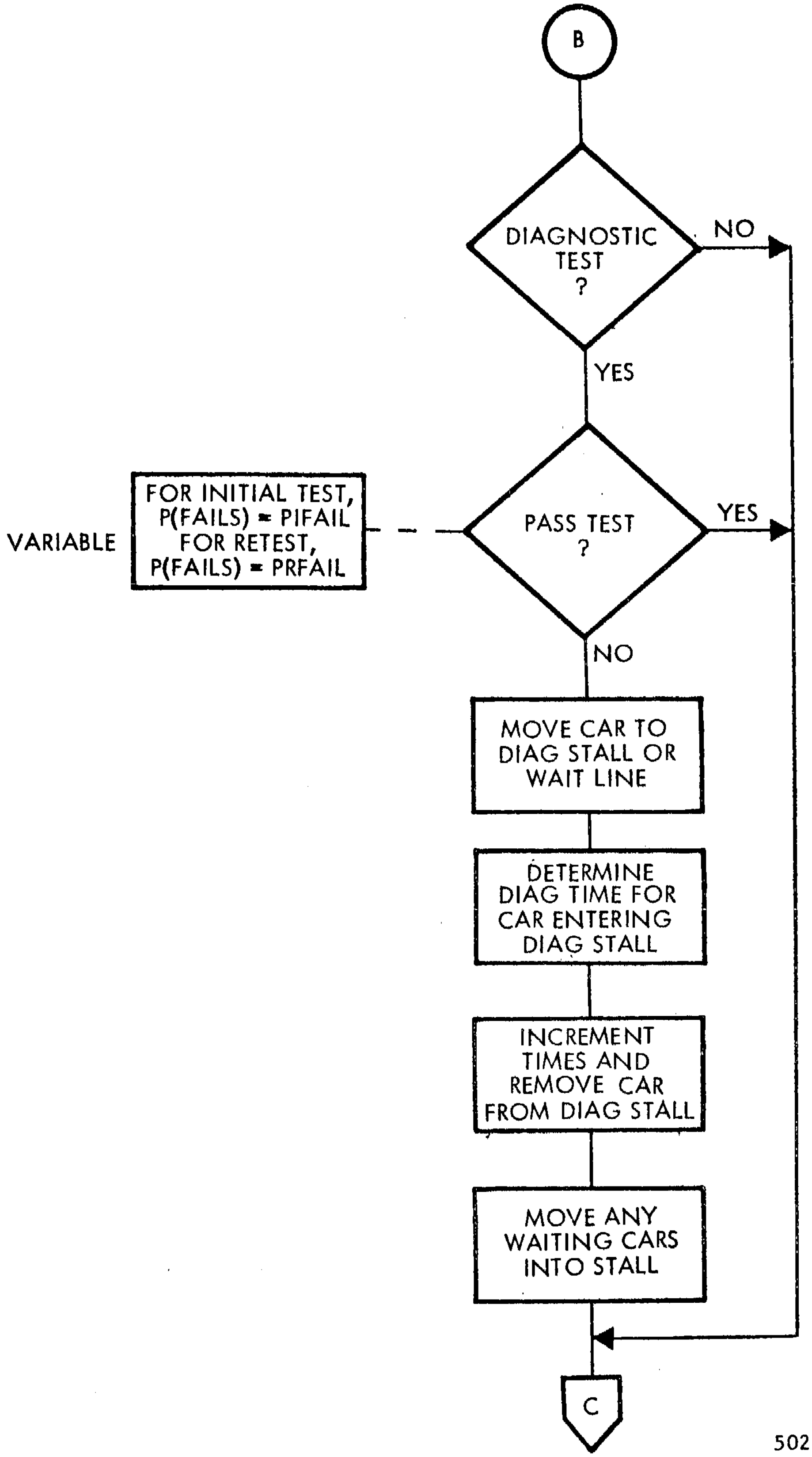

Figure 4-21. INSPECTION STATION SIMULATION MODEL FLOW CHART (Sheet 5 of 8)

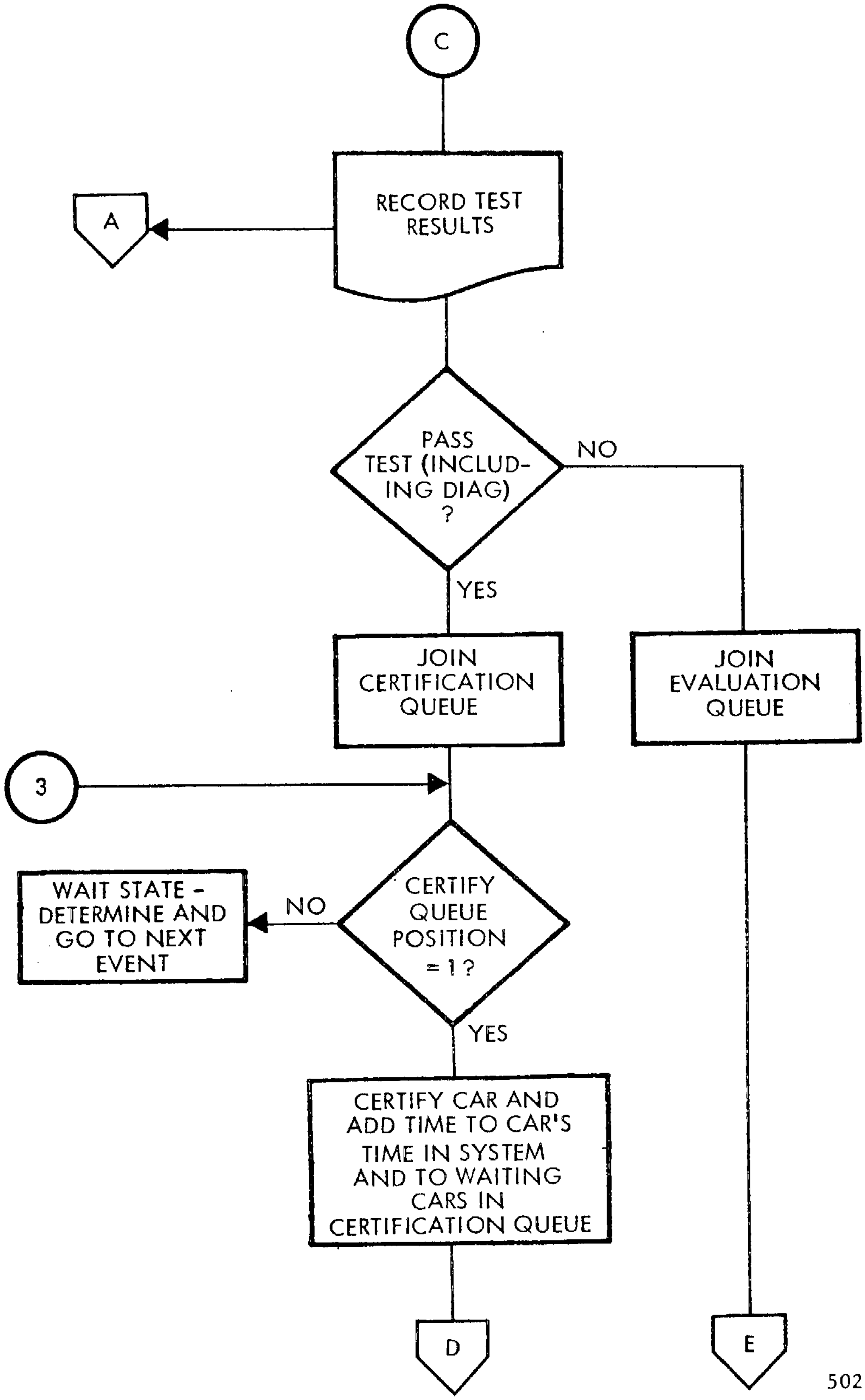

Figure 4-21. INSPECTION STATION SIMULATION MODEL FLOW CHART (Sheet 6 of 8)

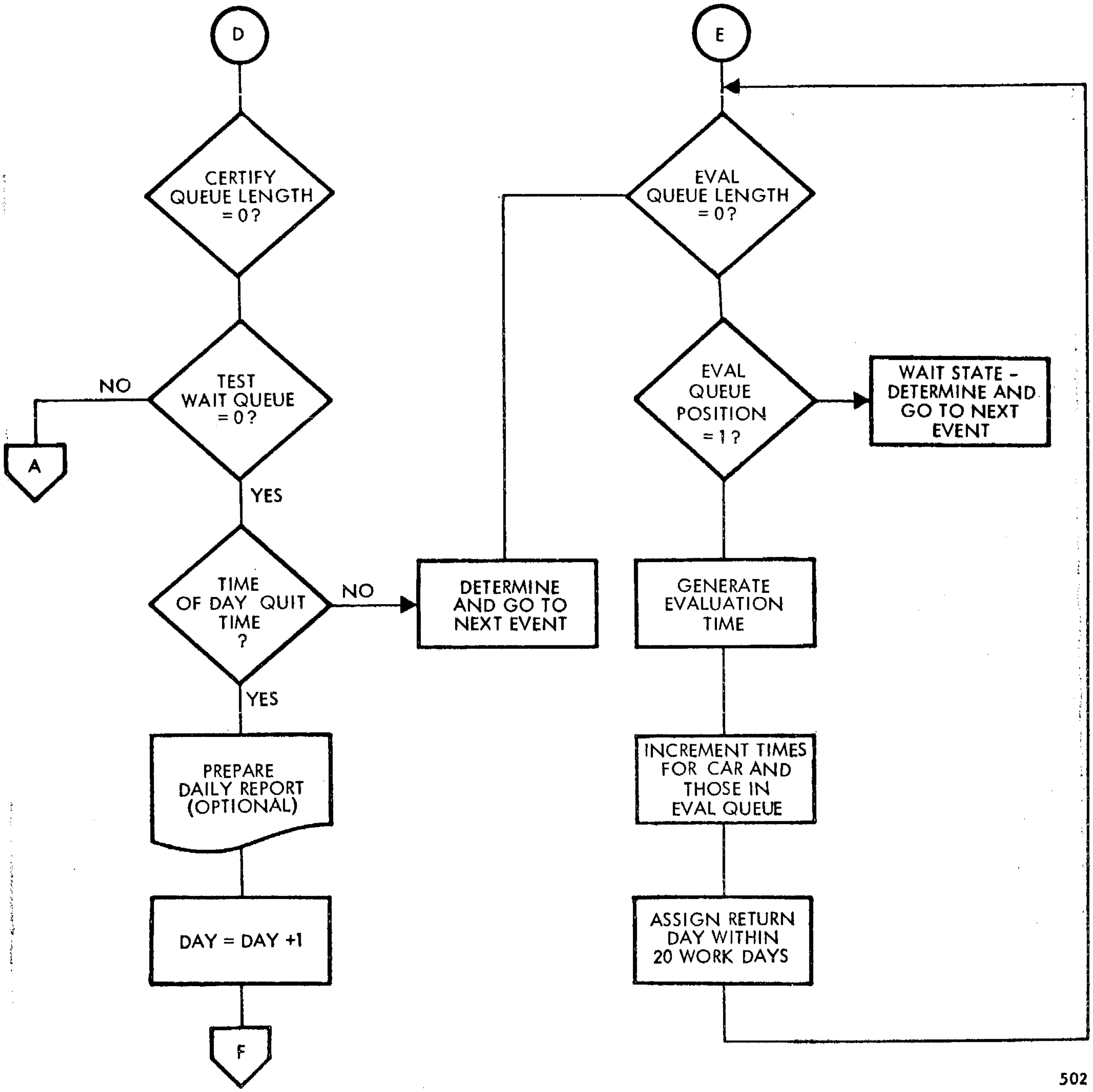

Figure 4-21. INSPECTION STATION SIMULATION MODEL FLOW CHART (Sheet 7 of 8)

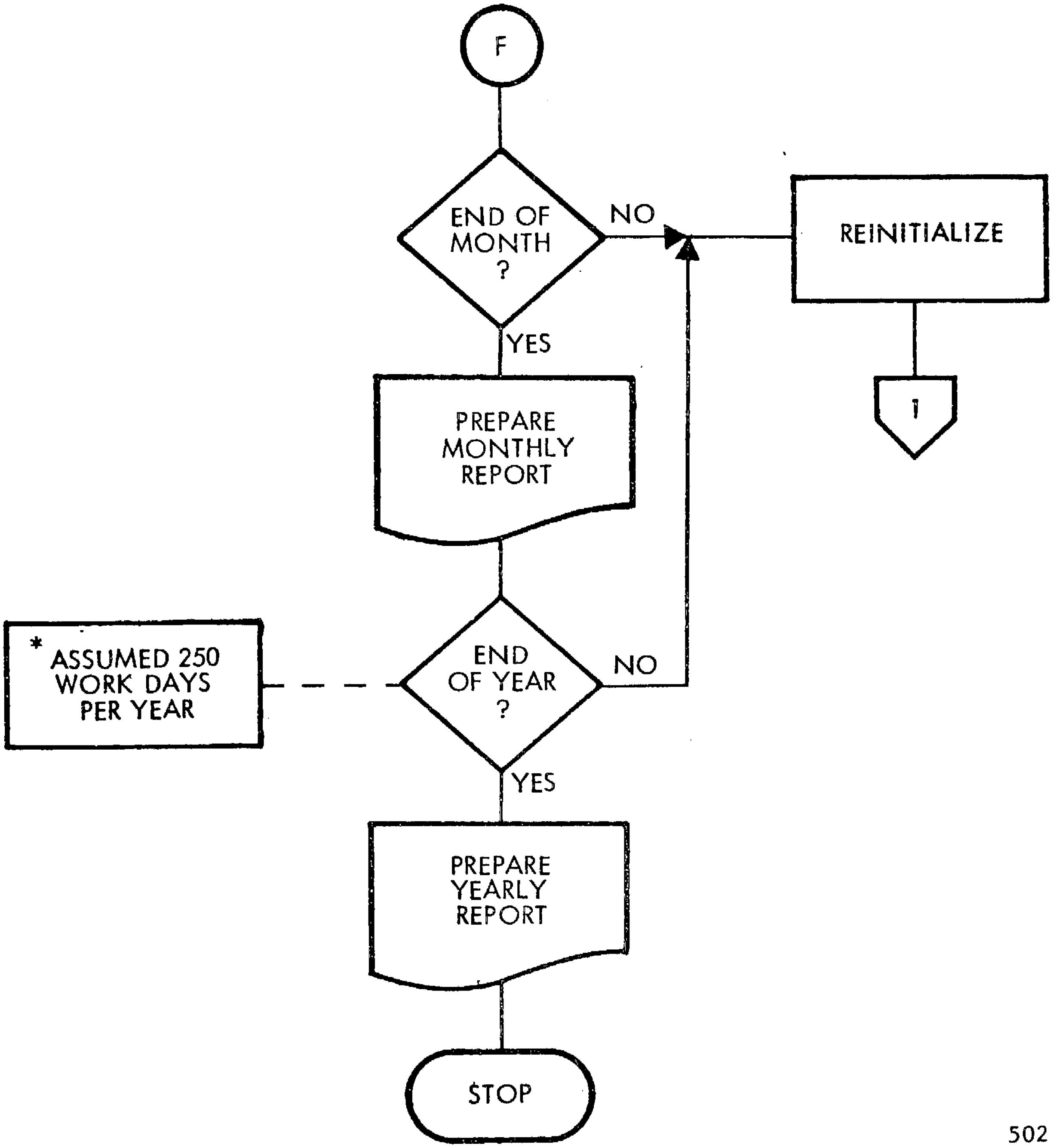

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Figure 4-21. INSPECTION STATION SIMULATION MODEL FLOW CHART (Sheet 8 of 8)

will be evaluated as to repairs required such as replacement of muffler or tailpipe or replenishment of oil or gasoline. Cars failing the emission test will be diagnosed in the case of the Diagnostic test regime only and/or evaluated as to repair required.

When a vehicle balks or reneges, a return date is randomly assigned. A forcing function is included to require that the vehicles initially arriving in a given month must return within that same month with the peak building toward the last day of the month. Vehicles failing the emission test are randomly assigned a retest date (or a certification date if retest is not required) that is within 20 working days of the failure date.

The model will proceed on a day-by-day basis for a year (assumed to be 250 working days) and accumulate information for summaries produced monthly and yearly. An optional output of the results of a randomly chosen day is also available for demonstration purposes. This daily output would be too bulky to produce for every day in the year. The content of the output reports is given in Table 4-12.

4.8.2 Location Analysis Methodology

To determine the optimum design and location of proposed inspection facilities within the State, it was first necessary to identify those vehicle population centers (VPCs) that would be likely sites for inspection facilities. Once such centers had been identified and quantified, they were analyzed by the computerized station simulation algorithm to determine the type and quantity of inspection stations required for each test regime by each VPC. The following paragraphs document those population centers identified and describe how they were selected.

Figures for vehicle population were obtained from two sources - The Department of Motor Vehicles and Reuben H. Donnelley Corp. The Department of Motor Vehicles keeps no records of vehicle population by city or postal zone. Only two private firms, of which R. H. Donnelley Corp. is one, have access to DMV computer tapes, and each firm selects from the total vehicle registrations of the State only certain classes of vehicles. Based upon Donnelley's compilation of 1970 California vehicle registration lists of privately owned light-duty passenger automobiles (under 6,001 pounds), vehicle population centers were identified that appeared to be significant either in the aggregate number of vehicles contained by each, or in the percentage of the total county or air basin vehicle population represented by a given center. Since R. H. Donnelley's statistics do not include leased vehicles, fleet vehicles, publicly owned vehicles, station wagons, or other similarly classed vehicles, it would be expected that Donnelley's figures would be somewhat lower than the total vehicle population requiring inspection. Summary DMV data listing total vehicle registration by county for calendar 1970 indicates that this discrepancy is often of the order of 25 percent. Because this analysis concerns the vehicle population of a given city rather than that of the county in which the city is situated, population conversion factors were required for each county to aid in determining a more realistic vehicle population closely approximating DMV totals. The conversion factor for each county was obtained by first subtracting DMV supplied early-renewal data (cars registered for 1971 in calendar 1970) for each county from DMV total automobile registrations by county for 1970. These figures, representing the actual number of nonexempt autos registered in each county, were divided by Donnelley's total auto registration figures, respectively, by county, to determine an escalation factor which was then applied uniformly to all identified vehicle population centers within a given county. Conversion factors for a given county were applied uniformly over all VPCs within that county under the assumption that the discrepancies within each county between DMV and Donnelley data are distributed throughout a given county in the same proportion as is the total spectrum of vehicles reported by Donnelley.

Once the numerically significant VPCs had been identified, it was then necessary to consider their geographic proximity to allow consolidation where appropriate. From the results of the public opinion survey described in detail in Section 7 of this report, it appears the public prefers a driving distance less than 10 miles.

The obvious next step was to map these identified centers geographically and to determine how many, if any, could be consolidated. Table 4-13 lists the VPCs identified initially and notes those which could be consolidated that are within regions of 5, or in some cases, 10 miles in radius.

Table 4-13. VEHICLE POPULATION CENTERS (VPCs)

VPC	*Population	Extended VPC *Population 5-Mile Radius	Centers Included In Extended VPC (by Number)
I. SOUTH COAST AIR BASIN			
Los Angeles County	(3,670,496)		
1. Alhambra	38,744	97,191	1,34,48
2. Altadena	21,466		
3. Arcadia	36,000		
4. Artesia	14,617		
5. Azusa	17,641		
6. Baldwin Park	22,177		
7. Bell	29,221		
8. Bellflower	28,414		
9. Beverly Hills	25,731		
10. Burbank	57,382		
11. Canoga Park	53,901	85,860	11,62
12. Claremont	14,519		
13. Compton	45,443	103,550	13,30,52
14. Covina	35,510		
15. Culver City	24,349		
16. Downey	53,029	141,743	7,16,37,40
17. El Monte	40,326	100,170	3,17,32,55
18. Encino	22,393		
19. Gardena	49,641		
20. Glendale	89,555	---**	

*Refer to text
( ) = DMV actual number of vehicles registered within county; for counties divided between two air basins, population is given first time county is noted.
**Indicates center could not be combined conveniently with any others.

Table 4-13. VEHICLE POPULATION CENTERS (VPCs) (Continued)

VPC	Population	Extended VPC Population	Centers Included In Extended VPC
21. Glendora	23,863		
22. Hawthorne	35,919	110,179	19,22,31
23. Huntington Park	21,820		
24. Inglewood	64,116	---*	
25. Lakewood	49,230	92,261	4,8,25
26. La Mirada	23,185		
27. La Puente	67,403	---*	
28. Long Beach	201,478	226,724	
29. Los Angeles	876,751	924,302	
30. Lynwood	24,352		
31. Manhattan Beach	24,627		
32. Monrovia	19,145		
33. Montebello	23,877		
34. Monterey Park	28,638		
35. North Hollywood	94,296	168,602	10,35,54
36. Northridge	33,041	61,934	36,45
37. Norwalk	43,767		
38. Pacoima	27,901		
39. Palos Verdes Peninsula	30,269		
40. Paramount	15,726		
41. Pasadena	83,118	119,448	2,41,53
42. Pico Rivera	26,403		
43. Pomona	45,450	59,969	12,43
44. Redondo Beach	38,713		
45. Reseda	28,893		
46. Rosemead	22,812		
47. San Fernando	90,601	105,902	38,47
48. San Gabriel	29,809		
49. San Pedro	37,265	62,511	49,61
50. Santa Monica	54,197	105,482	15,50,58
51. Saugus	15,347		
52. Southgate	33,895		
53. South Pasadena	14,864		
54. Sun Valley	16,939		
55. Temple City	18,700		
56. Torrance	95,885	164,867	44,39,56
57. Van Nuys	115,696	138,089	18,57
58. Venice	26,936		
59. West Covina	36,274	135,465	5,6,14,21,59
60. Whittier	89,673	139,952	33,42,60
61. Wilmington	25,246		
62. Woodland Hills	31,959		
<u>Santa Barbara County (SCAB Portion)</u>	(131,625)	(10-Mile Extension)	
1. Santa Barbara	63,322	79,723	

*Indicates center could not be combined conveniently with any others.

Table 4-13. VEHICLE POPULATION CENTERS (VPCs) (Continued)

VPC	Population	Extended VPC Population	Centers Included In Extended VPC
Orange County	(748,217)		
1. Anaheim	98,297		
2. Buena Park	37,668		
3. Costa Mesa	40,389		
4. Fullerton	47,670		
5. Garden Grove	66,275		
6. Huntington Beach	59,245		
7. Orange	43,443		
8. Santa Ana	108,937		
Riverside County (SCAB Portion)*	(223,570)		
1. Riverside	91,240		
2. Corona	17,766		
3. Hemet	15,307		
San Bernardino County (SCAB Portion)	(319,870)		
1. San Bernardino - Redlands	91,312		
2. Ontario - Upland	53,210		
3. Rialto	17,142		
Ventura County	(200,946)		
1. Ventura	37,787		
2. Oxnard	39,309		
3. Thousand Oaks	21,370		
II. SAN FRANCISCO BAY AREA AIR BASIN			
Alameda County	(481,764)		
1. Alameda	30,070		
2. Berkeley	63,535		
3. Fremont	48,057	---***	
4. Hayward	83,783	144,541	4,7,8
5. Livermore	20,148	---***	
6. Oakland	169,557	274,606	1,2,6**
7. San Leandro	46,365		
8. San Lorenzo	14,393		

*Refer to text following
**Includes Lafayette in Contra Costa County
***Indicates center could not be combined conveniently with any others

Table 4-13. VEHICLE POPULATION CENTERS (VPCs) (Continued)

VPC	Population	Extended VPC Population	Centers Included in Extended VPC
<u>Contra Costa County</u>	(281,929)		
1. Antioch	14,670	29,330	1,6
2. Concord	60,161	108,536	2,5,8
3. El Cerrito	15,470		
4. Lafayette	14,278		
5. Martinez	14,858		
6. Pittsburg	14,660		
7. Richmond	66,581	82,051	3,7
8. Walnut Creek	33,517		
<u>Marin County</u>	(108,072)	5-Mile Extended	10-Mile Extended
1. Mill Valley	14,970		
2. Novato	17,067		
3. San Rafael	37,759	46,456 (3,4)	78,494 (1-4)
4. San Anselmo	8,697		
<u>Napa County</u>	(39,285)		
1. Napa	31,791	35,119	1,2
2. St. Helena	3,328		
<u>San Francisco County</u>	(288,056)		
1. San Francisco	287,394		
<u>San Mateo County</u>	(308,460)		
1. Belmont	14,333		
2. Burlingame	23,456		
3. Daly City	37,959	100,501	3,6,8,11
4. Menlo Park	32,079		
5. Millbrae	12,940		
6. Pacifica	17,926		
7. Redwood City	45,532	143,873*	
8. San Bruno	20,421		
9. San Carlos	17,067		
10. San Mateo	55,522	106,252	1,2,5,10
11. South San Francisco	24,195		
<u>Santa Clara County</u>	(542,650)		
1. Campbell	18,836		
2. Cupertino	18,306		

*Includes Palo Alto in Santa Clara County

Table 4-13. VEHICLE POPULATION CENTERS (VPCs) (Continued)

VPC	Population	Extended VPC Population	Centers Included in Extended VPC
3. Los Altos	24,304		
4. Los Gatos	21,132	---*	
5. Mountain View	34,193		
6. Palo Alto	46,836		
7. San Jose	242,408		
8. Santa Clara	44,101	62,936	1,8
9. Saratoga	15,471	---*	
10. Sunnyvale	53,597	130,400	2,3,5,10
<u>Solano County</u>	(81,427)		
1. Vallejo	41,927	---*	
2. Fairfield	15,794	27,175	
3. Vacaville	11,381		
<u>Sonoma County</u>	(104,213)		
1. Santa Rosa	46,970		
2. Petaluma	17,251		
III. SAN JOAQUIN VALLEY AIR BASIN			
<u>Amador County</u>	(5,853)		
1. Jackson	1,838		
<u>Calaveras County</u>	(6,472)		
<u>Fresno County</u>	(195,153)		
1. Fresno	136,446		
<u>Kern County (SJVAB Portion)</u>	(156,869)		
1. Bakersfield	96,418		
<u>Kings County</u>	(27,164)		
1. Hanford	14,310		
2. Lemoore	5,904		
3. Corcoran	3,796		
4. Avernal	1,711		
<u>Madera County</u>	(18,744)		
1. Madera	12,345		
2. Chowchilla	3,779		

*Indicates center could not be combined conveniently with any others.

Table 4-13. VEHICLE POPULATION CENTERS (VPCs) (Continued)

VPC	Population	Extended VPC Population	Centers Included in Extended VPC
Mariposa County	(2,948)		
1. Mariposa	1,632		
2. Yosemite National Park	504		
Merced County	(45,838)	10-Mile Extension	
1. Merced	18,843		
2. Atwater	6,394		
3. Los Banos	5,167		
San Joaquin County	(135,465)		
1. Lodi	20,167		
2. Stockton	82,817	102,984	
Stanislaus County	(94,336)		
1. Modesto	55,852		
2. Ceres	5,440		
3. Oakdale	6,133		
4. Turlock	12,098		
Tulare County	(94,043)		
1. Porterville	17,143	23,597	
2. Visalia	23,529	---*	
Tuolumne	(10,584)		
1. Sonora	5,851		
IV. SACRAMENTO VALLEY AIR BASIN			
Butte County	(48,697)		
1. Chico	20,962		
Colusa County	(6,126)		
1. Colusa	2,865		
El Dorado County	(21,630)		
1. Placerville	7,603		
2. South Lake Tahoe	7,145		

*Indicates center could not be combined conveniently with any others.

Table 4-13. VEHICLE POPULATION CENTERS (VPCs) (Continued)

VPC	Population	Extended VPC Population	Centers Included in Extended VPC
Glenn County	(8,965)		
1. Orland	4,152		
2. Willow	3,444		
Nevada County	(13,377)		
1. Grass Valley	7,612		
2. Nevada City	3,326		
Placer County	(37,971)		
1. Roseville	12,739		
2. Auburn	9,297		
Sacramento County	(312,774)		
1. Carmichael	24,034		
2. Citrus Heights	14,200		
3. Sacramento	207,344		
4. West Sacramento	7,613		
Shasta County (SVAB Portion)	(37,421)		
1. Redding	22,153		
Sierra County	(1,110)		
1. Loyalton	537		
Sutter County	(19,555)		
1. Yuba City	15,088		
2. Live Oak	2,345		
Tehama County	(13,434)		
1. Red Bluff	7,708		
2. Corning	2,991		
Yolo County	(40,658)		
1. Davis	11,316		
2. Woodland	12,690		

Table 4-13. VEHICLE POPULATION CENTERS (VPCs) (Continued)

VPC	Population	Extended VPC Population	Centers Included In Extended VPC
Yuba County	(20,532)		
1. Marysville	14,612		
2. Olivehurst	3,268		
V. SAN DIEGO AIR BASIN			
San Diego County	(644,452)	5-Mile Extended	
1. San Diego	316,024	345,297	
2. La Mesa	31,613	45,346	
3. El Cajon	38,120	54,799	
4. Escondido	26,499	30,243	
5. Oceanside	21,455	45,769	
6. Chula Vista	42,880	67,751	
VI. SOUTHEAST DESERT			
Kern County (SEDAB Portion)	35,750		
Los Angeles County (SEDAB Portion)	67,200		
San Bernardino County (SEDAB Portion)	106,500		
1. Barstow			
Imperial County	34,261		
Riverside County (SEDAB Portion)	71,500		
San Diego County (SEDAB Portion)	17,040		
VII. NORTH CENTRAL COAST AIR BASIN			
Monterey County	(109,415)		
1. Monterey	15,398		
2. Salinas	42,633		

Table 4-13. VEHICLE POPULATION CENTERS (VPCs) (Continued)

VPC	Population	Extended VPC Population	Centers Included in Extended VPC
San Benito County	(3,313)		
1. Hollister	6,972		
Santa Cruz County	(67,003)		
1. Santa Cruz	30,650		
2. Watsonville	17,619		
VIII. SOUTH CENTRAL COAST AIR BASIN			
San Luis Obispo County	(49,766)		
1. San Luis Obispo	17,093		
Santa Barbara County (SCCAB Portion)		10-Mile Extension	
1. Lompoc	17,095		
2. Santa Maria	28,390	29,876	
IX. NORTH COAST AIR BASIN			
Del Norte County	(6,807)		
1. Crescent City	5,367		
Humboldt County	(46,730)		
1. Eureka	19,966	5-Mile Extension 30,454 10-Mile Extension 34,790	
Lake County	(11,142)		
1. Lakeport			
Mendocino County	(23,830)		
1. Ukiah			
Siskiyou County (NCAB Portion)	2,800		

Table 4-13. VEHICLE POPULATION CENTERS (VPCs) (Continued)

VPC	Population	Extended VPC Population	Centers Included in Extended VPC
Trinity County	(2,955)		
1. Weaverville			
X. NORTHEAST PLATEAU			
Lassen County	(7,072)		
1. Susanville	3,982		
Modoc County	(3,322)		
1. Alturas	2,040		
Shasta County (NPAB Portion)	4,900		
Siskiyou County (NPAB Portion)	11,000		
1. Dunsmuir	1,587		
2. Mt. Shasta	1,844		
3. Yreka	3,622		
XI. GREAT BASIN VALLEY AIR BASIN			
Alpine County	(195)		
Inyo County	(7,675)		
1. Bishop			
Mono County	(1,637)		

Once the pertinent VPCs had been identified and described, they were each converted by the station simulation algorithm to a requirement for a given number of lanes for each of the test regimes as described in paragraph 4.8.1.

These potential VPC inspection station sites must not be assumed to be precisely defined to the extent that possible future stations should be designed and built to their specification. The VPC locations eventually selected for station placement must, in addition, utilize local historical vehicle registration figures for each area considered to establish precisely growth patterns in vehicle population. The sites selected for analysis in this study are merely for the purpose of feasibility analysis; they are not, nor should they necessarily be interpreted to be final prescriptions for station construction.

Table 4-14 presents Department of Motor Vehicle registration totals by county. These figures are adjusted for early renewal registrants; thus they represent the

Table 4-14. 1970 PASSENGER AUTO REGISTRATION BY COUNTY

Alameda	481,764	Placer	37,971
Alpine	195	Plumas	5,611
Amador	5,853	Riverside	223,570
Butte	48,697	Sacramento	312,774
Calaveras	6,472	San Benito	8,313
Colusa	6,126	San Bernardino	319,870
Contra Costa	281,929	San Diego	644,452
Del Norte	6,807	San Francisco	288,056
El Dorado	21,630	San Joaquin	135,465
Fresno	195,153	San Luis Obispo	4,979
Glenn	8,965	San Mateo	308,460
Humboldt	46,370	Santa Barbara	131,625
Imperial	34,261	Santa Clara	542,650
Inyo	7,675	Santa Cruz	67,003
Kern	156,869	Shasta	37,421
Kings	27,164	Sierra	1,110
Lake	11,142	Siskiyou	15,284
Lassen	7,072	Solano	81,427
Los Angeles	3,670,496	Sonoma	104,213
Madera	18,744	Stanislaus	94,336
Marin	108,072	Sutter	19,555
Mariposa	2,948	Tehama	13,434
Mendocino	23,830	Trinity	2,955
Merced	45,838	Tulare	94,043
Modoc	3,322	Tuolomne	10,584
Mono	1,637	Ventura	200,946
Monterey	109,415	Yolo	40,658
Napa	39,285	Yuba	20,532
Nevada	13,377		
Orange	748,217	TOTAL	10,004,155

actual number of indigenous passenger automobiles registered in California as of December 31, 1970. Comparing the total reported by DMV with Table 4-15, the estimates by air basin of the California vehicle population, a discrepancy of approximately 575,000 vehicles is apparent. Although this discrepancy represents approximately 6 percent of the population, comparison of county totals indicates approximately 400,000 vehicles unaccounted for in Los Angeles and Orange counties. Account is taken of this in the assignment of station lanes to VPC sites in these areas.

In the cases of those counties divided between two air basins, where Donnelley data was lacking, a procedure first suggested by Paul Downing and Lytton Stoddard of U.C. Riverside in their paper "Benefit/Cost Analysis of Air Pollution Control Devices for Used Cars," was used.

Rules of significant figures were observed throughout. Downing and Stoddard's procedure is described as follows (excerpted from their paper cited above):

> First, the urban population for 1970 within each air shed of the county was determined from State data (Department of Finance, 1970). The total of all urban population throughout the county was then found by adding together

Table 4-15. ESTIMATED AIR BASIN VEHICLE POPULATIONS

1.	South Coast	4,394,218
2.	San Francisco Bay	2,266,158
3.	San Joaquin Valley	768,903
4.	Sacramento Valley	582,547
5.	San Diego	589,206
6.	Southeast Desert	332,000
7.	North Central Coast	184,424
8.	South Central Coast	181,553
9.	North Coast	95,114
10.	North East Plateau	26,301
11.	Great Basin Valley	9,508
	Total	9,429,932

the air sheds' urban population. The difference between this total and the total population of the county represented the total rural population. It was then assumed that most of the rural population would be concentrated near the urban centers within each air shed. It was also recognized, through, that there were areas in some counties that contained little or no urban concentration and yet had considerable rural population. Thus it was necessary to devise a weighting system that would at once reflect the importance of the urban centers in attracting and concentrating rural population and yet make allowance for those situations in which the rural population existed apart from urban centers. This was accomplished as follows:

1. Assume county "T" contains parts of two air sheds, "A" and "B."

2. The total land area of T is therefore A + B; the percentage of T represented by A is $\frac{A}{A + B}$ and by B is $\frac{B}{A + B}$

The system of weighting was then established:

3. Weighted A (WA) = $a \frac{A}{A + B} + b \frac{CA}{C}$, where a and b were some arbitrary weight factors whose sum = 1.0, CA was the urban population of air shed A within the county and C was the total urban population within the county. Also,

   Weighted B (WB) = $a \frac{B}{A + B} + b \frac{CB}{C}$, where a and b were the same weight factors as above and CB represented the urban population within the B air shed portion of the county.

4. "a" and "b" were next given arbitrary weights of 0.4 and 0.6, respectively, reflecting the authors' assumption of the greater importance of urban population over land area.

These equations were applied to all the counties of the State in which there were several air sheds. Then,

5. Total Population = Urban Population + Rural Population.

Therefore,

Rural population x WA = total rural population within air shed A (RA) and
Rural population x WB = total rural population within air shed B (RB).

Next, the total population for each air shed in the county was calculated.

6. CA + RA = TA (total population of A)
CB + RB = TB (total population of B)

Clearly, TA and TB must equal the total population of the county "T", and

7. $\frac{TA}{T}$ = that portion of the population of the county within air shed A (where T is total county population) and $\frac{TB}{T}$ is that portion of the population of the county within air shed B.

Finally, to derive the total car population of each air shed of the county it was assumed that there was some constant ratio of cars to population regardless of demographic considerations. Therefore

8. $\frac{TA}{T}$ x total cars in county = cars in air shed A, and
$\frac{TB}{T}$ x total cars in county = cars in air shed B.

The total car population for a particular air shed was calculated by adding the estimates derived in equation 8, for counties which partially fell in that air shed and the DMV total car population estimates for those counties which fell completely in the air shed.

In conversation, Downing indicated that the use 60/40 weighting was indeed arbitrary. However, no better estimate of the actual situation could be obtained. Probably the most significant error obtained in combining Downing-Stoddard's technique with that described earlier occurred in the Shoutheast Desert Air Basin. Although relatively few population centers are evident in this basin, the combined estimating processes indicate a total of 332,000 vehicles residing there. Until better data becomes available, few better estimates can be obtained for this basin that contains portions of five of the eight counties that are divided between two basins.

4.8.3 Station Lane Assignment

The computerized station simulation algorithm assigned a number of lanes to a given VPC strictly on the basis of the current population identified for that VPC, and on the basis of annual vehicle throughput assigned to a given test regime. This procedure resulted in fractional numbers of lanes in many cases. These primary assignments were then escalated on the basis of the previously noted growth rate of 3.4 percent annually. In addition, account had to be taken of those vehicles residing in close proximity to a VPC not noted in the aggregate population assigned to that VPC, because the nearby community may have been too small to have been recorded. In general, fractional lane assignments were incremented to the next higher integral number of lanes if at least one lane was indicated and the fractional portion of lanes exceeded 0.2; or if more than seven lanes were indicated, an additional lane was included. If a VPC required an integral number of lanes larger than one (to one decimal place), an additional lane was added for every seven. Based upon the throughput rates indicated, station assignments by air basin are presented in Table 4-16.

Table 4-16. SUMMARY LANE ASSIGNMENTS

	Test Type			
	Certificate of Compliance	Idle	Key-Mode	Diagnostic
Annual Vehicle Throughout per Lane	7500	32000	25000	13020
Air Basin	Total Lane Equivalents Required*			
1. South Coast	635	148	194	368
2. San Francisco Bay Area	332	78	94	190
3. San Joaquin Valley	112	26	33	61
4. Sacramento Valley	86	17	24	47
5. San Diego	86	20	29	48
6. Southeast Desert	41	10	9	26
7. North Central Coast	27	7	10	16
8. South Central Coast	27	7	8	16
9. North Coast	14	3	4	8
10. Northeast Plateau	4	2	2	3
11. Great Basin Valley	2	1	1	1
Total	1366	319	398	784

*One lane equivalent is one stationary lane or the required number of mobile lanes to achieve the throughput of a single stationary lane.

4.9 INSPECTION STATION OPERATION AND PROGRAM MANAGEMENT

This discussion addresses the questions of State versus private operation of vehicle inspection stations and the necessary overall program management required at regional and State levels. Various combinations of State and private cooperation are possible. There are basically three general combinations: (1) complete State ownership and operation of the program, (2) private ownership and operation with State management, and (3) private operation under contract to the State.

Various benefits and liabilities result from private operation of the individual test stations. The net balance may be determined by qualitative and subjective factors beyond the scope of this study. However, several of the more obvious benefits and disadvantages can be outlined here. Comparisons of the program on the basis of economic factors will be conducted in the section on cost-effectiveness.

The State must retain ultimate program management responsibility to ensure satisfactory and effective operation of the program. The degree of control exercised and the resulting State organization structure required depends on the specific combination of State and private cooperation in operating the local stations.

4.9.1 Program Management

The overall management structure has been analyzed independently of the test regime implemented, specific agency charged with program administration, and the nature of individual station operation.

The statewide program has been separated into three fundamental management levels - Program Manager, Regional Management, Station Management. The exact titles, responsible agency, and operational subdivisions have been left open to further consideration.

4.9.1.1 Program Management Responsibilities - Program management was assigned responsibility for establishing personnel standards, training programs, inspection procedures, enforcing inspection personnel and facility performance standards, scheduling vehicles, and compiling records of passed and failed vehicles.

Regional management was assigned responsibility for implementing procedures established by the program manager, providing equipment and personnel support for individual inspection stations when required, providing periodic surveillance and certification of each station and its personnel, supplying materials and equipment required for local stations, and operating mobile stations where required. These functions require competent technical personnel to perform repair of instruments and equipments in the local station and to inspect the facility personnel and equipment performances. It is recommended that responsibility for enforcing repair facility performance also be assigned to the regional management.

Station management was assigned responsibility for maintaining high performance of inspectors, accurate calibration and proper operating condition of equipment (with regional management direction and assistance as needed), rapid correction of deficiencies determined by regional management inspection teams, certification of passing vehicles, and documentation of failing vehicles.

4.9.1.2 Program Management Personnel Requirements - Six levels of personnel have been identified for the overall program management plus three levels of station management. The personnel assignment matrix is shown in Table 6-20 in the Cost Analysis. Pay scales for these personnel are shown in Table 6-19. Program Management personnel were assigned in proportion to the vehicle population of each region except that a minimum personnel complement of one manager, one technician, and one clerk was assigned to each air basin. Station management personnel were assigned according to station size.

4.9.1.3 Program Management Equipment Requirements - Office equipment has been assigned on the basis of personnel in each regional office. One desk and chair has been allocated to each individual. Additional clerical equipment has been assigned proportionately to the number of clerical personnel assigned. Laboratory test equipment and supplies have been allocated as inspection support equipment costs to each inspection station.

4.9.1.4 Responsible Agency - Subject to political decision, program management could be assigned to the Highway Patrol, the Department of Motor Vehicles, the Air Resources Board, or an independent agency such as the Business and Transportation Agency. The Highway Patrol conducts existing Certificate of Compliance enforcement for both individual vehicle owners and the participating private garages. Should a modified Certificate of Compliance program be implemented, management functions could continue to be assigned to the Highway Patrol. Since the program implementation will probably be tied to vehicle registration, the administrative agency also could be the Department of Motor Vehicles.

However, since the ultimate objective of the program is air pollution abatement, the logical regional division would be the 11 Regional Air Basins established by the California Air Resources Board. Although these divisions cut across existing administrative and governmental boundaries of local governments and other State agencies, this particular configuration is most realistic in reflecting the regional nature of the vehicular air pollution problem. It is presumed that the ARB expects to establish regional air pollution control authorities for each air basin. Hence, the Vehicle Inspection Program would logically be assigned to the ARB Regional Office and could share equipment and personnel with the other operating divisions of the Regional Office.

The Highway Patrol may still be charged with the responsibility for enforcing individual driver and owner compliance. Administrative control could be placed with the DMV for vehicle scheduling. Failure to produce a valid emission certificate would prevent reregistration of the vehicle in question. Lack of current registration tags on the license would result in CHP citation.

4.9.2 <u>Complete State Ownership and Operation of Inspection Stations</u>

Actual cost to the State may be less and direct control over the program should be better if the State has complete operational control of the stations. Ideally, the State program management would provide the individual stations with whatever support functions would be necessary. Supplies and equipments would be purchased through the State, effecting considerable economies because of volume purchasing. The State would provide instrument calibration, periodic inspection of the inspection stations and personnel, and assistance in repairing equipment. Mobile sites would be administered by the regional program management offices.

All inspection personnel would be State employees following procedures established and enforced by the program management office. Training requirements and periodic performance tests would ensure that the inspectors were performing correctly and keeping up with changes in emission control systems.

4.9.3 <u>Private Ownership and Operation of Stations</u>

Private ownership represents the lowest direct cost to the State. It would be an extension of the existing Certificate of Compliance program conducted annually and with greater surveillance of participating garages. The private owners would be required to obtain the equipments specified in the station requirements discussion for the regime selected. The local owner then would be responsible for correct calibration and operation of the equipment and correct adherence to the inspection procedures established by the program management office. Periodic inspection would be carried out by State inspectors to ensure that equipment and personnel were performing as desired. This program has advantages in sparsely populated areas where a fixed State site would be uneconomical.

A potential conflict of interest occurs, however, if the private inspection stations also derive part of their income from repairs recommended as a result of the inspection procedure. The public acceptability of this program is relatively low according to public opinion surveys. Special inspection-only stations may appear, but probably would not be individually managed as are repair garages.

4.9.4 Contractor Owned and Operated

This program involves a single corporation running a statewide inspection program on a contracted fee basis. The regional program management functions would reside with the private company as would the projected station support activities if the program were entirely State owned and operated. The State would need a program management office to administer and control the private company. This program has an advantage in that one manager would ultimately be responsible for the private company's performance under the contract. Records and operational data would be supplied to the State. However, an inspection team would still be required by the State to ensure program compliance at the individual station level. This program would probably require the largest State expense since the contractor would require a profit and the State would have to duplicate part of the administrative organization of the private contractor.

SECTION 5
EFFECTIVENESS CRITERIA AND EVALUATION

This section analyzes the program effectiveness of the four test regimes. In the previous sections, the requirements for the emission inspection facilities were established based on functional and operational considerations and analyses. Equipping and staffing a statewide network of inspection and test facilities that satisfy these requirements have provided a basis for determining the technical feasibility of such a program. Assuming that each of the four test regimes is capable of meeting the overall objectives, then a method should be devised to select from among these alternatives the one most suitable for the task.

The section begins with a definition of effectiveness measures and discusses the factors to be considered in their formulation and utilization. An effectiveness index is developed that considers the effects of exhaust emissions, vehicle population, model-year distribution, average vehicle miles driven, and anticipated inspection failure rates. The experiment designed to obtain empirical operational data for the calculation of effectiveness measures is then described. Various aspects of the experiment such as vehicle selection, test scheduling, and service centers assignment are discussed.

The results of the vehicle testing and maintenance program are used to generate effectiveness indices for each test regime. Statistical analyses of vehicle test data are presented along with an evaluation of maintenance personnel performance. The section concludes with an evaluation and comparison of the effectiveness measures on state, regional, cumulative, and total program bases.

5.1 TEST EFFECTIVENESS INDEX

The objective of this study is to determine the overall feasibility and costs of implementing an inspection program that would lead to automotive emission reductions. The effectiveness and benefits of such a program should be considered in terms of emission reductions and advantages to the motorist and the general public. In the following paragraphs, an effectiveness index is defined and developed. A discussion of the varying contributions of the three pollutants (hydrocarbons, carbon monoxide, and oxides of nitrogen) to the total program is presented. Considering the effects of vehicle population and distribution, a generalized equation for determining measures of effectiveness is derived.

5.1.1 Definition of Effectiveness Measure

Measures of effectiveness are used to evaluate how well a particular concept satisfies identified objectives. In a complex system comprised of many pieces of equipment, software packages, personnel, and procedures, a single performance indicator might be difficult to obtain or justify. The characteristics of system elements considered both individually and collectively could be used as effectiveness measures. However, such a plan would be undesirable since it would involve much time, effort, and arbitration. What is appropriate would be a single index that would represent the total program's appraised evaluation. The accepted effectiveness measure should necessarily relate to the program intent and be quantifiable. Consequently, for this analysis, a measure of effectiveness for each test regime will be the amount of vehicle emission pollutant reduction achieved.

5.1.2 Development of an Effectiveness Index

The effectiveness of a test regime will be related to the amount of pollutants removed from inspected and serviced vehicles. Based on the operational data gathered for each test regime, a quantitative measure will be derived and extrapolated for the applicable vehicle population. Total emission reduction can then be calculated for a given year per test regime.

Note that the emphasis is on vehicle emission reduction, and not on total air pollution reduction which would be more indicative of overall program effectiveness. Given that a satisfactory reaction model(s) exist (there are many in development which represent various schools of thought and interest (reference 18)), then the total effects of reducing any, all, or portions of the pollutant could be determined.

Since the pollutants, and the atmospheric reaction products, have adverse effects to varying degrees on different objects, the significance of reductions becomes difficult to comprehend. That is, the amount of HC, CO, and NO_x emitted in the atmosphere under a set of environmental and meteorological conditions affects differently exposed animal and human life, vegetation, and manufactured products. To be representative of the test regime's effectiveness, the index should consider these factors.

Equation (1) below is a simplified form of the effectiveness measure.

$$MOE = k_1 \Delta HC + k_2 \Delta CO + k_3 \Delta NO_x \quad (1)$$

where

- MOE = measure of effectiveness
- ΔHC = amount of hydrocarbon reduction due to vehicle maintenance
- ΔCO = amount of carbon monoxide reduction due to vehicle maintenance
- ΔNO_x = amount of oxides of nitrogen reduction due to maintenance
- $k_{1,2,3}$ = proportional contribution to program objective.

5.1.3 Weighting of Emitted Pollutants

As mentioned previously, the extent to which each major pollutant contributes to the total program objective should be determined. Many considerations are involved. After the initial controls on crankcase exhaust, the emphasis was placed on HC and CO. When the downward trend in these pollutants became firmly apparent, the controls on oxides of nitrogen received greater emphasis. Thus, if the effectiveness index were to reflect this shifting concern, a time varying weighting scheme should be employed.

Past studies have shown that levels of NO_x are adversely affected by efforts to reduce HC and CO concentrations. This was evident in earlier attempts to reduce these latter two pollutants. The future model-year vehicles (1971 and after) will have better controls and achieve greater reductions for all three major pollutants. Thus, the effectiveness index should consider and reflect the tighter limits imposed (and attainable) on the newer model vehicles.

Other studies have investigated and have attempted to determine the relative effects of air pollution. However, little quantitative information is available to fully evaluate the impact on reducing the three pollutants of immediate concern. The adverse consequences of emission pollutants on animal and human life, on vegetation, and on manufactured products have been mentioned as specific reasons for reducing emissions. In addition, aesthetic considerations such as being able to see the surrounding environs without visual impairment or the odor of "clean" air can only be quantified indirectly. These factors as they are affected by vehicle emissions are discussed below.

5.1.3.1 <u>Effects on Animal and Human Life</u> - Hydrocarbons and oxides of nitrogen, the compounds which result in the production of oxidants, are emitted from a wide variety of stationary and mobile sources. Oxidants in the urban atmosphere result from the photochemical reactions of HC and NO_x and efforts to control oxidants must therefore be directed at controlling the reactants (reference 19). Oxidants concentrations of 0.3 ppm for 3 hours produce impaired breathing to exposed animals. For humans, exposure to 0.1 ppm for 1 hour results in eye irritation and possible impairment of lung function in persons with chronic pulmonary disease. It has also been shown that physical performance is impaired in athletic events for those participants exposed to oxidants at least 1 hour prior to physical activity. Carbon monoxide exposure of 10 ppm for 4 hours also affects psychomotor functions. The question remains however, as to how much reduction in emissions must be achieved to be effective. That is, given a desired level of an air contaminant, what is the related emission standard which will effect the desired result. Another unknown but significant factor is the proportionate contribution of each (HC, CO, NO_x) to the total problem. Without this knowledge, meaningful weighting of contributors is seriously constrained.

It is recognized that the determination and specification of damage functions is the task of technical experts in the appropriate areas of concern. However, it is very evident that these experts do not specify the losses in terms readily usable to the system and cost analysts (reference 20). For example, changes in respiration rates or drowsiness are not useful for effectiveness studies, whereas absenteeism or efficiency rates would be more applicable.

5.1.3.2 <u>Effects on Vegetation</u> - The Ambient Air Quality Standards previously cited, state that both ozone and PAN (peroxyacyl nitrate), products of vehicle emissions, cause irregular spotting and/or flecking of leaf surfaces on many species of vegetation. Prolonged exposure to nitrogen dioxide (0.5 ppm for 12 - 19 days) damages sensitive plants such as the tomato. It has been shown that ozone affects the upper side of plant leaves by killing the cells and causing the leaves to turn yellow and to drop prematurely. On the other hand, PAN affects the lower side of the leaves, turning them brown or producing a silvery sheen.

The Environmental Protection Agency of the National Air Pollution Control Administration (NAPCA) reports that "scanty data does exist which would permit the construction of simple-minded physical damage functions, but the translation of these to dollars would be all but impossible. This can be attributed primarily to the quality of existing air pollution data and the lack of scientific evidence on cause-effect relationships of air pollution" (reference 21). Included in the information provided by the Environmental Protection Agency was a report from the Bureau of Plant Pathology, California Department of Agriculture, which showed that air pollution causes crop losses to fruits and trees, field crops, vegetable crops, nursery stock, and cut flowers. Losses range from a low of 2 percent to a high of 30 percent of crop value (reference 22). Although "smog is not identified as the pollutant causing the damage, in reality at least 95 percent of these losses could be attributed to the smog component" (reference 21). It was further stated that smog severely damages millions of pine trees to some degree.

The 1969 loss to California crops as reported by the Department of Agriculture totaled $44.5 million of which $33.6 million was incurred by citrus products. Next heaviest loss was experienced by ornamental nursery stock at $1.0 million followed by losses of $935,000 to the grape industry. Products suffering at least a half million dollars loss were alfalfa and beet.

Further detailed information is contained in the referenced document which is included in Appendix C. What is not available, however, is the relationship among smog components, concentration levels, and related crop effects or losses. The quantitative effectiveness of reducing or precluding the emissions of HC, CO, and NO_x cannot be evaluated without these relationships.

5.1.3.3 Effects on Manufactured Products - The Ambient Air Quality Standards report states that ozone concentrations of 0.02 ppm for 1 hour causes cracking of stressed rubber. Additionally, 50 days of exposure to 0.02 - 0.06 ppm results in deterioration and loss of tensile strength of exposed wet cotton textiles. In a survey conducted by a research team at the California Institute of Technology, it was concluded that ozone materially affects the interior and exterior painting of homes (reference 23). In the analysis of replies from the cities of Mountain View and Glendale, it was determined that there is a significant difference in paint durability and appearance when used in these two cities which are statistically similar but geographically dissimilar. The report also shows that metallic objects and asphalt driveways are deleteriously affected to a greater degree in Glendale than in Mountain View.

This analysis, although enlightening (there were many other studies like this uncovered during the data acquisition portion of this study), does not provide any relationship between ozone concentration levels, duration, and specific damages. Thus, the effects of reducing ozone concentration would be difficult to quantify. Additionally, the effects of reducing HC, CO, and NO_x as related to vehicle-emitted ozone has not been well-defined in the past. All these factors should be considered before the total effectiveness of emission reductions on manufactured products could be evaluated.

5.1.3.4 Aesthetic Considerations - Nitrogen dioxide is a red-brown gas that produces atmospheric discoloration. Also affecting visibility is oxidant concentration of 0.07 ppm. The reaction products of HC and NO_x are oxidants which contribute to photochemical smog. The Air Quality Criteria for nitrogen dioxide states that concentration of 0.25 ppm produces coloration effects that are objectionable and seriously limit distant-object visibility. Objects viewable at a 20-mile distance are visually degraded with increasing concentrations of nitrogen dioxide such that at the maximum specified level, the objects viewable at 10 miles distance appear objectionably degraded.

The effects of emission reductions have not been quantified nor have sufficient relationships been developed to the extent that projections can be made. That is, should the concentration level be reduced to half of the existing limits, it is unknown what the effects would be on viewing distant objects. Furthermore, it is undetermined to what extent the relationship between oxidant levels and nitrogen dioxide concentrations limit visibility and contribute to atmospheric discoloration.

As an example, will reductions in one component suffice to improve visibility, and if so to what extent; or will the solution require reductions in both components (in what proportions) before noticeable improvement is achieved? The total effectiveness of emissions reductions cannot be objectively evaluated until questions such as these are fully investigated.

5.1.3.5 Proportional Weighting Based on Emission Standards - Since there cannot exist a consensus of opinions on an acceptable proportion to allocate to each of the three primary pollutants, then the analysis could be facilitated by considering various combinations. The effects of the various mixes are evaluated and compared in paragraph 5.4. Listed below are three such combinations as determined by the applicable State standards. The fourth combination, which is totally arbitrary, considers the pollutants equally important to the program. A description of the mathematical process and the selection rationale is provided in the following paragraph.

Proportional Weighting Criteria

K_{HC}	K_{CO}	K_{NO_x}	Rationale
0.60	0.10	0.30	1970 - 1971 California Standards
0.45	0.03	0.52	1974 California Emission Standards
0.72	0.01	0.27	1966 California Emission Standards
0.33	0.33	0.33	Arbitrary equal weighting

5.1.3.5.1 Selection of Proportional Weighting Factors - The set of weighting factors shown above represent the spectrum of prevailing emphasis on the three principal pollutants within the air pollution control and public health disciplines. They are based on published data available from various local, State and Federal agencies.

The simplest weighting would consider the pollutants being equal in importance. The reduction in emissions would merely be summed and reported as total tons of pollutants prevented from entering the atmosphere. This technique is generally used in simplified analyses published by the various air pollution control agencies such as the Los Angeles County Air Pollution Control District (LACAPCD) for use by the general public. This method of weighting tends to emphasize reduction of CO since CO represents the greatest single mass emission initially. Using this criteria the weighting factors would be: 0.33, 0.33, 0.33.

A more sophisticated analysis of effectiveness would rank the pollutants by some measure of relative importance. This, of course, is difficult and depends to some extent on the individual's own experience, interests, and bias. Several different relative rankings can be obtained from published exhaust emission standards for new vehicles published by the California ARB and by the Federal Air Pollution Control Office of the Environmental Protection Agency (EPA). The emission standards have, in general, been fairly consistent; however, three basic weighting criteria are evident.

It is assumed that these standards represent analysis by qualified personnel of the relative importance of the pollutants and, therefore, can be used as a guide in determining the proportional weighting that should be assigned to each pollutant. The rationale for the standards will not be dealt with in this report. The weighting factors were determined for three model years (1966, 1974, and 1970). A sample calculation of the weighting factors for 1970 is shown below:

a. Identify emission standards:

$HC = 2.2$ gm/mile $\quad CO = 23$ gm/mile $\quad NO_x = 4$ gm/mile

b. Sum the allowable emissions:

$HC + CO + NO_x = 29.2 \text{ gm/mile} = T$

c. Calculate proportional contribution:

$$\frac{HC}{T} = 0.074 \qquad \frac{CO}{T} = 0.79 \qquad \frac{NO_x}{T} = 0.14$$

d. Calculate inverse ratios:

$$A_1 = \frac{T}{HC} = 13 \qquad A_2 = \frac{T}{CO} = 1.3 \qquad A_3 = \frac{T}{NO_x} = 7.3$$

e. Determine new total:

$$\frac{T}{HC} + \frac{T}{CO} + \frac{T}{NO_x} = 21.7 = K_o$$

f. Determine normalized weighting:

$$A_1 + A_2 + A_3 = K_o$$

$$\frac{A_1}{K_o} = K_{HC} = 0.60 \qquad \frac{A_2}{K_o} = K_{CO} = 0.10 \qquad \frac{A_3}{K_o} = K_{NO_x} = 0.30$$

5.1.4 Effects of Vehicle Distribution and Model Years

As stated, the effectiveness index, equation (1), is incomplete in that it does not include variations in vehicle emissions. It should be readily obvious that the effectiveness of any vehicle emission inspection and maintenance program would be highly dependent on the existing vehicular distribution. Better control and reduction of emitted pollutants is achieved with each newer model-year vehicle. Consequently, as the older vehicles are phased out of the program through normal attritional reasons such as age or accidents, the reductions on a total program basis would not be as large during the latter years as those realized during initial implementation. The effectiveness measure should reflect the changing vehicle population distribution and the respective reductions.

Equation (2) below includes the effects of vehicle population and distribution. The expected annual average vehicle-miles driven is also included to convert emission reduction (expressed in grams/mile) to total weight of emitted pollutants. To accommodate and evaluate the effects of different inspection failure rates, a term has been added to consider changes in emission cutoff limits. For this study, a fixed rejection rate of 50 percent was used for each test regime.

$$MOE = \sum_{i=1}^{20} \sum_{n=1}^{3} F \; P_i D \; M \; K_n W_n(y_i) \; C \qquad (2)$$

where

MOE = measure of effectiveness, in tons of pollutants

F = expected inspection failure rate, in percent

P_i = vehicle total population for i^{th} year

D = vehicle distribution by model-year

M = vehicle average miles driven per year

K_n = proportional weighting of pollutant to program objective

$W_n(y_i)$ = magnitude of pollutant change as function of model-year in grams per vehicle mile

y_i = calendar year

C = conversion factor, grams to tons

n = index of pollutants, 1 = HC, 2 = CO, 3 = NO_x

i = index of program calendar years.

5.1.4.1 Vehicle Population and Distribution Projections - Attempts to obtain more precise motor vehicle registrations projected into future years from sources such as the State Division of Motor Vehicles, R. H. Donnelly, Inc., and the California Air Resources Board were unsuccessful. Consequently, the vehicle population projection for future program years as used in this analysis will be based on the projected increase of 3.6 percent annually. This was calculated using data from the annual statistical issue of Automotive Industries which included U.S. motor vehicle registrations for the period 1900 - 1970 (reference 24). The average percentage rate increase was calculated using registration data for the years 1956 through 1970, which exhibited relative stability in passenger vehicles registrations. It is acknowledged that California registrations would not necessarily follow the national average; however, since the registration data would be common to all test regimes any lack in accuracy would not affect the relative rankings achieved.

Table 5-1 shows the California vehicle distribution by model-year for any given calendar year (reference 25). For purposes of analysis, it has been assumed that this proportional distribution would be constant and applicable throughout the total program duration.

Table 5-1. 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

5.2 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. Consequently, approximately half of the vehicle testing remains to be completed as of the publication date of this report. As much of the operational data as could be utilized are included in the analysis. 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.

5.2.1 Hypothesis Testing

The purpose of this study is to compare the relative merits of the four 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 four 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 four test regimes.

Hypothesis a, above, states that the four 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.

5.2.2 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 5-2 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 26).

Table 5-3 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 three 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 reference 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.

Table 5-2. 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 5-3. IMPORTED VEHICLES IN CLASS P/C-7

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

5.2.2.1 Vehicle Assignment - Table 5-4 identifies the test variables under observation during this experiment. The assignment algorithm was designed to incorporate all the considerations of randomness and representativeness. See Appendix D for a description of this algorithm as used for this study. In brief, the block 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.

Table 5-4. 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	4	Certificate of Compliance, Idle Test, Key Mode, and Diagnostic Test
Test period	4	1st, 2nd, 3rd, 4th quarter

5.2.2.2 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 test scheduling algorithm developed for this effort is completely described in Appendix E.

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.

5.2.3 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 four test philosophies. A valid evaluation and comparison of individual performance among the four 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 must be answered before such a decision could be rendered with any degree of confidence. These questions are stated below.

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?

5.2.3.1 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.

5.2.3.2 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 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 the other three test regimes six each. 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 uniform level of information for the participating facilities personnel and the logistics costs of transferring test vehicles within a large geographic area.

5.2.3.3 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 sample, only the top three (in terms of registrations) foreign vehicles 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 would be difficult.

Assuming that by the end of the second quarter testing (June 1971) there would be 600 vehicles processed of which approximately 300 would be serviced, then each maintenance center would have processed 12 vehicles, again discounting the fact that foreign vehicles are already constrained. Given that each facility services 12 vehicles, it is highly doubtful that it would have been exposed to the total spectrum of repair and adjustment options. Even after the total 1200 vehicles are processed, it is 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.

5.2.4 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 four 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.

5.3 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 the 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 ARB approved the 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 of the data available on serviced vehicles is performed 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 previously described under paragraph 5.1.

5.3.1 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.

5.3.1.1 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 two and three 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 in the appropriate methods for emission reduction. Attendees included representatives from Northrop, Olson Laboratories, and the Air Resources Board.

5.3.1.2 General Test Procedures - All vehicles in the program were initially given a hot start seven-mode test at the Northrop-Olson Laboratory inspection facility, which is completely equipped and staffed to perform each of the four test types. A complete description of the equipments and systems as installed at Northrop is provided in Appendix F. 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 Idle tests were transferred to those facilities receiving the ARB-provided Idle equipments.

Both the 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.

5.3.1.3 Emissions Limits - The experiment was designed to fail 50 percent of the vehicles tested in each of the test regimes, but Certificate of Compliance 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 ARB. 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. Using the results of previous studies by the ARB 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 5-5 for emission test limits.

5.3.1.4 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 G for description of additional instructions.

Table 5-5. 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

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 H describes the Idle test procedures conducted at the service facilities.

The Key Mode test was conducted by Olson Laboratory, Inc., 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 sent to the appropriate maintenance facility. At these facilities, the procedures were as outlined by the truth charts shown in Appendix I.

The Diagnostic Test concept is such that the detailed analysis conducted at the inspection facility would result 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 J contains an example of the instruction sheet.

5.3.1.5 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 will be discussed in a subsequent section.

5.3.2 Sensitivity Analysis of Operational Data

This section presents a supplemental analysis and discussion to the existing computer and statistical programs. A pass-fail limit analysis of the Idle test mode is included that can also be applied to the Key Mode and Diagnostic test procedures. Repair skill levels and excess repair analyses are presented for the Idle, Key Mode, and Diagnostic test regimes.

5.3.2.1 Summary and Recommendations - A summary and recommendation of the pass-fail limit analysis of the Idle Test data, and the excess repair and skill level analysis for the Idle, Key Mode, and Diagnostic Tests is presented:

a. Pass-Fail Limits, Idle Test Mode - When using the revised limits of +100 ppm HC and 1.0 percent CO above the original Idle test limits, the failure rate would decrease by approximately 10 percent (43 percent down to 33 percent). If high emitter limits apply, then the failure rate would be approximately 14 percent. These failure rates are based on an analysis of the idle test vehicles only. The same recommended limit criteria could also be applied to the Key Mode and Diagnostic test to statistically study the distribution of failure rates.

b. Pass-Fail Limits, 2500 rpm - Fifty-two percent of the vehicles in the Idle test group would have failed if the Idle and 2500 rpm limits had been applied. Only 42 percent failed when using the original Idle fail limits.

   Idle tests alone are not adequate indicators of failed vehicles, because Idle emissions are weighted relatively low in the Idle Modes of the California seven-mode exhaust test. However, when adding a 2500 rpm (neutral) test mode, the failure criteria improves because the idle and main circuits in the carburetor can be analyzed. The addition of the 2500 rpm criteria would be more representative of the emissions measured during the seven-mode tests.

c. Skill Levels, Idle Test Mode - The analysis showed that the participating repair facilities need additional instruction in the use of HC and CO instruments as diagnostic and quality control tools. In many cases, correct idle adjustment alone would have been sufficient to pass the vehicles which had received excess repairs.

d. Skill Levels, Key Mode - This analysis showed that additional training to the participating repair facilities is needed for interpreting truth chart measurements.

e. Skill Levels, Diagnostic Test Mode - The analysis shows that closer technical supervision of test personnel is necessary to assure more accurate tuneup diagnosis and justified repair costs for lower emissions. In the Diagnostic test mode, the repair facility followed written instruction reasonably well.

f. Excess Repair Summary - A distribution summary of the failed vehicles is presented in Table 5-6. The table shows that the failure rate was approximately equal over the three test modes. It also shows the distribution of the failed vehicles with possible excess repair costs and whether they were justified or not justified. Excess repair costs were set at $50.

Note in Table 5-6 that the Key Mode test showed the test number of failed vehicles with repair in excess of $50 (8/63 vehicles or 13 percent for Key Mode vs 24 percent (11/45) and 32 percent (22/68) for the Idle test and Diagnostic test modes).

In the Idle test mode, most of the excess repairs were not justified (nine out of eleven). In the Key Mode test two out of eight excessive repairs were not justified. The Diagnostic test had six out of 22 excessive repairs which were not justified.

g. Test Procedure Errors - When reviewing the measured data, test procedure errors were not evident. This was checked by comparing emission levels between similar test modes of the seven-mode cycle and the applicable test regime data. Idle rpm data was not always recorded during the Idle test as required by the test procedures.

5.3.2.2 Pass-Fail Limit Analysis - A pass-fail limit sensitivity analysis is presented for the idle test group of failed vehicles and includes the following categories:

a. Marginal measurements
b. Revised limits
c. High emitters
d. 2500 limits
e. Repair skills
f. Excessive repairs.

Table 5-6. SUMMARY OF FAILED VEHICLES

Exhaust Control	Total Cars In Sample	Total Failed	Number of Failed Vehicles: Failed W/Repair Cost in Excess of $50	Repair Justified: Yes	Repair Justified: No
1. Idle Test Mode (Cars 1 through 448):					
a. Controlled	55	20	4	2	2
b. Uncontrolled	51	25	7	0	7
	106	45	11	2	9
2. Key Mode Test (Cars 1 through 533):					
a. Controlled	62	22	3	2	1
b. Uncontrolled	72	41	5	3	2
	134	63	8	5	3
3. Diagnostic Test Mode (Cars 1 through 533):					
a. Controlled	59	19	4	3	1
b. Uncontrolled	71	49	18	13	5
	130	68	22	16	6

The purpose of this analysis is to determine the failure rates if alternate pass-fail emission limits had been applied.

5.3.2.2.1 Marginal Measurements - Marginal measurements are broadly defined as those exhaust emission measurements of the failed Idle test vehicle group which almost passed the original Idle limits. Marginal measurements would allow for uncontrolled test variables such as ambient temperature, vehicle preconditioning, and test driver errors.

In reviewing the Idle group data set, it became apparent that only a few of the failed Idle test group vehicles were in the marginal measurements category. In order to avoid an overlap into the revised limit category, the marginal measurement hydrocarbon fail limit was arbitrarily set at 50 ppm above the original Idle test limits. The carbon monoxide marginal limit was set at 0.5 percent above the original Idle test limits. Table 5-7 lists the marginal Idle test, revised Idle test, high emitter Idle test, and 2500 rpm limits for the uncontrolled and controlled test vehicles. Also presented are the original Idle test limits.

Table 5-7. PASS-FAIL LIMITS, IDLE TEST MODE

Emission Measurement	Original Limits	Marginal Idle Test Limits	Revised Idle Test Limits	High Emitters Idle Test	Limits @ 2500 rpm
1. Uncontrolled					
HC, ppm	700	750	800	1000	350
CO, %	6.0	6.5	7.0	10.0	4.0
2. Controlled					
a. Engine Modification					
HC, ppm	350	400	450	700	200
CO, %	5.0	5.5	6.0	10.0	1.5
b. Air Injection					
HC, ppm	250	300	350	500	200
CO, %	4.0	4.5	5.0	8.0	1.5

5.3.2.2.2 <u>Revised Limits</u> - Revised limits are defined as limits which are set substantially less stringent than the original fail limits. In this category it was intended to measure just how many less vehicles would fail the Idle tests with the revised limits. The revised limits would also determine if this category was really an outlier group, or if it should be included as part of the original limit failed test group.

As established in the learning phase of this program, the original fail limits for the idle tests were designed to fail approximately 50 percent of the vehicles. A 35 percent failure rate was arbitrarily chosen to determine how many less vehicles would fail the idle test.

In reviewing the Idle test group data set, approximately 35 percent of the vehicles would fail the idle test limits if the hydrocarbon limit was established at 100 ppm above the original Idle test limits (Table 7.7, Learning Phase Report) (reference 27). The carbon monoxide fail limit was established at 1.0 percent above the original limits (see Table 5-7).

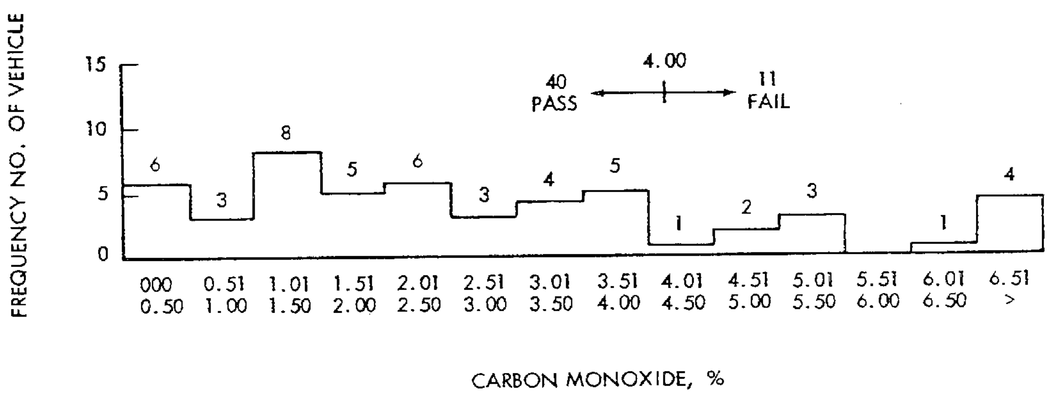
5.3.2.2.3 <u>High Emitters</u> - High emitters are defined as failed Idle test vehicles which have extremely high emissions. This group of vehicles may have gross maladjustments or components which needed major repair.

In the high emitter category, the intent was to determine what portion of the original Idle test vehicles failed because of extremely high idle emissions. In reviewing the Idle test data, a large portion of the failed sample showed emissions at approximately twice the value of the original fail limits. Several vehicles in this group also had emissions greater than the measurement instrument's capability.

The high emitter fail limits were arbitrarily set at twice the original fail limits and/or equal to the maximum measurement capability of the instrument (see Table 5-7).

5.3.2.2.4 <u>2500 Limits</u> - The 2500 limits are defined as fail limits for exhaust emission measurements conducted at 2500 rpm in neutral. The purpose of this category was to determine how many additional vehicles would have failed if the 2500 rpm emission data were also part of the Idle test fail criteria. The 2500 data would provide a reasonable measure of the carburetor's main circuit emission performance. Of course, it is recognized that the idle circuit mixture influences the main circuit mixture at the 2500 rpm (neutral) test mode. However, the Idle test alone measures only the idle circuit emission performance. In addition to the Idle test limits, the 2500 rpm limits would provide more complete evidence of failed vehicles.

In order to establish the 2500 rpm fail limits, a frequency plot of the emission measurement is shown in Figures 5-1 and 5-2. The fail limits were arbitrarily chosen where two distinct populations (pass-fail groups) were evident from the frequency plot (see Table 5-7).



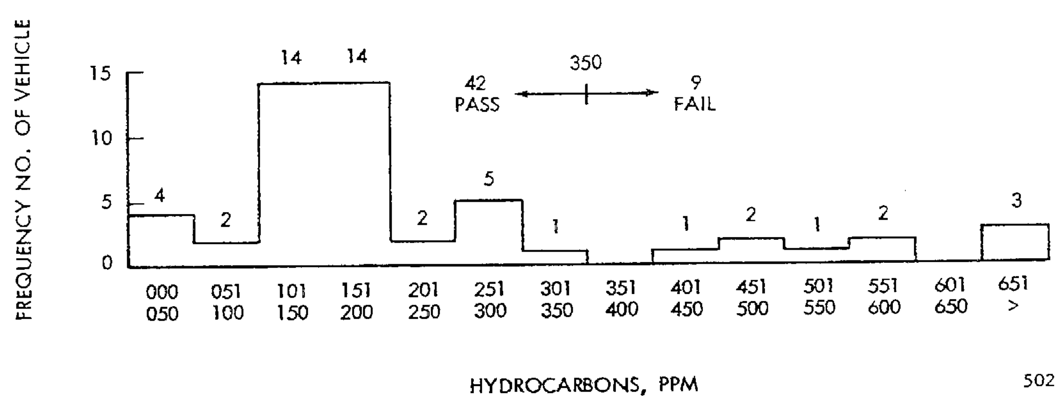


Figure 5-1. 2500 RPM EMISSION DISTRIBUTION IDLE TEST MODE - 51 UNCONTROLLED VEHICLES

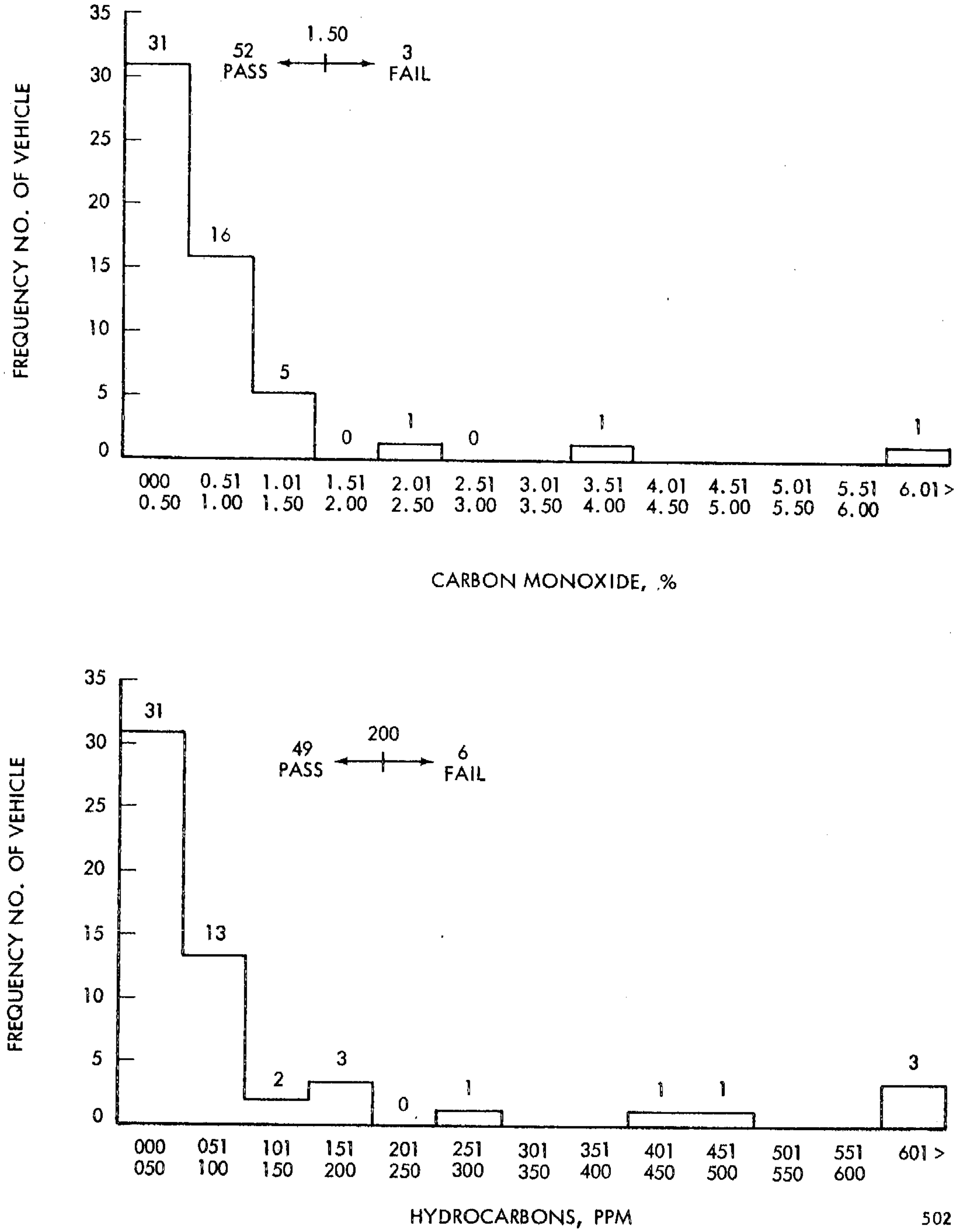


Figure 5-2. 2500 RPM EMISSION DISTRIBUTION IDLE TEST MODE - 55 CONTROLLED VEHICLES

5.3.2.2.5 Discussion of Pass-Fail Limits - This discussion is limited to 106 vehicles in the Idle test group of the first 448 vehicles tested in the program. Out of the 106 Idle test vehicles, a total of 45 controlled and uncontrolled vehicles failed the original idle test limits.

To evaluate the fail criteria, a matrix of the fail limits in each category versus the fail criteria was established and is presented in Table 5-8. This tabulation presents the fail criteria as originally established which was based on emission limits for HC and/or CO. As an alternate, one might ask, "How many cars would have failed if one had just measured idle CO or HC alone?" The last column presents the number of vehicles which failed the original Idle test limits and were exited from the test system still failing. Table 5-8 shows the fail limits and the failure criteria rank ordered in terms of decreasing failed vehicles

Table 5-8. NUMBER OF FAILED VEHICLES, IDLE TEST MODE
106 VEHICLES IN SAMPLE

Fail Criteria	Original Limits	Marginal Measurements	Revised Limits	High Emitters	Exit Fail*
1. UNCONTROLLED					
HC and/or CO	25	23	19	10	3
CO only	21	18	15	7	1
HC only	13	12	11	7	3
Both HC and CO	9	8	7	4	1
2. CONTROLLED					
a. ENGINE MOD					
HC and/or CO	16	14	13	3	1
CO only	14	13	12	2	0
HC only	4	4	4	1	1
Both HC and CO	3	3	3	0	0
b. AIR					
HC and/or CO	4	4	3	2	0
CO only	3	2	2	1	0
HC only	4	4	3	1	0
Both HC and CO	3	3	2	0	0
3. TOTAL FAILED					
HC and/or CO	45	41	35	15	4
CO only	38	33	29	10	1
HC only	21	20	18	9	4
Both HC and CO	15	14	12	4	1

*Failures based on original Idle test limits.

Originally, a total of 45/106 vehicles (42 percent) failed the Idle test HC and/or CO limits (Table 5-8). The marginal limits failed a total of 41/106 vehicles (39 percent). The revised limit group represents a failure rate of 35/106 vehicles (33 percent). The high emitters represent an overall failure rate of 15/106 vehicles (14 percent).

Four out of 106 vehicles failed the Idle tests and were exited from the system (Table 5-8). Two of the uncontrolled vehicles were exited because a valve regrind was required to comply (a review of the original data confirmed this statement). The third uncontrolled vehicle was exited per ARB instructions. One controlled vehicle (car number 177) was exited because of failing the Idle test HC limits. In reviewing the original data, and the statements by the dealer, the thermal vacuum switch was inoperative and the distributor vacuum advance chamber was connected directly to the manifold vacuum. If the distributor vacuum line had been connected to the carburetor's ported spark passage, the vehicle may have met the HC Idle limit.

The distribution of the failed vehicles is shown by fail criteria in Figure 5-3 (data are from Table 5-8). The original criteria was established as failing the HC and/or CO limit. Note that the CO only fail criteria would have failed almost as many vehicles, regardless of the limits (38/45 or 85 percent in the original limit category).

The distribution of failed test vehicles by emission control systems is shown in Figure 5-4 (data are from Table 5-8). This plot shows the distribution of the fail limits for each control system. Note that the distribution for the AIR vehicles shows less failure response to the various fail limit categories. In this case, air injection may be masking moderate emission problems except on vehicles with very high idle emission levels.

Table 5-9 shows the distribution of failed Idle test vehicles by including the 2500 rpm emission measurement as part of the Idle test fail criteria. The first column in the table shows the distribution of failures as originally proposed (idle limits only). The second column shows the distribution of failures if both the idle and/or 2500 rpm limits failure criteria had been applied to each vehicle. The third column shows the number of failed vehicles for the 2500 rpm limit only. Table 5-9 shows that 55/106 vehicles (52 percent) would have failed if the idle and/or 2500 rpm limits had applied, while only 45/106 vehicles (42 percent) would have failed using the idle limit only.

The data for the idle and CO fail criteria are shown in Figure 5-5 for both the controlled and uncontrolled vehicle groups. Note that the failure rate for the 2500 rpm only criteria is not a good indicator by itself.

Idle tests alone are not adequate indicators because idle emissions are weighted relatively low in the idle related modes of the standard California 7-mode exhaust test. However, when adding the 2500 rpm criteria, it becomes a better failure criteria because the carburetor is primarily operating in the main circuit at 2500 rpm in neutral. When operating at 2500 rpm in neutral, the idle circuit is operating and does contribute to the measured emission because of high manifold vacuum, but only to a small degree. This is more representative of the measured emissions during the acceleration modes which are heavily weighted in the 7-mode cycle.

Idle adjustments will not cure carburetor main circuit problems. In reviewing the 2500 rpm data, 8/45 vehicles (18 percent) of the failed Idle test vehicles would still have failed after service and/or adjustment at the repair facility.

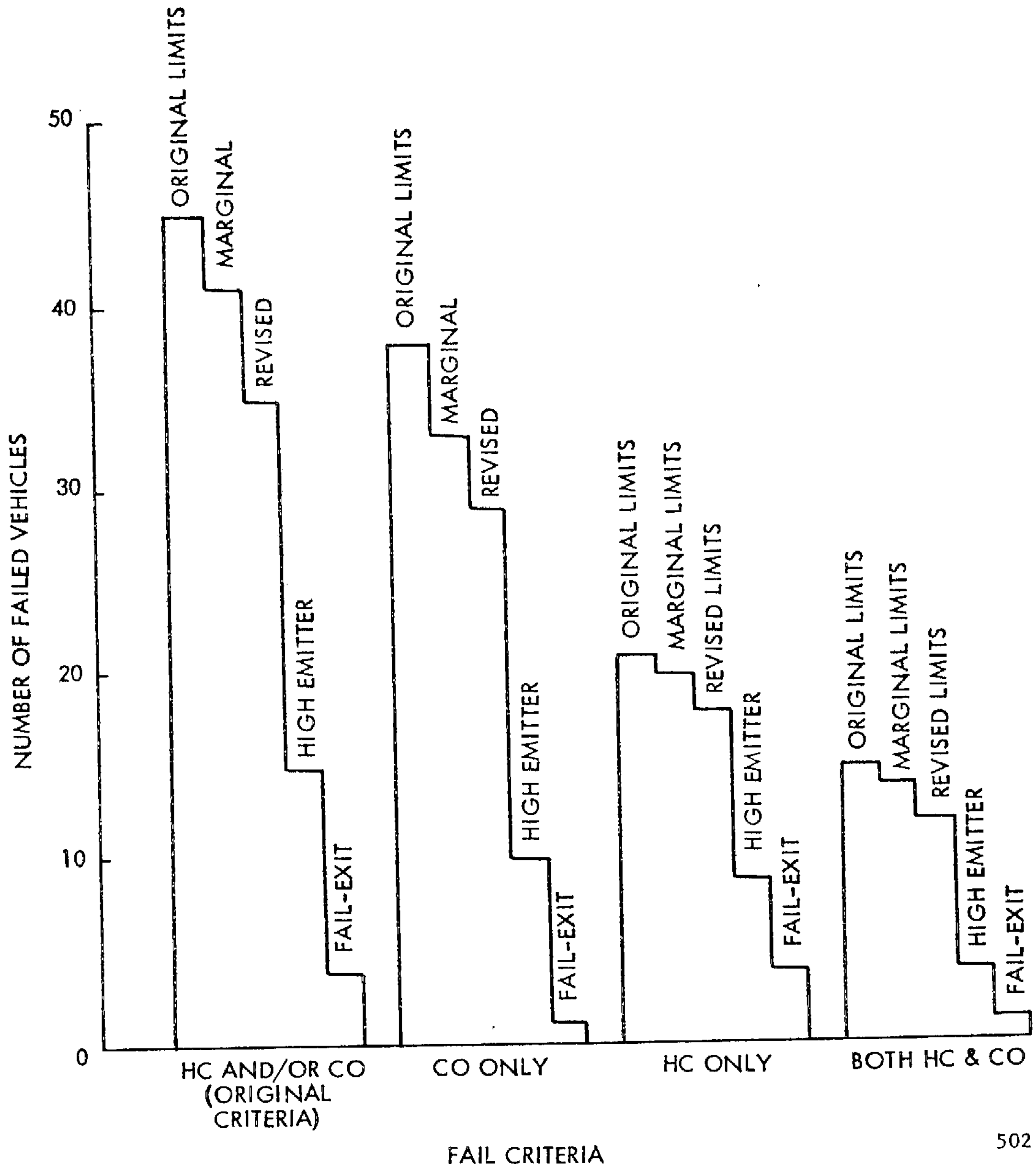


Figure 5-3. DISTRIBUTION OF FAILED VEHICLES, IDLE TEST MODE BY FAIL CRITERIA - CONTROLLED AND UNCONTROLLED VEHICLES

5.3.2.3 Excess Repair Analysis - The intent of this section is to identify the failed test vehicles that received possible excessive (and/or unjustified) repairs. An analysis of excess repairs of the failed test vehicles is presented for the Idle, Key-Mode, and Diagnostic Test modes.

An excess cost criteria was established for identifying the failed vehicles which may have received excessive repairs. First, repair cost frequency distributions of all failed vehicles were tallied and are shown as bar charts in Figures 5-6 and 5-7. The bar charts show the distribution of the total retail costs (parts and labor) for each $10.00 increment.

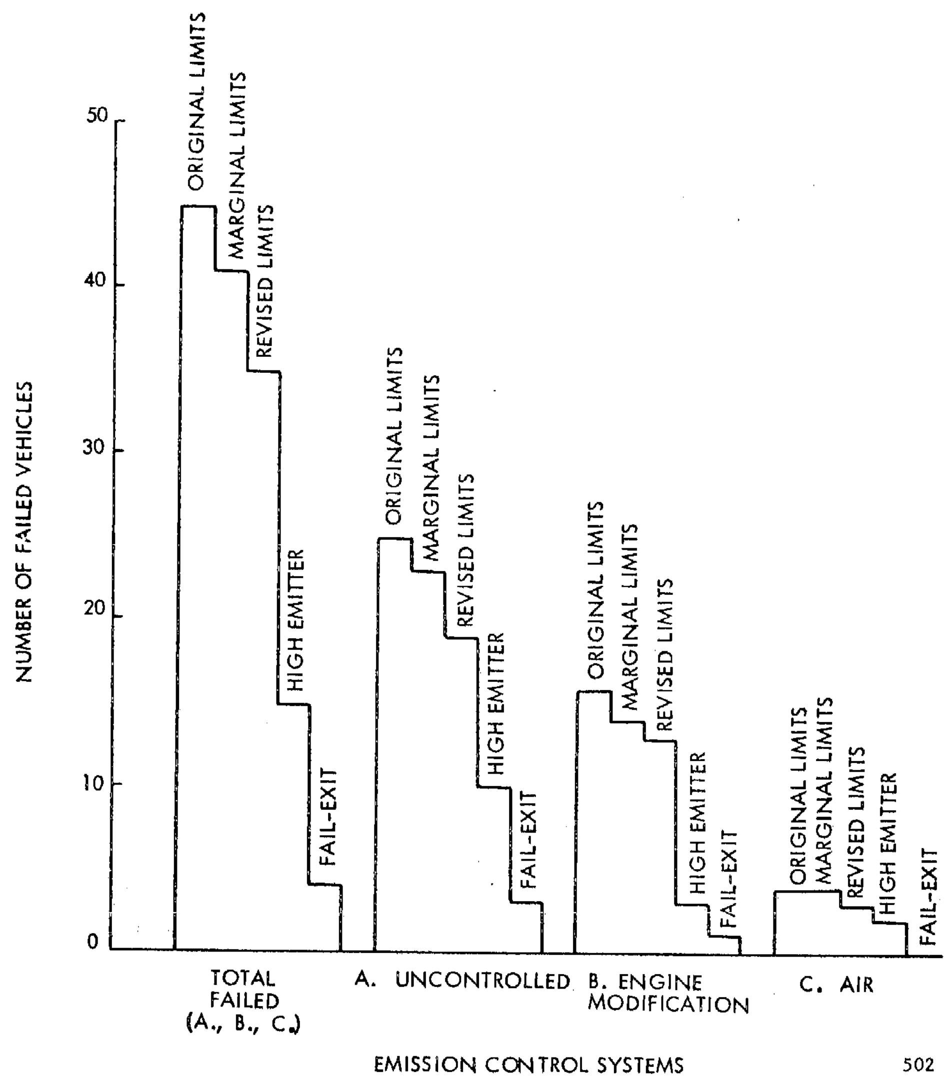


Figure 5-4. DISTRIBUTION OF FAILED VEHICLES, IDLE TEST MODE BY EMISSION CONTROL SYSTEMS

A $50.00 repair cost limit was established as being possibly excessive. For this discussion, the failed vehicles with repair costs of $50.00 or greater were reviewed to determine if the repairs were excessive or justified. It must be recognized that the discussion is based on a review of the recorded data only. In some cases this may not be adequate for an accurate excessive repair analysis.

Table 5-9. NUMBER OF FAILED VEHICLES, IDLE TEST MODE BY IDLE AND 2500 RPM FAIL CRITERIA 106 IDLE TEST VEHICLES

Group	Idle Limits Only	Idle and/or 2500 RPM Limits	2500 RPM Limits Only
Uncontrolled Group	25	32	13
Controlled Group	20	23	7
Total	45	55	22

5.3.2.3.1 Idle Test Mode - The repair facility was originally instructed to repair the failed Idle test vehicles only as necessary to comply with the original Idle test emission limits. An analysis of each car with repair bills in excess of $50.00 was made of the data recorded by the repair facility as well as a review of the Idle test data. The attempt here was to determine whether the vehicle needed these repairs in order to comply with the Idle test criteria.

Table 5-10 lists the failed Idle test cars which had repair costs in excess of $50.00. The table also shows whether the repair service was justified, and comments on reasons why they were not justified. In summary, Table 5-10 shows that only two of the eleven vehicles had justified repair costs in excess of $50.00. In most cases, the emission analysis showed that a correct idle mixture and speed adjustment would have been adequate to comply with the vehicle Idle test criteria. This would have moved these cars back down to the under $20.00 repair cost bracket.

The excess repairs may have been conducted in all honesty, but the analysis does show that repair skill levels for the Idle test regime are lacking when adjusting or tuning for low emissions.

The repair skill levels were analyzed by reviewing idle CO's before and after service. Also, these data were compared to the 7-mode Idle CO data for test error problems. The skill levels for the Idle test mode were broadly categorized into two groups:

a. Inadequate Adjustment Techniques - This group had some idle mixture changes which yielded either an increase or a decrease in idle CO levels

b. Good Adjustment Techniques - This group had good idle CO adjustments which were at or near the vehicle manufacturer's specification. This group also showed substantial reductions in idle CO after idle adjustment.

The auto technician who is making inadequate idle adjustments is doing one of two things:

a. He is not using the CO meter at all to make idle adjustments

b. He is using the CO meter, but doesn't understand how to adjust idle CO levels and maintain good idle quality.

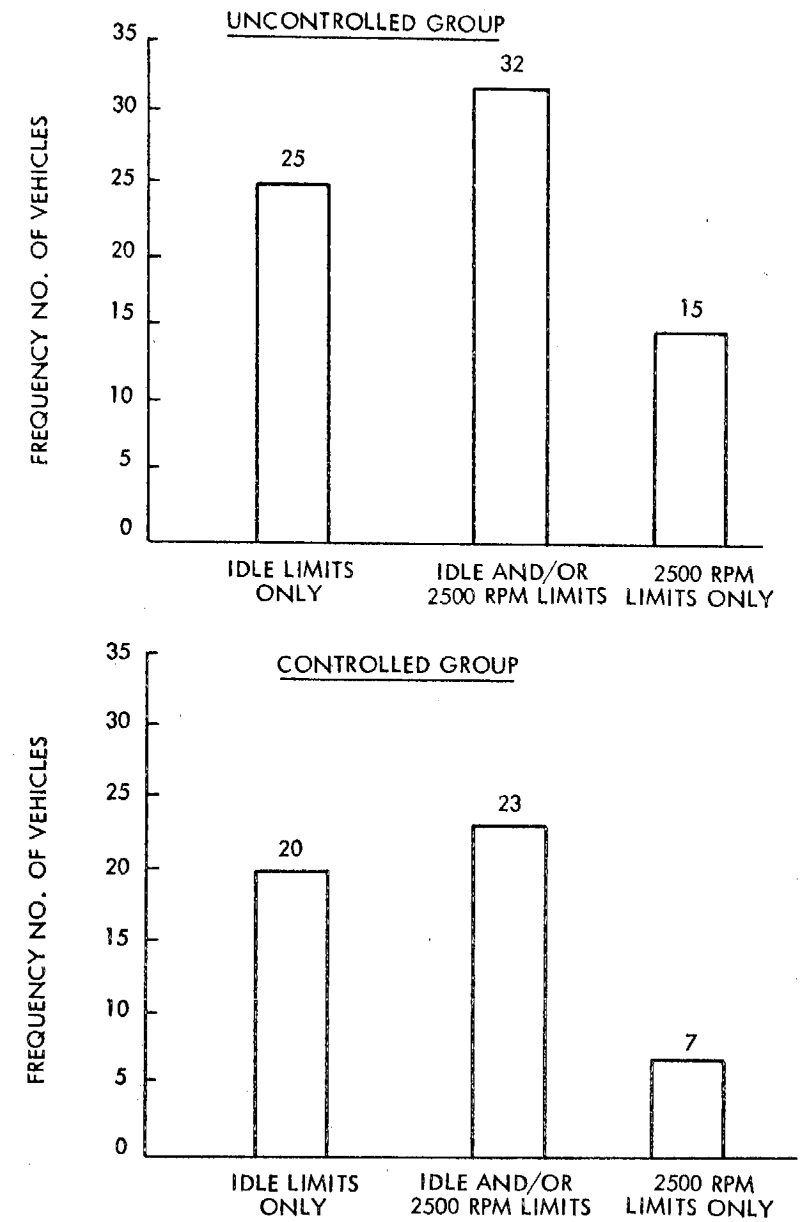


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Figure 5-5. DISTRIBUTION OF FAILED VEHICLES, IDLE AND 2500 RPM FAIL CRITERIA - 106 VEHICLES IN SAMPLE

Of course, the auto technician who made adequate idle adjustments may have been fortunate by chance. This statement comes from a review of the repair facilities who conducted the service. The data shows that no particular repair facility was better on idle adjustment technique than any of the other participating repair facilities.

The above discussion points out the need for training the auto technician in carburetor malfunction diagnosis and idle adjustment techniques. With proper training of auto technicians, many of the vehicles would have shown substantial emission reductions when retesting the vehicle.

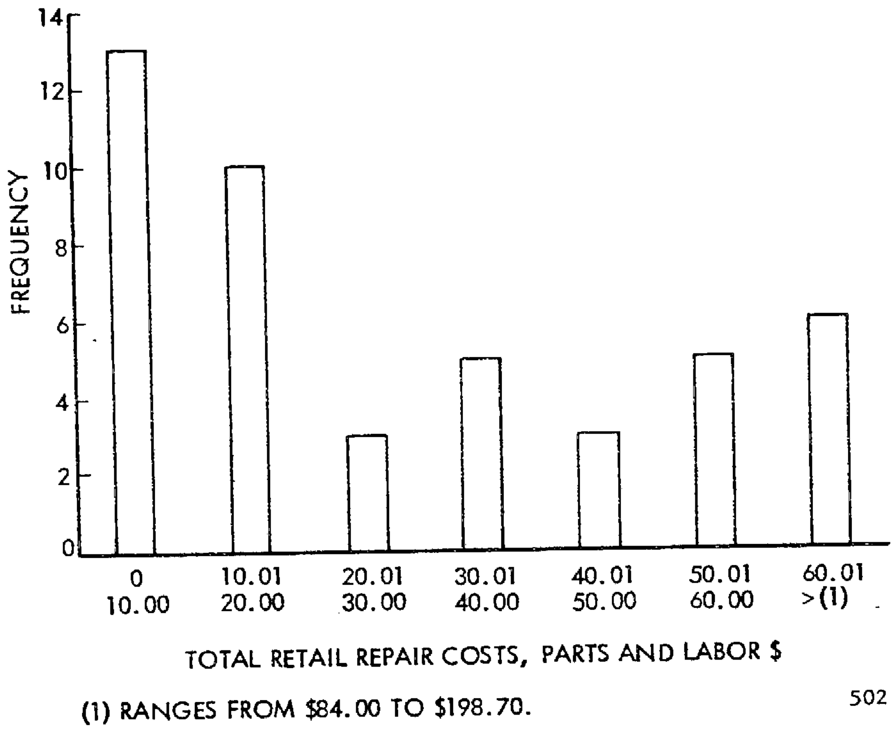

Figure 5-6. COST DISTRIBUTION OF 45 FAILED IDLE TEST VEHICLES

For on-going work, technicians at each repair facility should receive additional training in the use of the HC and CO meter as a diagnostic tool. The technician's performance after training could be controlled by setting "after adjustment limits" for retest purposes.

5.3.2.3.2 <u>Key Mode Excess Repair Analysis</u> - The repair facility was originally instructed to diagnose and repair the failed Key Mode test vehicles with only the aid of the "truth chart." During the tests the idle, low cruise, and high cruise HC and CO data were recorded on the truth chart and forwarded to the repair facility. The vehicle was repaired in accordance with the truth chart and returned for retesting.

An analysis of each car with repair bills in excess of $50.00 was conducted by reviewing the truth chart as well as the before and after service 7-mode test data. Judgments were made on each vehicle to determine the justification of the repair from an emission standpoint.

Table 5-11 lists the failed Key Mode vehicles which had repair costs in excess of $50.00. Justification for repair and comments are also shown. Six out of eight vehicles had justified repair costs over $50.00. This indicates that the repair facility made a correct diagnosis and followed up with repair service which enabled the vehicle to ultimately comply with the Key Mode emission limits. However, two of the eight vehicles received repairs which were excessive and not justified (Table 5-11). In one case (car 300), the minor tuneup was not justified because the truth chart did not indicate ignition missfire. In the second case (397), only the idle adjustment was necessary to comply with the Key Mode test limits.

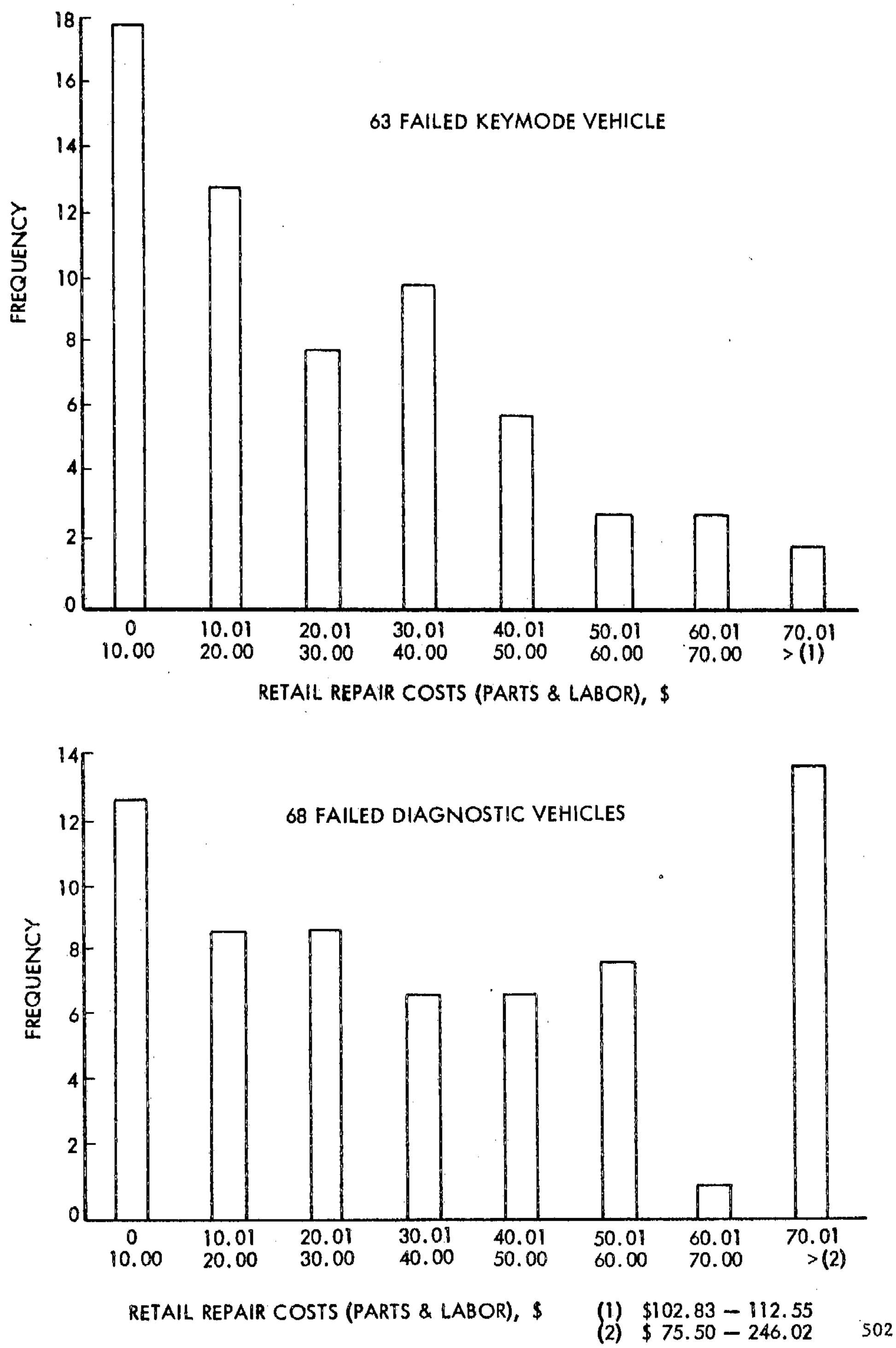

Figure 5-7. REPAIR COST DISTRIBUTION OF FAILED VEHICLES

Table 5-10. FAILED IDLE TEST CARS WITH REPAIR COSTS EXCEEDING $50

Table 5-10. FAILED IDLE TEST CARS WITH REPAIR COSTS EXCEEDING $50

Car No.	Exhaust Control Equipment(1)	Exhaust Control Repair	Minor Tuneup(2)	Major Tuneup(3)	Carburetor: Clean, Overhaul	Carburetor: Install Rebuilt	Valve Regrind	Total Cost, $(4)	Repair Service Justified?	Comments
116	0			X		X		$ 75.50	No	Ignition tuneup and rebuilt carburetor not justified
163	0					X		59.95	No	Rebuilt carburetor not justified
206	0		X				X	169.00	No	Car only needed idle adjustment; valve regrind not justified
213	0				X		X	121.70	No	Valve regrind not justified
231	0		X					52.91	No	Needed idle adjust only to comply
246	0			X	X			84.10	No	Ignition tuneup not justified
247	0			X	X			57.50	No	Needed idle adjust only to comply
177	1		X					50.32	No	Thermostatic vacuum valve switch disconnected. Minor tuneup not justified
212	1					X	X	198.70	Yes	Valve regrind justified
412	1		X					50.61	No	Thermostatic vacuum valve switch disconnected; minor tuneup not justified
30	2	X						93.87	Yes	New air pump installed, justified

(1) 0 - No exhaust control; 1 - Engine Mod; 2 - AIR
(2) Ignition tuneup (points, plugs, cond.) only
(3) Ignition and carburetor tuneup
(4) Retail parts and labor

Table 5-11. FAILED KEY MODE VEHICLES WITH REPAIR COSTS EXCEEDING $50

Table 5-11. FAILED KEY MODE VEHICLES WITH REPAIR COSTS EXCEEDING $50

Car No.	Exhaust Control (Garage)	Repair Exhaust Control	Minor Tuneup	Major Tuneup	Carburetor		Valve Regrind	Total Cost	Repair Service Justified?			
					Clean, Overhaul	Install Rebuilt			Yes	Excess Estimated Cost	Real Cost	Comments
19	2 (4)		X (1)		X			54.42	X			Minor tuneup justified
21	2 (2)			X				102.83	X			Excess parts installed
464	1 (6)					X		68.90	X			Could have overhauled carburetor
397	0 (5)			X (1)	X (1)			50.45		40.00	10.45	Exit fail, idle adjust would have passed car
493	0 (4)					X		67.25	X			Exit-fail-rich cruise CO
98	0 (6)			X	X			50.15	X			Exit fail - idle HC, less misfire at idle
131	0 (6)		X				X	112.55	X			
300	0 (2)			X (1)	X			63.75		22.00	4.00	Minor tuneup not justified; float was problem

(1) Not required to pass Key Mode test

As a result of the unjustified repairs of the Key Mode vehicles, the estimated excess and real costs are listed in Table 5-11. As the invoices were reviewed, the excess repair costs (parts and labor) were estimated. In view of the Key Mode failures which had excess repairs, the analysis shows the participating repair facilities need some additional training in the interpretation of the truth charts.

5.3.2.3.3 Diagnostic Test Excess Repair Analysis - For the Diagnostic test mode, the emission test facility personnel conducted the engine tuneup diagnosis of the failed Diagnostic test vehicles. The repair facility received the diagnostic report with explicit repair instructions. In most cases the repair facility repaired the cars as instructed by the diagnostic chart.

An analysis of each car with repair bills in excess of $50.00 was conducted by reviewing the diagnostic chart, diagnostic emission test data, and the 7-mode emission results. Judgment for excess repairs was primarily based on the diagnosis conducted by the test personnel rather than the performance of the repair facility.

Table 5-12 lists the failed Diagnostic test vehicles which had repair costs in excess of $50.00. Repair service justification and comments are also included. Sixteen of the 22 vehicles had justified repair costs over $50.00. This indicates that the test personnel made correct diagnosis that was required to meet the Diagnostic test emission limits. However, in some cases the test personnel tended to diagnose excessively in terms of the replaced parts. Two examples are distributor caps and rotors. Six of the 22 vehicles received excessive repairs which were diagnosed or repaired incorrectly. The most common incorrect diagnosis was the installation of new carburetors as instructed by the test personnel.

As a result of the unjustified repairs, estimated excess and real costs (parts and labor) are included in Table 5-12. The analysis shows that the test personnel who diagnose the vehicles need closer supervision to assure correct diagnosis prior to the repair of the failed vehicle.

5.3.2.4 Errors of Commission and Omission - The test regimes evaluated in this study are analyzed as to reduction of the exhaust pollutants HC, CO, and NO. Vehicles failing a pre-established set of limits are subjected to varying levels of maintenance and the reductions in emissions noted.

The question arises as to the ability of the test regimes to detect the high emitters. Two types of errors may occur; errors of commission and errors of omission. Errors of commission relate to those cars that were said to be high emitters and were serviced when they were in fact low emitters. Errors of omission applies to cars that are high emitters and went undetected.

To determine a cutoff point for differentiating high emitters from low emitters, the assumption was made that if the test regime was successful in detecting the high emitters, these high emitters would be included in a group of vehicles representing the proportion of the total tested population corresponding to the ratio of the failed vehicles in a test regime to the total vehicles in the test regime. For example, 31 of 67 uncontrolled vehicles failed the Idle test so these 31 should appear in the 31/67 worst percentile of the total population of 278 uncontrolled cars tested if the Idle test is totally effective in detecting high emitters.

Table 5-12. FAILED DIAGNOSTIC VEHICLES WITH REPAIRS EXCEEDING $50

Table 5-12. FAILED DIAGNOSTIC VEHICLES WITH REPAIRS EXCEEDING $50

Car No.	Exhaust Control (Garage)	Minor Tuneup	Major Tuneup	Carburetor		Valve Regrind	Other Repairs	Total Cost	Repair Service Justified			
				Clean, Overhaul	Install Rebuilt				Yes	Excess Estimated Cost	Real Estimated Cost	Comments
84	0(6,8)	X						$138.15	X			Head gaskets replaced.
138	0(1)			X				89.85	X			Some excess parts.
141	0(4)		X	X				70.00	X			
154	0(2)	X(1)						52.33		$20.00	$ 32.33	Diagnosis was correct (idle mixture). Adjust points and timing. Dealer replaced intake and exhaust manifold gaskets, which was not justified.
175	0(5)		X	X				51.98	X			Passed second retest. Cylinder #7 wire cause for failure.
241	0(1)		X					71.50	X			Failed and exited from system. Carburetor main circuit could have been repaired.
245	0(6)	X						71.54	X			
280	0(6)	X				X		246.02		55.00	181.02	Excess parts cost (16 valves) only 1 was needed (unless all valves were thin)
295	0(5)		X					72.94	X			Repairs justified; some excess parts.
283	0(6)		X	X	X			131.95		42.00	89.95	New carburetor not justified.
296	0(7)			X	X(new)			50.15	X			Overhaul caused "carburetor emulsion tube to crack." New carburetor installed after overhaul.
322	0(6)		X					72.05	X			Some excess parts. Original diagnosis was minor tuneup and idle adjustment which was incorrect. Problem was main circuit.

Table 5-12. FAILED DIAGNOSTIC VEHICLES WITH REPAIRS EXCEEDING $50 (Continued)

Table 5-12. FAILED DIAGNOSTIC VEHICLES WITH REPAIRS EXCEEDING $50 (Continued)

Car No.	Exhaust Control (Garage)	Minor Tuneup	Major Tuneup	Carburetor: Clean, Overhaul	Carburetor: Install Rebuilt	Valve Regrind	Other Repairs	Total Cost	Repair Service Justified: Yes	Excess Estimated Cost	Real Estimated Cost	Comments
323	0(6)		X					$123.18	X			Fail and exit still had high CO at cruise. High costs due to labor in tightening head bolts (leaky head gaskets).
332	0(6)		X		X(new)	X		198.55		$ 23.00	$175.55	Fail and exit due to high CO at cruise. New carburetor was cause. Excess ignition parts replaced. Valve regrind justified.
378	0(2)		X	X			Fuel Tank	104.80		26.00	78.80	Clean fuel tank; was not necessary.
387	0(6)		X	X				59.30	X			Some excess parts.
479	0(6)	X				X		178.68	X			$110 valve labor appears high.
505	0(2)				X(new)			51.64	X			Could have rebuilt carburetor.
62	1(2)	X						50.95	X			
37	2(4)	X						57.60	X			Excess parts (wires).
210	2(1)	X						60.42	X			Starter neutral switch replaced.
281	1(6)		X	X	X(new)			112.20		65.00	47.20	Old carburetor could have been repaired. Excess ignition repair; not necessary.

(1) Adjustments only

Since the Certificate of Compliance test called for service on every vehicle tested, its further discussion will be omitted. The percentiles calculated for the controlled and uncontrolled group of the remaining test regimes are shown in Figure 5-8. The values of HC and CO were ranked in order in controlled and uncontrolled groups and a tally was made of the number of high emitters detected and the number of high emitters in the "bad" group that were undetected.

The difference between the number of cars failed and the number of high emitters detected is the number of "good" vehicles that were failed in error. The tabulation is shown in Table 5-13.

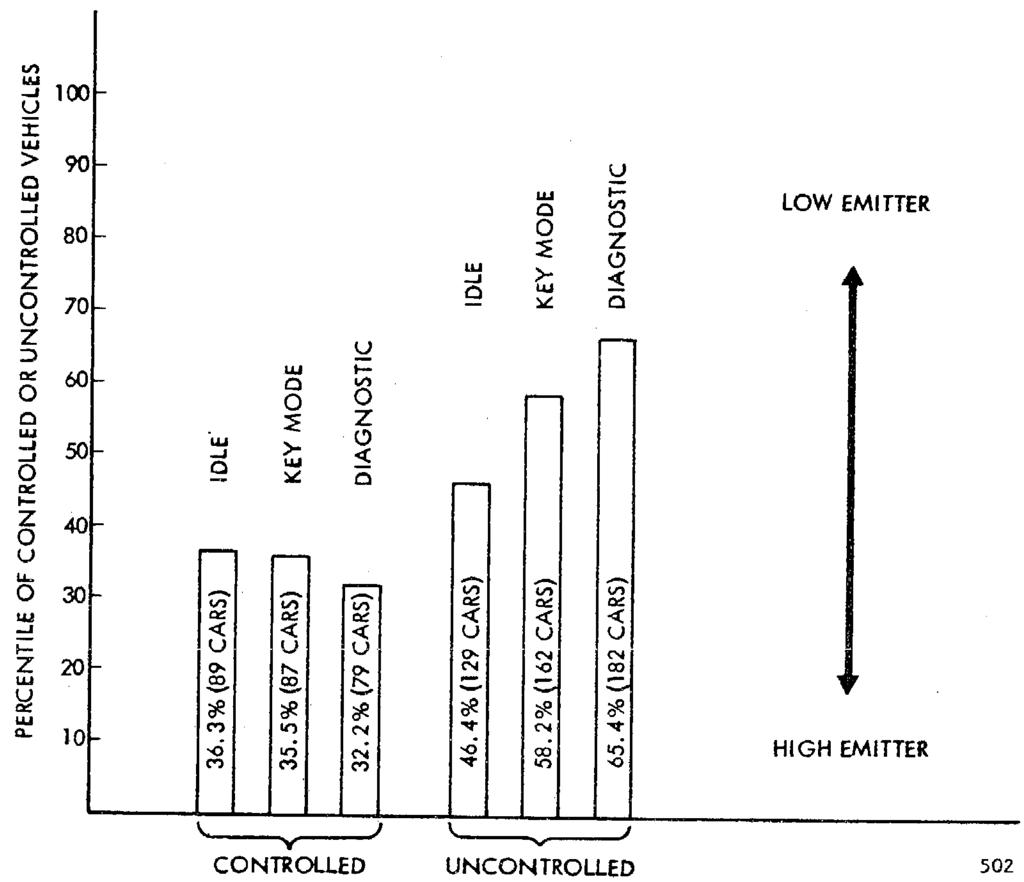

Figure 5-8. SPECTRUM OF FAILED TEST REGIME VEHICLES WITH RESPECT TO ALL VEHICLES IN A SUBSET

The tabulated numbers were then expressed as a percent of the failed cars within each test regime. Figure 5-9 displays the effectiveness of each of the test regimes to detect high emitters. It indicates that the Diagnostic test was more capable of detecting HC malfunctions in cars with high mileage, namely uncontrolled cars. This was due primarily to the ignition system breakdown under heavy load. With that exception, the test regimes were all the more effective in detecting high CO emitters than high HC emitters. When combined, Diagnostic is slightly more effective than Key Mode in identifying high emitters with Idle a close third.

Table 5-13. ERRORS OF COMMISSION (1) AND ERRORS OF OMISSION (2)

Group	Test Regime		
	Idle	Key Mode	Diagnostic
Controlled:			
Total	66	62	59
Failed	24	22	19
HC			
Failed Bad Car	16	15	8
Failed Good Car (1)	8	7	11
Passed Bad Car (2)	8	7	9
CO			
Failed Bad Car	20	15	11
Failed Good Car (1)	4	7	8
Passed Bad Car (2)	8	5	5
Uncontrolled:			
Total	67	72	75
Failed	31	42	49
HC			
Failed Bad Car	18	29	45
Failed Good Car (1)	13	13	4
Passed Bad Car (2)	16	18	8
CO			
Failed Bad Car	22	34	39
Failed Good Car (1)	9	8	10
Passed Bad Car (2)	15	15	13
All Vehicles:			
Total	133	134	134
Failed	55	64	68
HC			
Failed Bad Car	34	44	53
Failed Good Car (1)	21	20	15
Passed Bad Car (2)	24	25	17
CO			
Failed Bad Car	42	49	50
Failed Good Car (1)	13	15	18
Passed Bad Car (2)	23	20	18
HC and CO			
Failed Good Car (1)	9	7	7
Passed Bad Car (2)	35	37	18

Errors of commission and omission are presented in Figure 5-10 as a percent of the vehicles failed in each test regime. In total, there were more errors of omission than commission when HC and CO are viewed separately. When HC and CO are taken together such that a high emission level in either will cause the vehicle to fail the test; Idle did not detect an amount equal to 63.6 percent of the high emitters, Key Mode missed an amount equal to 57.8 percent of the failed cars, and Diagnostic only missed an amount equal to 26.5 percent of its failed cars.

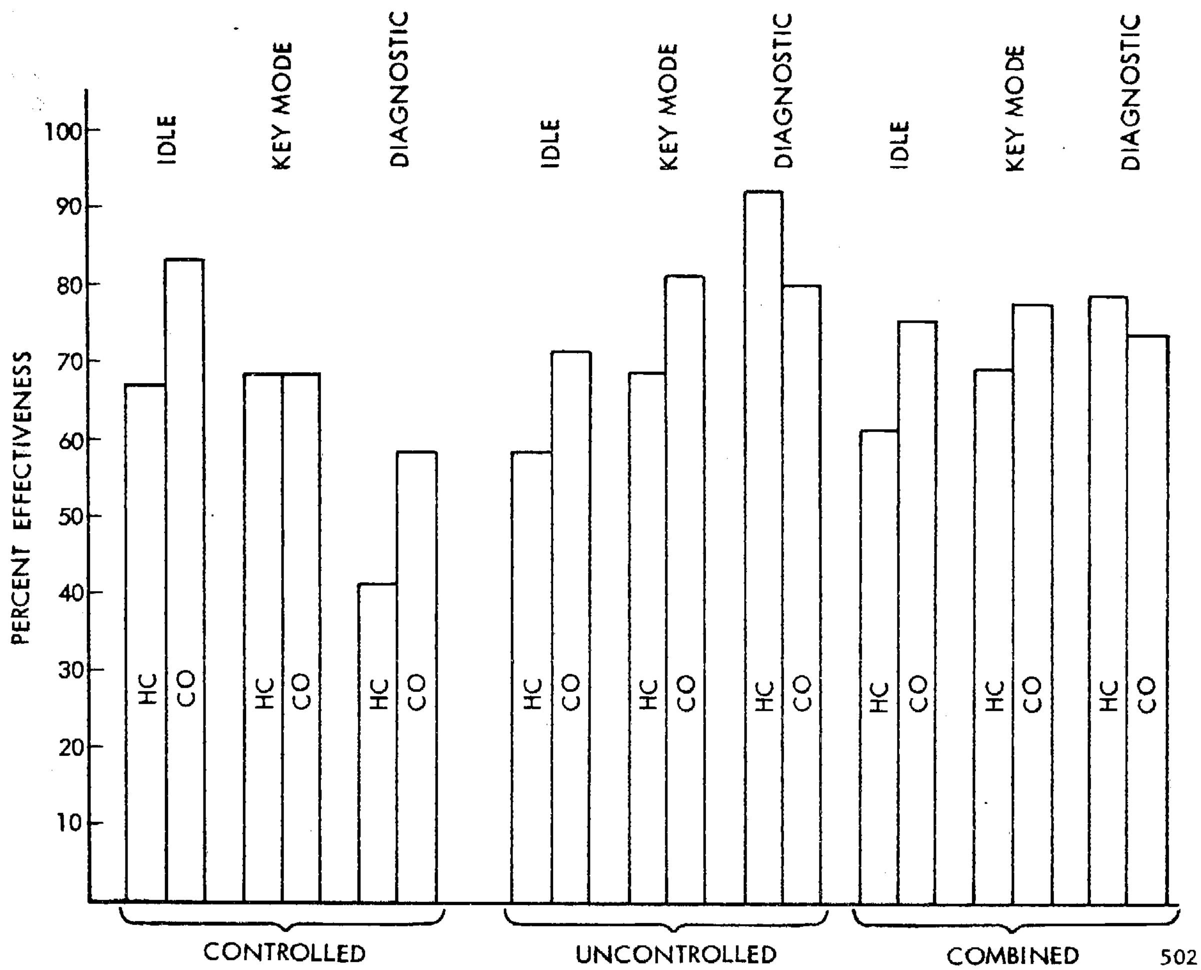

Figure 5-9. EFFECTIVENESS IN SELECTING HIGH EMITTERS

The Diagnostic test regime, therefore, detected more high emitters, failed fewer "good" cars, and missed considerably fewer bad cars than Idle or Key Mode. Key Mode was better than Idle at not failing good cars and missed slightly fewer bad cars.

5.3.3 Statistical Analysis

The intent of the testing program was to evaluate the effectiveness of four test and service regimes in reducing California air pollution. The test program, of necessity, could only measure a representative sample of the California automotive population. Thus, the response of the sample provides an estimate of the emission reduction to be achieved on a statewide basis. This section considers how good this estimate is.

5.3.3.1 Range of Emission Reduction - Figure 5-11 summarizes the HC emission reduction data obtained during the tests as well as presenting the mean emission observed after service. The lower point of each triangle denotes the observed emission reduction. The line under the triangle indicates the range within which the HC emission reduction for all cars in California would be expected to fall if they were all subjected to the indicated test and service regime. Specifically there is a 95 percent confidence that the HC reduction (in an algebraic sense) would be at least the

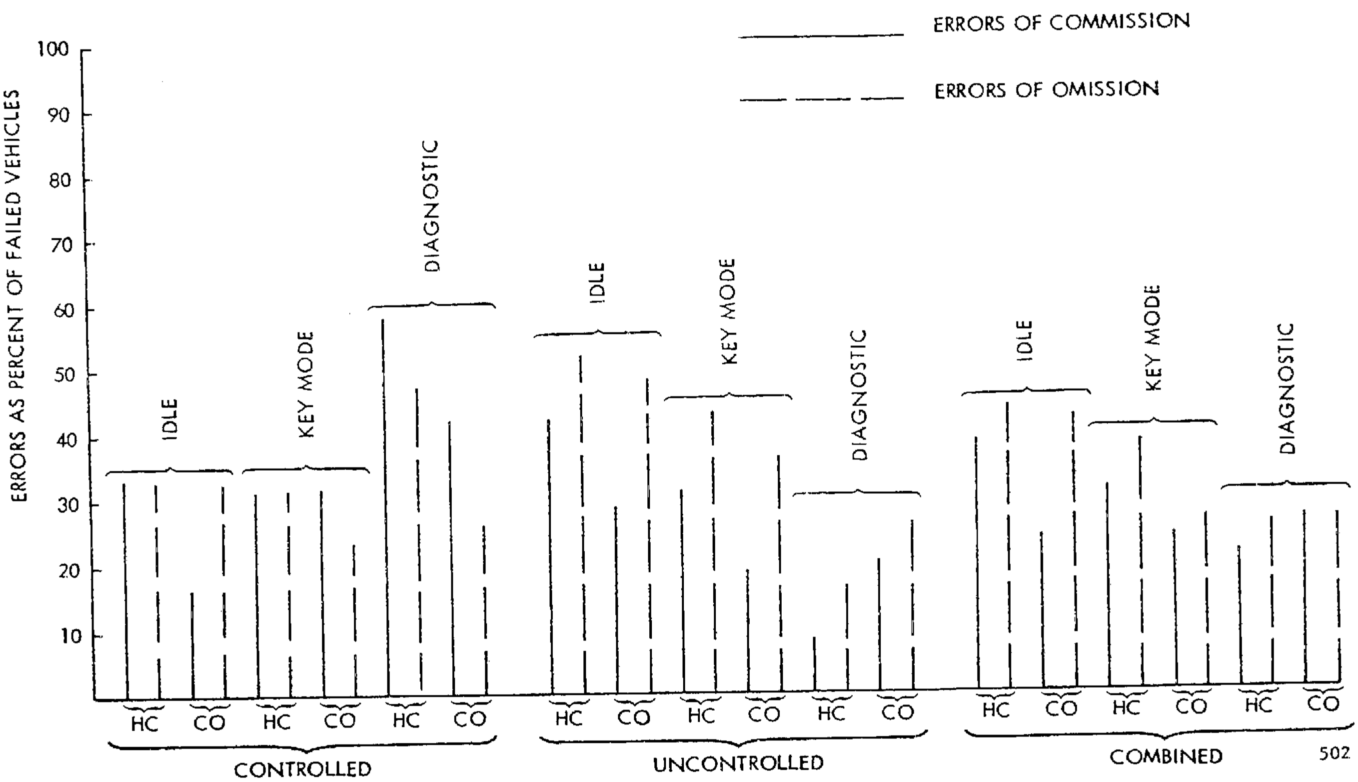

Figure 5-10. RELATIONSHIP OF ERRORS OF COMMISSION AND OMISSION BY TEST REGIMES

amount indicated by the left end of the line and a 95 percent confidence that the reduction will not exceed (again, in an algebraic sense) the amount indicated by the right end. This data was obtained using the students "t" test (reference 28). These confidence intervals for the length of the line are determined by the number of cars tested and the variability of emissions between cars.

When the testing program is complete, there will be data available on about twice as many cars. The mean reductions will be somewhat different and the length of the line (confidence interval) will decrease by about 30 percent. This is due to the distribution approaching Gaussian normal where the uncertainty in the mean is a function of $1/\sqrt{n}$. Figures 5-12 and 5-13 present, in a similar format, emission reduction data for CO and the NO_x, respectively. Note that the abscissa scales are different. When a line extends to a negative value, the effect of the test and service regime on the California population could be detrimental. When the mean value is negative, the regime is more likely to cause a detrimental effect than a beneficial one.

A study of these confidence limits indicates that all test and service regimes reduce HC emissions. For CO, the certificate of compliance is ineffective; the other regimes are effective in reducing emissions. For the oxides of nitrogen, all test and service regimes tend to increase emissions; however, there is a slight possibility of a reduction. This detrimental result should be anticipated since existing cars and control devices were not designed with NO_x emissions in mind; in fact, the control efforts for new cars has increased the emission of this pollutant.

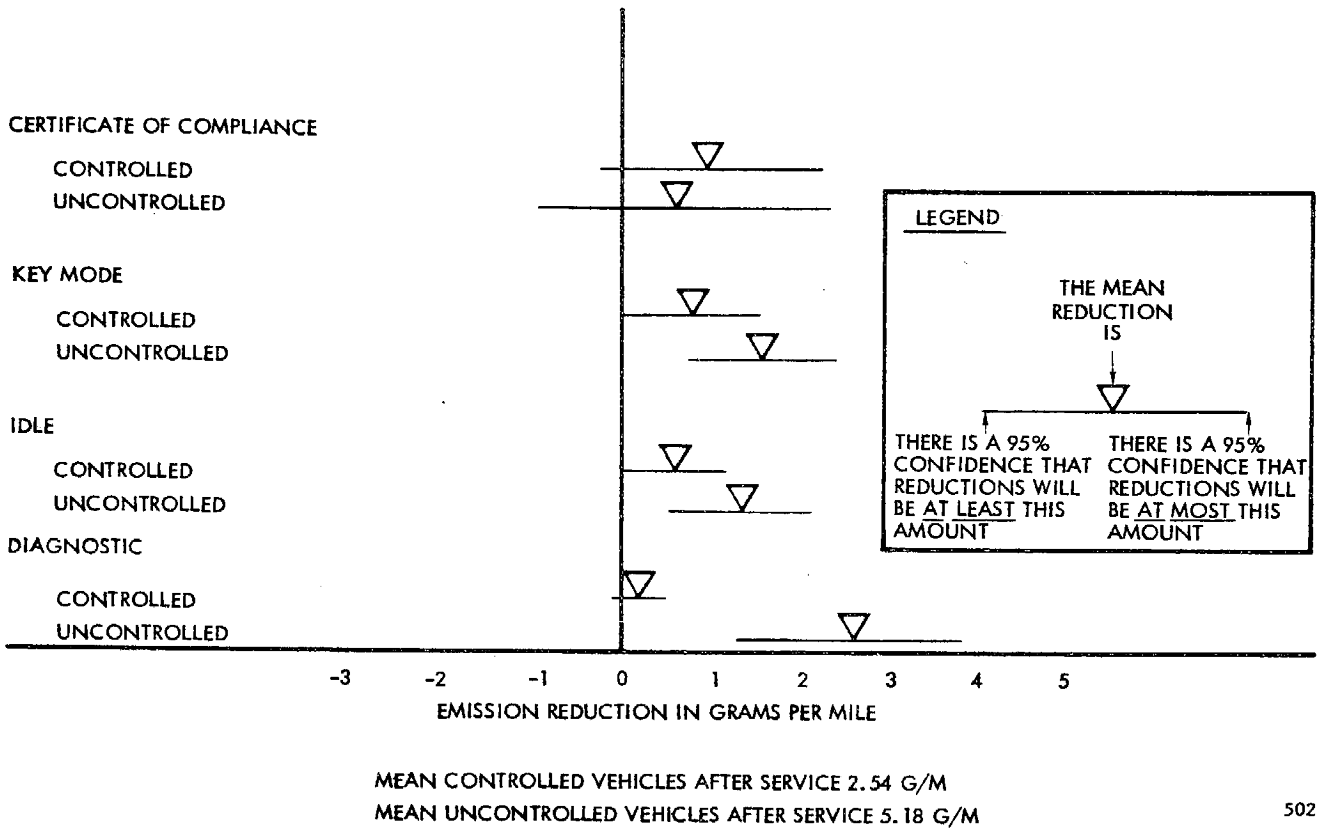

Figure 5-11. CONFIDENCE OF HYDROCARBON REDUCTION BY EACH TEST AND SERVICE REGIME FLEET RESULTS

The data of Figures 5-11, 5-12, and 5-13 were determined by assuming the reduction in emissions is a Gaussian normal distribution. This is mathematically justified by Liapounoff's theorem, which states that the probability distribution of a sum of random variables tends towards a Gaussian distribution as the number of components increases without limit (reference 29). To test this tendency, a "t" test was performed to test the significance of the emission reduction of those cars which failed the original test and were serviced and then retested. The test was made assuming the original distribution was either Gaussian or log normal. Table 5-14 shows the results of this test and shows that it makes little difference which distribution is used. The NO_x data was not converted to log normal since the distribution appeared to be Gaussian normal. Table 5-14, thus, validates the use of the result of Liapounoff's theorem; the assumptions of Figures 5-11, 5-12, and 5-13 are, therefore, substantiated.

5.3.3.2 Pass Fail Criteria - Paragraph 5.3.2 discussed the criteria by which cars were passed or rejected in the various test and service regimes. The objective was to fail one-half of the cars while actually 0.4756 were failed in the Idle, Key Mode, and Diagnostic Tests (all Certificate of Compliance cars failed). However, the failure rates for the various test and service regimes vary from a low of 0.3220 to a high of 0.6901. The individual failure rates (Table 5-6) are not representative of the desired failure rate of one-half. This fact is taken into account in normalizing the cost effectiveness data.

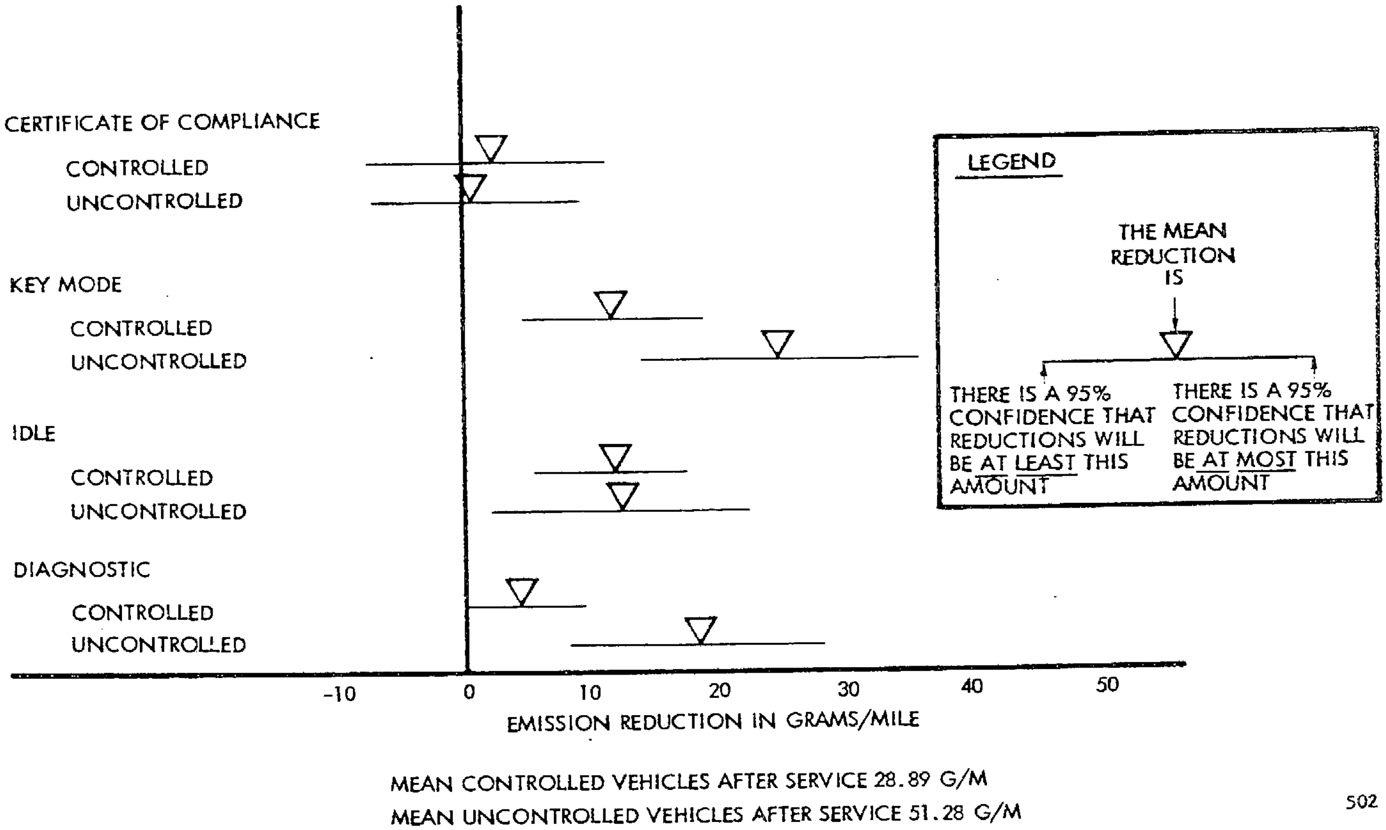

Figure 5-12. CONFIDENCE OF CARBON MONOXIDE REDUCTION BY EACH TEST AND SERVICE REGIME FLEET RESULTS

For the statistician, the cumulative binomial distribution for the data of Table 5-6 indicates that, in four of the six cases considered, the probability of having more failures than observed is greater than 0.985 or less than 0.001. The uncontrolled cars tested in the Idle and Key Mode tests are the only two that could be from a binomial distribution with a failure probability of one-half; the cumulative probabilities of having more failures are 0.6101 and 0.1444, respectively.

5.3.3.3 Input Sample Homogeneity - The formal logic of the statistical process requires that one be sure the input data to each test and service regime is the same. This homogeneity was the objective of the experimental design. It was not possible to obtain a meaningful proof that the experimental design did or did not function as anticipated. However, as was seen in paragraph 5.3.3.1, the difficulties in determining the experimental distribution are not important.

A Kolmogorov-Smirnov test was run on the cars failing the emission criteria. The purpose of this test was to compare the observed population distributions with the following theoretical distributions: Gaussian, exponential, Cauchy, uniform, or log normal. Only one case, NO_x for controlled cars, had even a reasonable probability of falling within one of these populations; that probability was 0.77 of being Gaussian. All other probabilities were less than 0.37. However, attempts were made to analyze the emissions of cars submitted to the various test and service regimes. The Student "t" test was used to evaluate the differences in the means while a

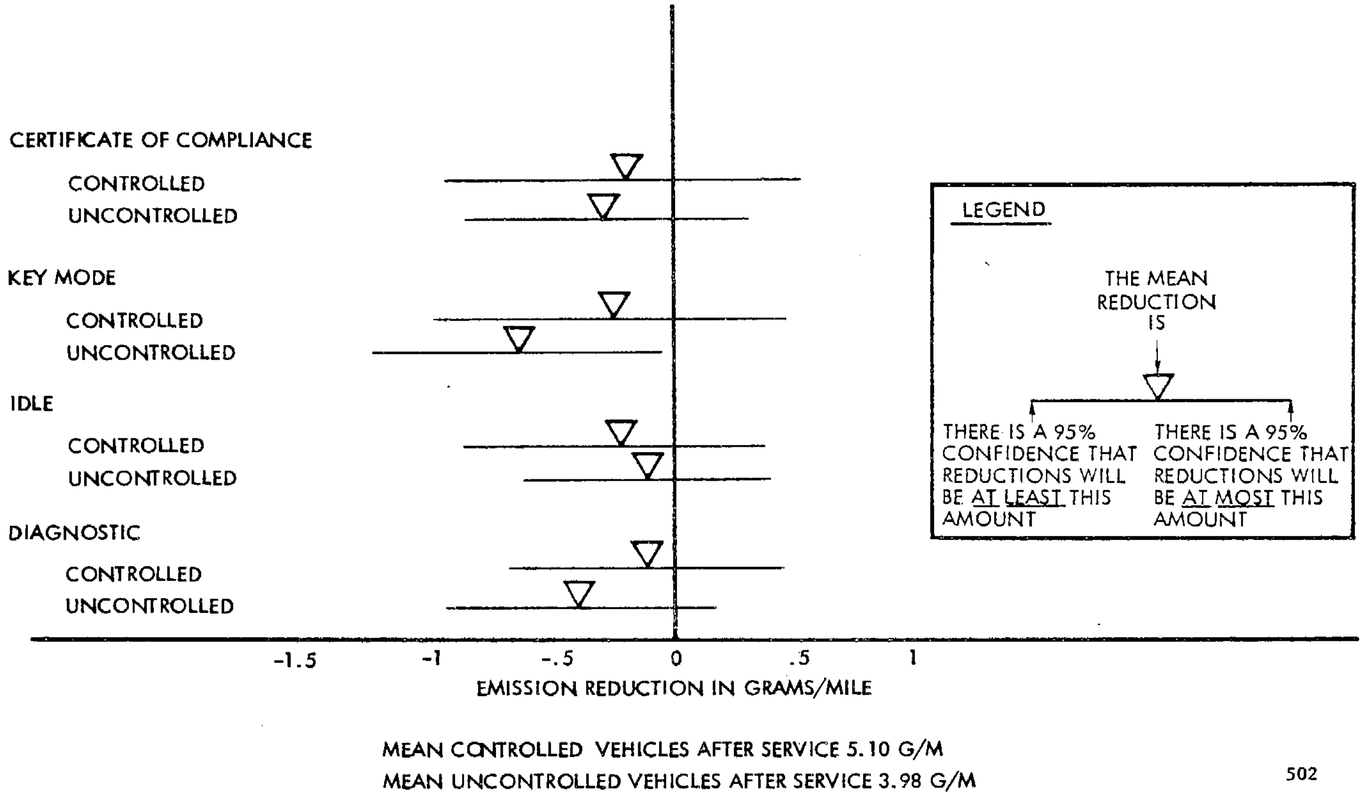

Figure 5-13. CONFIDENCE OF NO_x REDUCTION BY EACH TEST AND SERVICE REGIME FLEET RESULTS

Bartlett Chi squared test was used to compare variances. Both the Gaussian and log normal distributions were utilized. The results are conflicting; no doubt due to the inability to find the proper population distribution. The only consistent non-homogeneous samples were those uncontrolled cars submitted to the Certificate of Compliance measurement of CO. This group was cleaner than the remainder.

5.3.3.4 Confidence Analysis of Test Results - Some cars may fail the emission tests when they should not have and vice versa, due to errors associated with the measuring equipment, the operators, the weather, etc. In one case, the car owner is subjected to unnecessary expense and in the other undetected excessive emissions are produced. To investigate the magnitude of this problem, a random sample of fifty cars which had passed the initial tests (Idle, Key Mode, and Diagnostic tests) were subjected to retesting some 4 to 30 hours later to determine the repeatability of the measurements and the number of previously passed cars that would fail on the second test.

The investigation showed that 4 percent of the previously passed cars failed the second test; another 4 percent of the ones failing the first time would pass on a second trial without service. The latter statement is based upon the fact that each car has a true emission level which we do not know. When a measurement is made, this true value plus some random measurement error is actually measured. Experience has shown that this random error is usually symmetrically distributed about the true

Table 5-14. PROBABILITY THAT THE USE OF A GIVEN TEST AND SERVICE REGIME WILL DECREASE EMISSIONS

Test Regime	Pollutant					
	Hydrocarbons (HC)		Carbon Monoxide (CO)		Oxides of Nitrogen (NO_x)	
	Uncontrolled	Controlled	Uncontrolled	Controlled	Uncontrolled	Controlled
Certificate of Compliance	.72/.65	.92/.88	.50/.62	.54/.70	.35	.35
Key Mode	1.00/1.00	.98/.99	1.00/.99	1.00/1.00	0.0	.18
Idle	1.00/1.00	.97/.98	.99/1.00	1.00/1.00	.29	.18
Diagnostic	1.00/1.00	.88/.88	1.00/1.00	1.00/1.00	.04	.31

This table considers that population which fails the original test and was serviced. The variable tested is the difference between the emission before test and after test for a given car. The probability is the significance level of the Student "t" test. Numerator based on Gaussian distribution - NO_x Gaussian only. Denominator based on log normal distribution.

value (Gaussian normal distribution). Thus, if the test is set up to fail one half of the cars and 4 percent of those passing the first test fail the second test, a similar percentage of cars failing the first test would pass a second test without additional service.

The actual distribution of the measurement errors was estimated by comparing the differences in the two measurements for each car. Table 5-15 presents the errors observed for each of the three pollutants (HC, CO, and NO_x). This table shows that these errors are 10 percent or less of the mean. The measurement technique and the associated controls will produce repeatability around 2 percent of the mean for the same car and driver on successive tests. The observed errors in this test of fifty cars are, therefore, representative of the errors associated with the variability of the cars, the technique of different drivers, the ambient temperature, etc.

Table 5-15. OBSERVED ERRORS BETWEEN MEASUREMENTS (PERCENT OF MEAN)

Pollutant	Average Error	Expected Maximum Error (95% Confidence)
HC	6	10.4
CO	10	20
NO_x	7.6	15.4

Note: The computational procedure was to compute the mean and standard deviation of the absolute value of the error divided by the mean error. The expected maximum is the mean plus two standard deviations.

5.3.4 Vehicle Test Data

The empirical test data obtained from the 1200-vehicle main-test phase are presented in tabular format. Each of the following tables represents a segment of the total inspection and maintenance process which has been simplified and is depicted in Figure 5-14. The intent here is to determine whether or not a significant difference in total vehicles emissions profile occurs as a result of implementing a given short-cycle test regime.

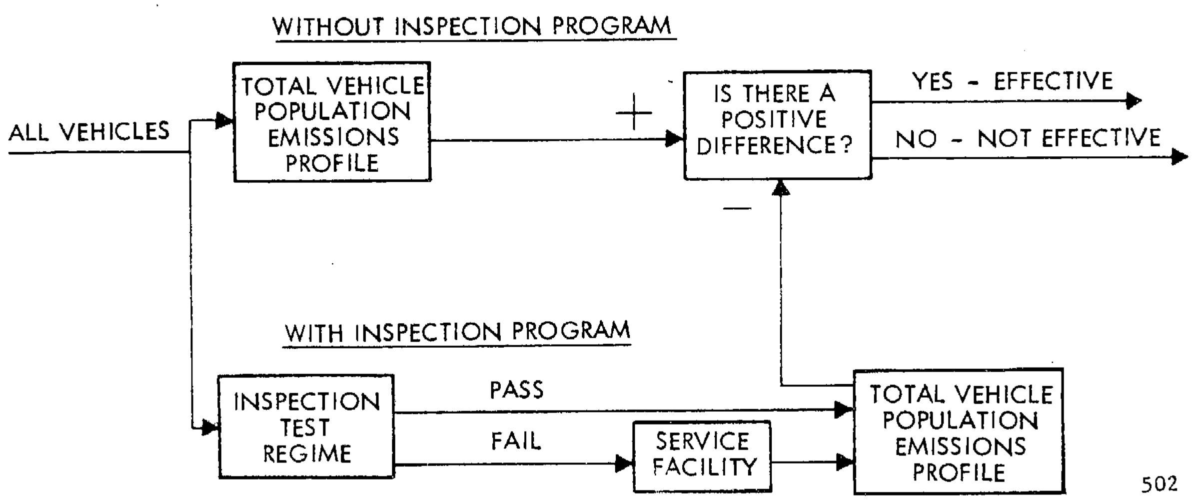

Figure 5-14. SIMPLIFIED EFFECTIVENESS DETERMINATION

5.3.4.1 Fleet Statistics Before Service - Table 5-16 presents the fleet statistics before service for the total 523 vehicles comprising the first two quarters of testing up to 1 May 1971, the date established by the ARB as final data acquisition day. The data is shown in terms of grams per mile since present and future standards are stated in those units. As such, the effectiveness measures are also determined, using those units.

The table shows the breakdown by test regimes and by emission pollutants for controlled and uncontrolled vehicles. Both the means and standard deviations are shown. For each of the test regimes, the number of controlled and uncontrolled vehicles are denoted.

Comparing all the tested vehicles within the four test regimes, it is apparent that the Diagnostic test regime was exposed to "cleaner" controlled vehicles in terms of HC (by 10 percent) and CO (by 12 percent). The other three test regimes appear to have received approximately the same vehicle population emission exposure in terms of HC concentrations. Other apparent dissimilarities exist in the Diagnostic test uncontrolled vehicles HC (15 percent higher than others), Certificate of Compliance uncontrolled vehicles CO (20 percent lower than others), and NO_x (10 percent higher than others).

Table 5-16. FLEET STATISTICS BEFORE SERVICE

Test Regime		HC (g/m)		CO (g/m)		NO_x (g/m)	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Certificate of Compliance	*(125)						
Controlled Vehicles	(61)	3.52	5.31	36.00	29.23	4.82	2.42
Uncontrolled Vehicles	(64)	6.62	6.37	55.22	32.59	4.08	2.01
Idle Test	(130)						
Controlled Vehicles	(63)	3.04	2.50	39.96	22.86	4.67	2.08
Uncontrolled Vehicles	(67)	6.36	3.13	67.87	40.56	3.43	1.75
Key Mode Test	(134)						
Controlled Vehicles	(62)	3.32	3.42	36.40	29.09	5.02	2.53
Uncontrolled Vehicles	(72)	6.26	3.26	70.83	42.93	3.59	2.09
Diagnostic Test	(134)						
Controlled Vehicles	(59)	2.67	1.00	31.62	17.76	5.15	1.76
Uncontrolled Vehicles	(75)	7.62	6.12	68.59	41.22	3.43	2.01
All Vehicles	(523)	5.05		51.93		4.22	
Controlled	(245)	3.14		36.07		4.91	
Uncontrolled	(278)	6.74		65.92		3.62	

*Numbers in parentheses indicate vehicle quantity

5.3.4.2 Vehicles Passing Initial Test - Table 5-17 shows the emission profiles of those vehicles passing initial test as a function of each test regime's established emission limits. Recall that these limits were set, based on the Learning Phase results, to reject approximately 50 percent of the inspected vehicles. The absence of Certificate of Compliance test data is due to the fact that this regime has no established limits and consequently all vehicles are theoretically "failed" and dispatched for service.

It is interesting to note that for HC measurements, all passed vehicles with emission controls were fairly close to the 1970 California and Federal Standards of 2.2 grams per mile (gpm). This is rather surprising when it is considered that the group includes 1966 through 1969 vehicles whose design standards were 3.35 gpm. Even the uncontrolled vehicles exhibited fairly close measurement grouping (4.7, 4.8, 4.9 gpm). (Refer to Table 1-1 for emission standards.)

Table 5-17. VEHICLES PASSING INITIAL TEST

Test Regime		HC (g/m)		CO (g/m)		NO_x (g/m)	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Certificate of Compliance *Not Applicable							
Idle Test	**(75)						
Controlled Vehicles	(39)	2.44	0.93	28.95	13.69	4.60	1.91
Uncontrolled Vehicles	(36)	4.89	1.69	51.98	26.96	3.88	1.62
Key Mode Test	(70)						
Controlled Vehicles	(40)	2.34	0.89	23.78	14.25	5.55	2.37
Uncontrolled Vehicles	(30)	4.78	1.58	44.97	24.17	4.58	2.17
Diagnostic Test	(66)						
Controlled Vehicles	(40)	2.48	0.88	25.17	14.44	5.37	1.87
Uncontrolled Vehicles	(26)	4.66	2.03	44.33	23.28	4.40	2.21
All Vehicles	(211)	3.45		35.36		4.78	
Controlled	(119)	2.42		25.94		5.18	
Uncontrolled	(92)	4.79		47.53		4.26	

* All Certificate of Compliance vehicles are sent for service and certification
**Numbers in parentheses indicate vehicle quantity

Considering the CO measurements, the Key Mode controlled vehicles (23.78 gpm) closely approximates the 1970 standards of 23 gpm. Both Idle and Diagnostic test vehicles, 29 and 25 gpm respectively, are relatively clean in view of the fact that 1966 through 1969 standards were 34 gpm.

5.3.4.3 Vehicles Failing Initial Test - Table 5-18 shows the emissions profile of those Vehicles Failing Initial Test and were subsequently dispatched to the service facilities. The Certificate of Compliance test shows a greater quantity of vehicles failed. As previously mentioned, all vehicles assigned to this regime were required to be serviced as directed by the ARB since there are no emission limits for certification.

5.3.4.4 Failed Vehicles After Service - Those vehicles failing the initial test are then serviced according to the procedures of the respective test regimes. Table 5-19 presents the data on those vehicles failing the initial testing and receiving service.

Table 5-18. VEHICLES FAILING INITIAL TEST

Test Regime		HC (g/m)		CO (g/m)		NO_x (g/m)	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Certificate of Compliance	*(125)						
Controlled Vehicles	(61)	3.52	5.31	36.00	29.23	4.82	2.42
Uncontrolled Vehicles	(64)	6.62	6.37	55.22	32.59	4.08	2.01
Idle Test	(55)						
Controlled Vehicles	(24)	4.02	3.71	57.84	23.67	4.78	2.37
Uncontrolled Vehicles	(31)	8.07	3.54	86.32	45.99	2.90	1.77
Key Mode Test	(64)						
Controlled Vehicles	(22)	5.11	5.23	59.36	34.99	4.04	2.57
Uncontrolled Vehicles	(42)	7.32	3.73	89.31	44.03	2.88	1.73
Diagnostic Test	(68)						
Controlled Vehicles	(19)	3.08	1.13	45.20	16.65	4.67	1.44
Uncontrolled Vehicles	(49)	9.20	6.95	81.46	43.00	2.92	1.70
All Vehicles	(312)	6.13		63.14		3.85	
Controlled	(126)	3.83		45.63		4.65	
Uncontrolled	(186)	7.70		75.01		3.31	

*Numbers in parentheses indicate vehicle quantity

The data for controlled vehicles in terms of HC shows the test regimes were able to reduce emissions down to relatively the same level (2.58 to 2.88 gpm). For uncontrolled vehicles, the HC range was greater, 4.82 to 6.06 gpm. The Certificate of Compliance with 6.06 gpm still exhibited a large standard deviation of 5.24 gpm indicating rather large extremes in measurements.

An interesting comparison is made when data from Table 5-17, Vehicles Passing Initial Test, are evaluated with those from Table 5-19, Failed Vehicles After Service. In every case, except Certificate of Compliance, which cannot be considered, the average vehicles passing the initial test were slightly better than the typical vehicle after service, when viewed in terms of HC and CO. On the other hand, those that received service tended to be lower in NO_x.

5.3.4.5 <u>Fleet Statistics After Service</u> - Vehicles requiring and receiving maintenance service are retested upon return. Thus, when these vehicles are combined with those previously passing the initial testing, the total vehicle population emission profile may be calculated. Table 5-20 shows the Fleet Statistics After Service, which includes all 523 vehicles.

Table 5-19. FAILED VEHICLES AFTER SERVICE

Test Regime		HC (g/m) Mean	HC (g/m) Std Dev	CO (g/m) Mean	CO (g/m) Std Dev	NO_x (g/m) Mean	NO_x (g/m) Std Dev
Certificate of Compliance	*(125)						
Controlled Vehicles	(61)	2.59	1.06	35.18	35.58	4.99	2.56
Uncontrolled Vehicles	(64)	6.06	5.24	54.72	26.79	4.31	2.13
Idle Test	(55)						
Controlled Vehicles	(24)	2.58	0.96	27.49	14.85	5.38	2.08
Uncontrolled Vehicles	(31)	5.01	1.65	59.55	34.44	3.13	1.80
Key Mode Test	(64)						
Controlled Vehicles	(22)	2.88	1.10	27.29	17.31	4.72	1.96
Uncontrolled Vehicles	(42)	4.82	1.34	45.15	23.16	3.99	1.64
Diagnostic Test	(68)						
Controlled Vehicles	(19)	2.67	0.96	30.71	15.05	5.00	2.09
Uncontrolled Vehicles	(49)	5.19	1.77	53.88	26.52	3.54	1.77
All Vehicles	(312)	4.28		44.47		4.32	
Controlled	(126)	2.65		31.66		5.02	
Uncontrolled	(186)	5.38		53.14		3.84	

*Numbers in parentheses indicate vehicle quantity

For the controlled vehicles, the fleet statistics indicate that the test regimes are relatively equal in terms of HC and NO_x levels after inspection and service. However, the CO level after Certificate of Compliance is approximately 20 percent higher than the other three test regimes.

For the uncontrolled vehicles, the fleet average for HC after Certificate of Compliance is 20 percent higher than the other three alternative test schemes, which exhibited fairly close grouping (4.80 to 5.01 gpm). In terms of CO levels after service, the Key Mode Test appears to be better than the other three by 10 to 20 percent. Relative to NO_x levels after service, the Idle Test results indicate a slight advantage over Diagnostic Test (10 percent) and an advantage of 20 percent over Key Mode and Certificate of Compliance.

Table 5-20. FLEET STATISTICS AFTER SERVICE

Test Regime		HC (g/m)		CO (g/m)		NO_x (g/m)	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Certificate of Compliance	*(125)						
Controlled Vehicles	(61)	2.59	1.06	35.18	35.58	4.99	2.56
Uncontrolled Vehicles	(64)	6.06	5.24	54.72	26.79	4.31	2.13
Idle Test	(130)						
Controlled Vehicles	(63)	2.49	0.93	28.40	14.04	4.90	1.99
Uncontrolled Vehicles	(67)	4.95	1.66	55.48	30.64	3.54	1.73
Key Mode Test	(134)						
Controlled Vehicles	(62)	2.53	0.99	25.02	15.36	5.26	2.25
Uncontrolled Vehicles	(72)	4.80	1.44	45.07	23.42	4.23	1.88
Diagnostic Test	(134)						
Controlled Vehicles	(59)	2.54	0.90	26.96	14.74	5.25	1.93
Uncontrolled Vehicles	(75)	5.01	1.87	50.57	25.70	3.84	1.96
All Vehicles	(523)	3.94		40.79		4.50	
Controlled	(245)	2.54		28.89		5.10	
Uncontrolled	(278)	5.18		51.28		3.98	

*Numbers in parentheses indicate vehicle quantity

5.3.4.6 Comparison of Before and After Service - Table 5-21 provides a comparison of Fleet Statistics Before and After Service. The data indicate that for controlled vehicles, all test regimes are effective in achieving a reduction in HC levels. Relative to CO levels after service, the Certificate of Compliance, although achieving a slight reduction, is definitely inferior to the other three. The NO_x after-service data indicate that a slight increase would occur regardless of test regime used for inspection and service. Interestingly, the magnitude and direction of change would be approximately the same for all four test regimes.

5.3.4.7 Effectiveness of Additional Service - The effectiveness of performing additional service on vehicles that fail to meet certain emission limits after having once been serviced, can be determined by referring to Table 5-22. The data presented are for all vehicles after service (one or more times) as compared with the data for the fleet after one service only. Desirability of enforcing repeated service until specified limits are met can be determined by noting the differences between the two mean values for each pollutant projected over all serviced vehicles (the means are based on all vehicles requiring service).

Table 5-21. COMPARISON FLEET STATISTICS BEFORE AND AFTER SERVICE

Vehicle/Test Regime	HC (g/m)		CO (g/m)		NO_x (g/m)	
	Before*	After*	Before*	After*	Before*	After*
Controlled Vehicles						
Certificate of Compliance (Mean)	3.52	2.59	36.00	35.18	4.82	4.99
Standard Deviation	5.31	1.06	29.23	35.58	2.42	2.56
Idle Test (Mean)	3.04	2.49	39.96	28.40	4.67	4.90
Standard Deviation	2.50	0.93	22.86	14.04	2.08	1.99
Key Mode Test (Mean)	3.32	2.53	36.40	25.02	5.02	5.26
Standard Deviation	3.42	0.99	29.09	15.36	2.53	2.25
Diagnostic Test (Mean)	2.67	2.54	31.62	26.96	5.15	5.25
Standard Deviation	1.00	0.90	17.76	14.74	1.76	1.93
Uncontrolled Vehicles						
Certificate of Compliance (Mean)	6.62	6.06	55.22	54.72	4.08	4.31
Standard Deviation	6.37	5.24	32.59	26.79	2.01	2.13
Idle Test (Mean)	6.36	4.95	67.87	55.48	3.43	3.54
Standard Deviation	3.13	1.66	40.56	30.64	1.75	1.73
Key Mode Test (Mean)	6.26	4.80	70.83	45.07	3.59	4.23
Standard Deviation	3.26	1.44	42.93	23.42	2.09	1.88
Diagnostic Test (Mean)	7.62	5.01	68.59	50.57	3.43	3.84
Standard Deviation	6.12	1.87	41.22	25.70	2.01	1.96
All Controlled Vehicles	3.14	2.54	36.07	28.89	4.91	5.10
All Uncontrolled Vehicles	6.74	5.18	65.92	51.28	3.62	3.98

*All 523 vehicles processed as of 1 May 1971

Table 5-22. EFFECTIVENESS OF ADDITIONAL SERVICE BEYOND INITIAL

Test Regime	HC (g/m)		CO (g/m)		NO_x (g/m)	
	All[1]	Once[2]	All[1]	Once[2]	All[1]	Once[2]
Controlled Vehicles						
Certificate of Compliance (Mean)	2.59	2.59	35.18	35.18	4.99	4.99
Standard Deviation	1.06	1.06	35.58	35.58	2.56	2.56
Idle Test (Mean)	2.58	2.75	27.49	35.44	5.38	5.17
Standard Deviation	0.96	0.98	14.85	24.03	2.08	2.14
Key Mode (Mean)	2.88	2.98	27.29	31.50	4.72	4.48
Standard Deviation	1.10	1.13	17.31	22.33	1.96	2.09
Diagnostic Test (Mean)	2.67	2.72	30.71	33.40	5.00	4.70
Standard Deviation	0.96	0.90	15.05	16.23	2.09	2.00
Uncontrolled Vehicles						
Certificate of Compliance (Mean)	6.06	6.83	54.72	55.06	4.31	4.27
Standard Deviation	5.24	7.68	26.79	26.69	2.13	2.15
Idle Test (Mean)	5.01	5.44	59.55	63.09	3.13	3.20
Standard Deviation	1.65	2.00	34.44	35.51	1.80	1.86
Key Mode Test (Mean)	4.82	5.21	45.15	54.93	3.99	3.73
Standard Deviation	1.34	1.71	23.16	35.96	1.64	1.77
Diagnostic Test (Mean)	5.19	6.07	53.88	63.19	3.54	3.39
Standard Deviation	1.77	2.65	26.52	34.74	1.77	1.84
All Controlled Vehicles	2.65	2.71	31.66	34.32	5.02	4.89
All Uncontrolled Vehicles	5.38	6.03	53.14	58.51	3.84	3.74

[1]Vehicle serviced more than once to achieve satisfactory emission level
[2]Vehicle serviced once and removed regardless of emission level achieved

Certificate of Compliance for controlled vehicles did not show any change because only one out of 61 vehicles with a marginal reading was affected. Averaged over the total fleet, the change was negligible. For the other test regimes regarding controlled vehicles, the data indicate that slight decrease (less than 8 percent) occur in HC emissions. In case of CO emissions, additional servicing realized an improvement of 28 percent for Idle, 15 percent for Key Mode, and 10 percent for Diagnostic. On the other hand, sending vehicles out for additional service caused the average vehicle to increase in NO_x emissions by a factor of 4, 5, and 6 percent for the Idle, Key Mode, and Diagnostic tests, respectively.

For the uncontrolled vehicles, additional servicing beyond the initial service appears to benefit Diagnostic test vehicles in terms of HC and CO (17 percent each) whereas NO_x increased less than 5 percent. Key mode vehicles showed less than 5 percent decrease in HC as a result of additional service, 21 percent decrease in CO, and 7 percent increase in NO_x due to additional service. For those vehicles in the Idle Test regime, there was a beneficial decrease in HC of 8 percent, decrease in CO of 6 percent, and decrease in NO_x of 2 percent. The Certificate of Compliance realized a decrease of 13 percent in HC and insignificant changes (less than 1 percent) in CO and NO_x.

5.3.4.8 Effects of Additional Service on Total Fleet - Table 5-23 summarizes the fleet statistics for all 523 vehicles. In one case, the total population is viewed as comprised of vehicles passing the initial inspection mixed with those receiving one or more maintenance service until certified as acceptable. These are noted under column heading "All." Compared with this set of vehicles are those passing the initial inspection mixed with those receiving only one service and are released regardless of emissions level achieved. The single-service set of vehicles is listed under "Once." A determination can now be made of the relative effectiveness of instituting a single-service policy which would essentially preclude the "ping-pong" effect of inspected vehicles vacillating between inspection and service facilities. Except for the uncontrolled vehicles processed by Certificate of Compliance, which showed a 17 percent increase in HC, all the other test regimes showed less than 10 percent changes in all emission pollutants.

A peculiarity regarding the Certificate of Compliance uncontrolled vehicles should be related. Vehicle 443, 1963 Valiant, was initially serviced and certified with 50.82 g/m of HC being emitted. Noting the extraordinary level, the vehicle was dispatched and serviced again, resulting in replacement of marginal PCV valve. Retested, the vehicle registered 3.5 g/m. The differential of 47 g/m averaged over 64 vehicles contributed significantly to the fleet average change. Further analysis of single-service effects will be discussed in the ensuing paragraphs.

5.3.5 Emission Reduction Data

The measurable emission reduction by vehicle model year is shown in Table 5-24. Average emissions reduction is shown for the fleet of serviced vehicles processed up to 1 May 1971. In a few cases, the vehicle sample for a given model year within a specific test regime was insignificant to yield a valid average (three or fewer vehicles). For these cases, two or more consecutive model years were combined to determine an average. These cases are identifiable by noting the similarity between consecutive model-years within a given test regime.

Table 5-23. ADDITIONAL SERVICE EFFECTS ON TOTAL FLEET

Test Regime	HC (g/m)		CO (g/m)		NO_x (g/m)	
	All[1]	Once[2]	All[1]	Once[2]	All[1]	Once[2]
Controlled Vehicles						
Certificate of Compliance (Mean)	2.59	2.59	35.18	35.18	4.99	4.99
Standard Deviation	1.06	1.06	35.58	35.58	2.56	2.56
Idle Test (Mean)	2.49	2.56	28.40	31.43	4.90	4.82
Standard Deviation	0.93	0.95	14.04	18.42	1.99	2.00
Key Mode Test (Mean)	2.53	2.57	25.02	26.52	5.26	5.17
Standard Deviation	0.99	1.02	15.36	17.76	2.25	2.32
Diagnostic Test (Mean)	2.54	2.56	26.96	27.82	5.25	5.16
Standard Deviation	0.90	0.89	14.74	15.39	1.93	1.92
Uncontrolled Vehicles						
Certificate of Compliance (Mean)	6.06	6.83	54.72	55.06	4.31	4.27
Standard Deviation	5.24	7.68	26.79	26.69	2.13	2.15
Idle Test (Mean)	4.95	5.14	55.48	57.12	3.54	3.57
Standard Deviation	1.66	1.84	30.64	31.47	1.73	1.76
Key Mode Test (Mean)	4.80	5.03	45.07	50.78	4.23	4.08
Standard Deviation	1.44	1.66	23.42	31.78	1.88	1.98
Diagnostic Test (Mean)	5.01	5.58	50.57	56.66	3.84	3.74
Standard Deviation	1.87	2.53	25.70	32.37	1.96	2.02
All Controlled Vehicles	2.54	2.57	28.89	30.25	5.10	5.03
All Uncontrolled Vehicles	5.18	5.62	51.28	54.88	3.98	3.91

[1]523 vehicles inspected and serviced as required to achieve satisfactory emissions level

[2]523 vehicles inspected, serviced if required (no more than once), and removed regardless of emissions level achieved

Table 5-24. EMISSION REDUCTION AS A FUNCTION OF TEST REGIME

Model Year	Certificate of Compliance			Idle Test			Key Mode			Diagnostic Test		
	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
1957 and Older	0.10	6.26	-0.75	1.56	14.80	0.27	3.27	69.81	-2.17	6.69	19.62	-0.40
1958	0.10	6.26	-0.75	1.56	14.80	0.27	3.27	69.81	-2.17	6.69	19.62	-0.40
1959	0.10	6.26	-0.75	1.56	14.80	0.27	3.27	69.81	-2.17	2.33	30.95	-0.53
1960	-0.63	4.17	-1.71	1.01	- 4.50	0.07	2.96	35.04	-1.29	8.56	17.27	-0.92
1961	-0.46	-11.56	-0.35	1.01	- 4.50	0.07	2.96	35.04	-1.29	8.56	17.27	-0.92
1962	0.85	1.08	-0.28	4.73	27.51	0.21	2.66	61.58	-1.36	3.21	18.36	0.18
1963	3.19	13.43	-0.09	2.94	21.83	-0.22	3.19	56.25	-1.80	5.17	42.92	-0.81
1964	0.06	- 6.20	0.20	3.84	34.30	-0.43	2.00	17.56	0.07	3.35	43.79	-1.42
1965	-0.30	- 3.10	0.01	2.74	41.40	-0.81	1.67	46.27	-0.79	2.49	26.18	-0.34
1966	0.23	- 7.15	0.31	3.05	26.94	-1.40	3.56	17.62	-0.82	0.47	10.61	0.07
1967	0.56	6.32	-0.67	3.05	26.94	-1.40	3.56	17.62	-0.82	0.01	14.42	-0.34
1968	0.25	9.38	-0.02	1.11	34.29	-0.18	1.02	46.07	-1.23	0.50	18.63	0.00
1969	2.76	- 0.95	-0.06	0.76	33.18	-0.63	0.43	29.94	-0.11	0.36	23.35	-1.45
1970	-0.14	- 2.41	-0.03	0.90	23.89	0.04	5.43	13.76	0.39	0.51	8.05	-0.26

Table 5-25 presents the data for Emission Reductions Based on Single Service Only. The total effectiveness of the single-service policy will be evaluated by projecting the measured reductions over the total population and comparing the relative differences obtained by using data from Table 5-24. A discussion of the results appears in paragraph 5.4.

Note that the tabulated data covers those vehicles for the model-years 1957 (and older) through 1970 which is in agreement with the contracted effort. However, the program, if implemented, may continue into the 1980s and beyond. Thus, some projections are necessary to anticipate vehicle performance and emission's deterioration within that time frame. This would then allow the effectiveness indices to be calculated and projected beyond the present year, and would facilitate determining the feasibility of implementing any of the candidate test philosophies.

5.3.5.1 Projection of Emission Reductions from 1971 to 1991 - An estimate of the emission reductions can be made by extrapolating the ability of the inspection test regimes to detect and correct engine malfunction and maladjustment. The following assumptions were explicitly involved in the calculation procedure:

a. The average failing vehicle will fail by the same percent of the applicable year's standard as the average failing vehicle in the 1968-1970 model years.

b. The effectiveness of the existing test regimes as determined from the sample vehicle fleet will not change significantly during the duration of the program

c. Exhaust emission control systems will continue to require regular maintenance, adjustment, or replacement of components

d. The principal cause of excessive exhaust emissions will be a malfunctioning engine which can be detected by the existing test regimes.

As emission control devices become more effective, each of the test regimes may have to be altered slightly to reflect new engineering solutions. Since the information on future devices and systems are not available, the percent effectiveness of each test regime in altering emissions of the failing vehicles is assumed to remain constant throughout the program. The particular control technique used may affect the ability of the various regimes to properly diagnose cause of failure, but would not affect ability to detect failure. The simplified equation for calculating emission reduction on future vehicles is as shown below:

Emission Reduction (ER) = Unserviced Emissions (UE) - Serviced Emissions (SE) (3)

$$ER = UE - SE$$

Where

ER - The average emission reduction of a pollutant

UE - The average emissions of a pollutant from the test fleet of controlled vehicles based on 1968-1970 models before service

SE - The average emissions of a pollutant from the test fleet of controlled vehicles based on 1968-1970 models after service.

Table 5-25. EMISSION REDUCTIONS BASED ON SINGLE SERVICE ONLY

Model Year	Certificate of Compliance			Idle Test			Key Mode			Diagnostic Test		
	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
1957 and Older	0.10	6.25	-0.75	1.48	11.75	0.24	2.95	45.81	-1.37	6.51	19.12	-0.27
1958	0.10	6.25	-0.75	1.48	11.75	0.24	2.95	45.81	-1.37	6.51	19.12	-0.27
1959	-0.87	4.17	-1.71	1.48	11.75	0.24	2.95	45.81	-1.37	1.65	20.02	-0.50
1960	-0.87	4.17	-1.71	1.48	11.75	0.24	4.13	29.71	-0.93	1.65	20.02	-0.50
1961	-0.46	-11.56	-0.35	4.20	16.89	0.06	-0.52	6.41	-1.41	11.43	8.68	-0.57
1962	0.85	1.08	-0.28	4.20	16.89	0.06	2.66	61.58	-1.36	3.12	20.23	-0.05
1963	-0.76	11.59	0.14	2.94	21.83	-0.22	3.15	53.01	-1.86	3.18	20.65	-0.32
1964	0.06	- 6.20	0.20	3.84	34.30	-0.43	1.49	22.90	0.10	2.51	30.63	-1.40
1965	-0.30	- 3.10	0.01	1.46	36.34	-1.13	0.84	28.79	-0.22	1.73	5.14	-0.14
1966	0.23	- 7.15	0.31	3.05	26.94	-1.40	3.73	14.62	-0.79	0.47	10.61	0.07
1967	0.56	6.32	-0.67	3.05	26.94	-1.40	3.73	14.62	-0.79	-0.62	16.68	-0.29
1968	0.25	9.35	-0.02	0.87	23.17	-0.08	1.11	46.05	-1.27	0.53	11.88	0.73
1969	2.76	- 0.95	-0.06	0.44	18.89	-0.11	0.35	19.87	0.53	0.36	23.35	-1.45
1970	-0.14	- 2.41	-0.03	0.87	21.43	0.09	4.74	14.63	0.42	0.12	4.51	0.14

Recognize that serviced emissions (SE) is a function of each test regime and reflects its ability to reduce the excess pollutants by some proportion. Then, equation (3) can be altered to incorporate the previously assumed fixed effectiveness.

$$ER = UE - SE = UE - \alpha UE = UE(1 - \alpha) \quad (4)$$

Where

α = The factor representing the amount of reduction in a given pollutant resulting from a given test regime.

Unserviced emissions (UE) are a function of engine malfunction and/or maladjustments. The degree of emission control system failure has been assumed constant during the program and equal to the degree of failure observed on the 1968-1970 test fleet. Hence, a hypothetical unserviced fleet average can be calculated for each year by multiplying that year's emission standards by a proportionality factor. Using the test results from the 1968-1970 model years, the typical failed vehicle exceeded the applicable standards in HC, CO, and NO_x by 36 percent, 57 percent and 25 percent respectively, corresponding to factors of 1.36, 1.57, and 1.25. Equation (4) can now be modified to include the effects of changing future standards.

$$ER = UE(1 - \alpha)$$

$$= \beta\,(STD)\,(1 - \alpha)$$

Where

β = The factor representing the amount the fleet average exceeded the emission standard for 1968-1970 before service. The fleet average emission divided by the emission standard.

STD = The appropriate emission standard for the particular model year considered.

Table 5-26 shows the calculated and projected emission reductions as a function of test regime and model year. Proposed 1975 and 1980 standards as listed in Table 1-1 Section 1, were used as inputs to the equation.

5.4 PROGRAM EFFECTIVENESS

The effectiveness of each test regime in achieving emissions reduction was discussed in terms of average vehicles. When these mean reductions by model years are used in the effectiveness equation discussed in paragraph 5.1, the projected annual and total program effectiveness measures are obtained. For each test regime, a 50 percent inspection rejection rate was used and the average distance driven per vehicle was assumed to be 12,000 miles per year. Emission profile degradation based on mileage was not included. Data for this will be forthcoming during latter half of 1200-vehicle testing. In the ensuing paragraphs, an evaluation and comparison of the four candidates program effectiveness is discussed in terms of weighted factors.

5.4.1 Equal Weighting of HC, CO, and NO_x

Figure 5-15 shows the emissions reduction for each of the four test regimes over a 20-year period beginning in calendar year 1972. The data plot shows the anticipated total emissions reduction in gross tonnage per year that is precluded from entering

Table 5-26. PROJECTED EMISSION REDUCTION AS A FUNCTION OF TEST REGIME (GM/MILE)

Model Year	Certificate of Compliance			Idle Test			Key Mode Test			Diagnostic Test		
	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
1971	0.97	2.0	0.02	0.92	30.5	-0.06	0.72	29.9	-0.32	0.52	16.6	-0.59
1972	0.68	2.2	0.02	0.63	31.0	-0.04	0.49	31.0	1.86	0.35	17.0	1.79
1973	0.68	2.2	0.02	0.63	31.0	-0.04	0.49	31.0	1.86	0.35	17.0	1.79
1974	0.68	2.2	0	0.63	31.0	-0.02	0.49	31.0	-0.10	0.35	17.0	-0.18
1975	0.24	0.19	0	0.21	15.9	-0.01	0.16	15.9	-0.08	0.12	8.7	-0.14
1976	0.24	0.19	0	0.21	15.9	-0.01	0.16	15.9	-0.08	0.12	8.7	-0.14
1977	0.24	0.19	0	0.21	15.9	-0.01	0.16	15.9	-0.08	0.12	8.7	-0.14
1978	0.24	0.19	0	0.21	15.9	-0.01	0.16	15.9	-0.08	0.12	8.7	-0.14
1979	0.24	0.19	0	0.21	15.9	-0.01	0.16	15.9	-0.08	0.12	8.7	-0.14
1980	0.11	0.05	0	0.11	8.1	-0.01	0.08	8.1	-0.03	0.06	4.4	-0.07
1981	0.11	0.05	0	0.11	8.1	-0.01	0.08	8.1	-0.03	0.06	4.4	-0.07
1982	0.11	0.05	0	0.11	8.1	-0.01	0.08	8.1	-0.03	0.06	4.4	-0.07
1983	0.11	0.05	0	0.11	8.1	-0.01	0.08	8.1	-0.03	0.06	4.4	-0.07
1984	0.11	0.05	0	0.11	8.1	-0.01	0.08	8.1	-0.03	0.06	4.4	-0.07
1985	0.11	0.05	0	0.11	8.1	-0.01	0.08	8.1	-0.03	0.06	4.4	-0.07
1986	0.11	0.05	0	0.11	8.1	-0.01	0.08	8.1	-0.03	0.06	4.4	-0.07
1987	0.11	0.05	0	0.11	8.1	-0.01	0.08	8.1	-0.03	0.06	4.4	-0.07
1988	0.11	0.05	0	0.11	8.1	-0.01	0.08	8.1	-0.03	0.06	4.4	-0.07
1989	0.11	0.05	0	0.11	8.1	-0.01	0.08	8.1	-0.03	0.06	4.4	-0.07
1990	0.11	0.05	0	0.11	8.1	-0.01	0.08	8.1	-0.03	0.06	4.4	-0.07
1991	0.11	0.05	0	0.11	8.1	-0.01	0.08	8.1	-0.03	0.06	4.4	-0.07

the atmosphere. Note that Certificate of Compliance exhibits relative ineffectiveness compared to the other three test regimes. According to Figure 5-15, Key Mode Test is better than Idle Test until 1979, after which they are equally effective through 1991. The effectiveness equation included the projected and estimated emission reductions for model-year 1971 through 1991.

Excluding these estimated reductions and including only the measured reductions for 1957 through 1970 model-year vehicles, the effectiveness data is plotted in Figure 5-16. Key Mode is again the best of the four regimes with Certificate of Compliance

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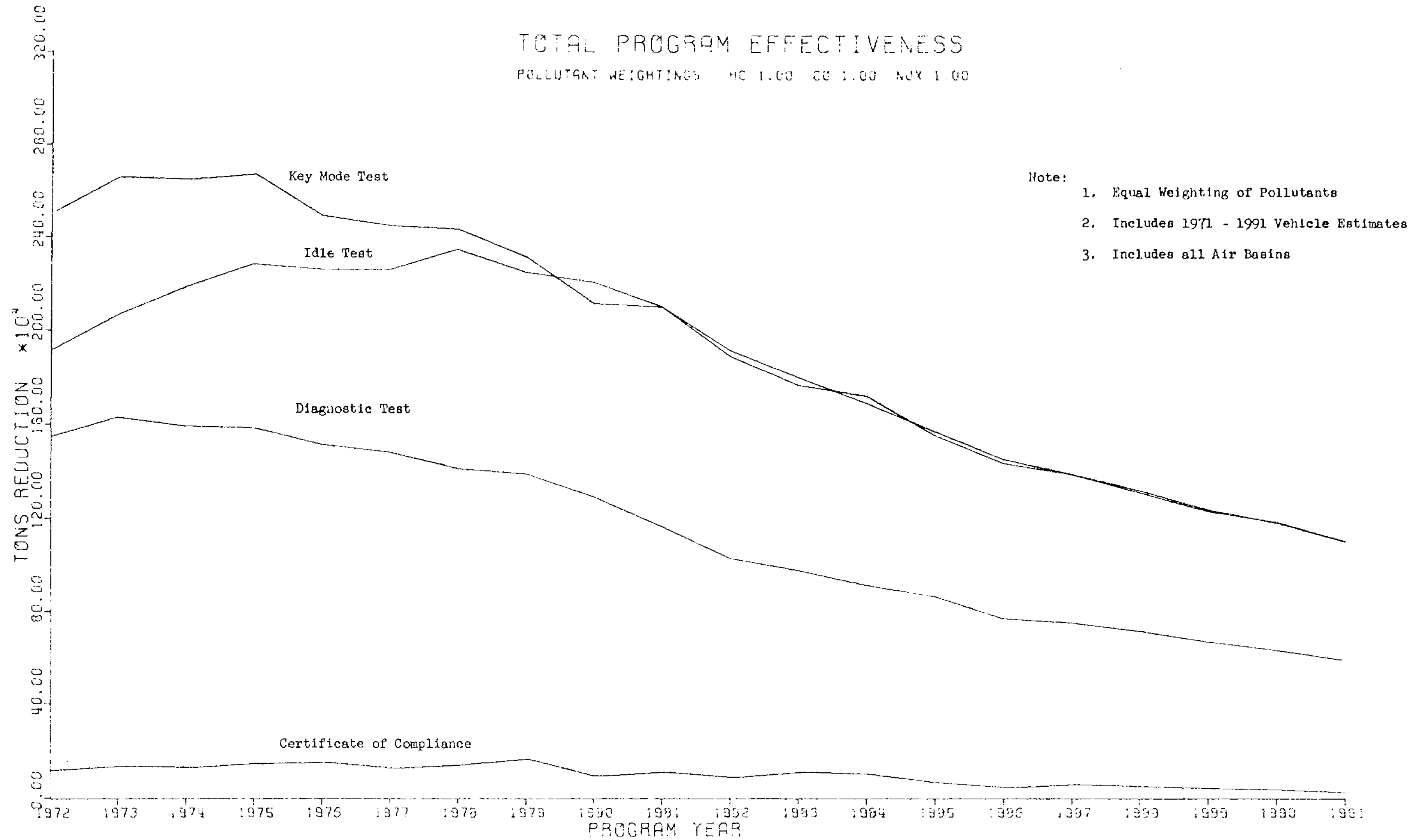

Figure 5-15. EQUAL WEIGHTING OF POLLUTANTS (MOD YR 1971-1991)

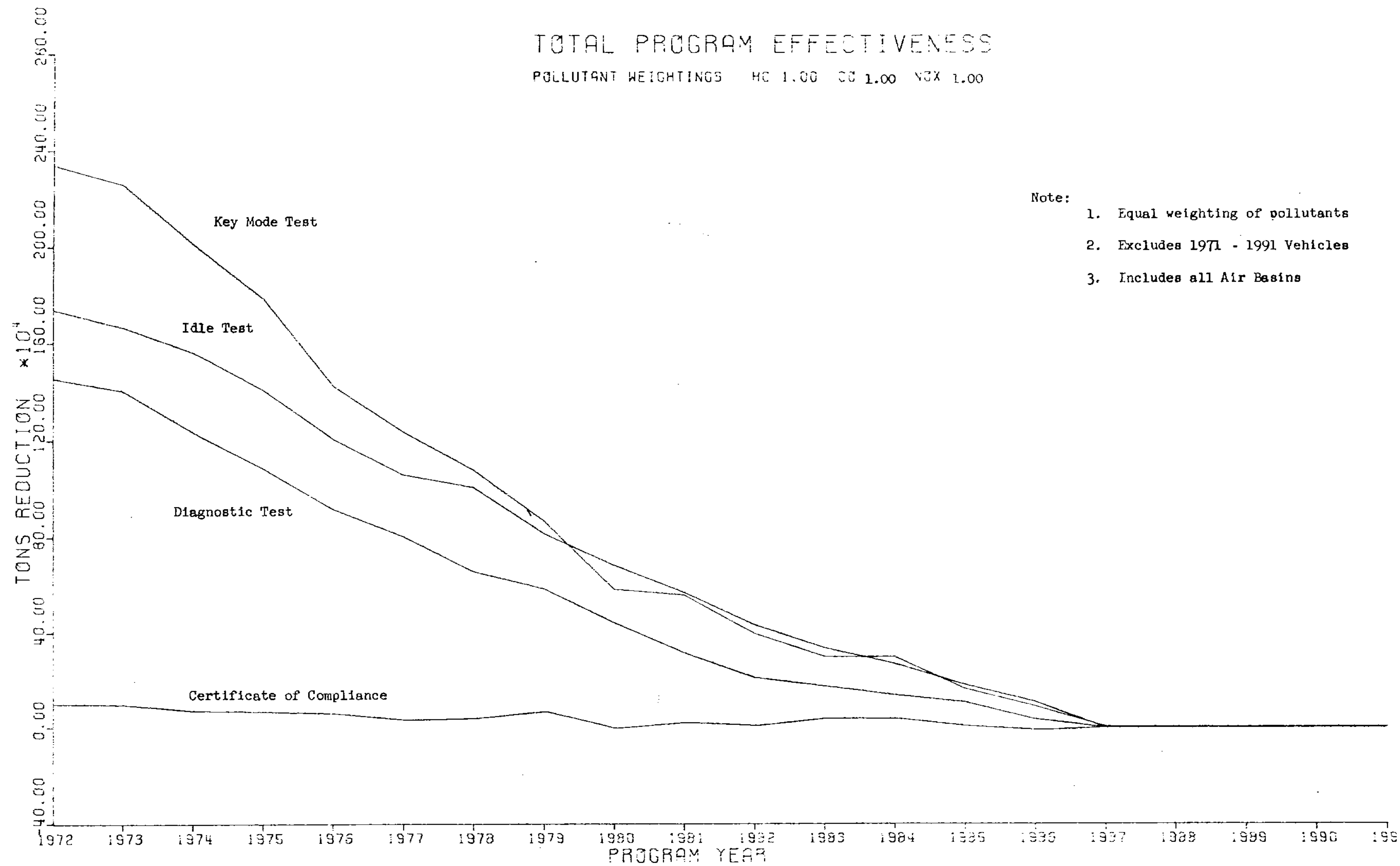

Figure 5-16. EQUAL WEIGHTING OF POLLUTANTS (MOD YR 1957-1970)

the worst. Idle test and Key Mode test are equally effective after 1979. All four regimes are noneffective after 1987. This is to be expected since most of the model-year 1957-1970 vehicles would no longer be in operation.

5.4.2 Weighting Based on 1966 California Standards

Using the 1966 California emission standards as a basis for determining the weighting factors, the proportional contribution of HC, CO, and NO_x are 0.72, 0.01, and 0.27, respectively. Normalizing with respect to HC, the derived weighting factors become 1.00, 0.01, and 0.38. Thus, the reductions for HC are unchanged; however, the reductions of CO and NO_x are proportionately reduced to 1 percent and 38 percent of true value.

Figure 5-17 shows the total program effectiveness for all air basins and includes the model-year 1971-1991 vehicle emission estimates. Key Mode test achieves a greater reduction than the other three test regimes from 1972 through 1986. Idle test and Diagnostic test are equally effective the first two years of operation, after which Idle Test is better throughout the program duration.

Figure 5-18 excludes the effects of the 1971 through 1991 model-year vehicles and projects the reductions achieved on 1970 and older vehicles. Key Mode test appears to have a slight edge over its closest competitor, Idle test, throughout the program. All test regimes, as plotted, become noneffective after 1987 because of reduction or elimination of 1957 through 1970 model-year vehicles.

5.4.3 Weighting Based on 1974 California Standards

Based on the 1974 California emission standards, the proportionality factors for HC, CO, and NO_x are 0.45, 0.03, and 0.52, respectively. Normalizing the values with respect to NO_x, the weighted contributions of HC, CO, and NO_x become 0.87, 0.06, and 1.0, respectively. Thus, for this mix of weighting factors, the emphasis is on NO_x.

Figure 5-19 shows program effectiveness for all 1971 model-year vehicles up through 1991, including all air basins. Key Mode test is better than the other three alternatives from initial implementation through 1987 after which it is relatively equal with Idle test, the closest competitor.

Figure 5-20 illustrates the effectiveness trends when estimated reduction for 1971-1991 model-year vehicles are excluded from the effectiveness equation. Key Mode test exhibits an advantage over Idle test throughout the duration of expected lifetime of the 1957-1970 model-year vehicles. After 1987 the test regimes are essentially noneffective due to absence of testable vehicles.

5.4.4 Weighting Based on 1970 California Standards

Using the 1970 California emissions standards as a guideline, the proportionality factors for HC, CO, and NO_x are 0.60, 0.10, and 0.30, respectively. The corresponding weighting factors, normalized to HC, are 1.00, 0.17, and 0.50.

Figure 5-21 depicts the weighted reductions as a function of test regime over the program duration. All 1971-1991 model-year vehicles are considered in the estimated total projections. Key Mode testing initially exhibits a greater effectiveness than does Idle test. After 1980, however, they are essentially equal in tons reduction.

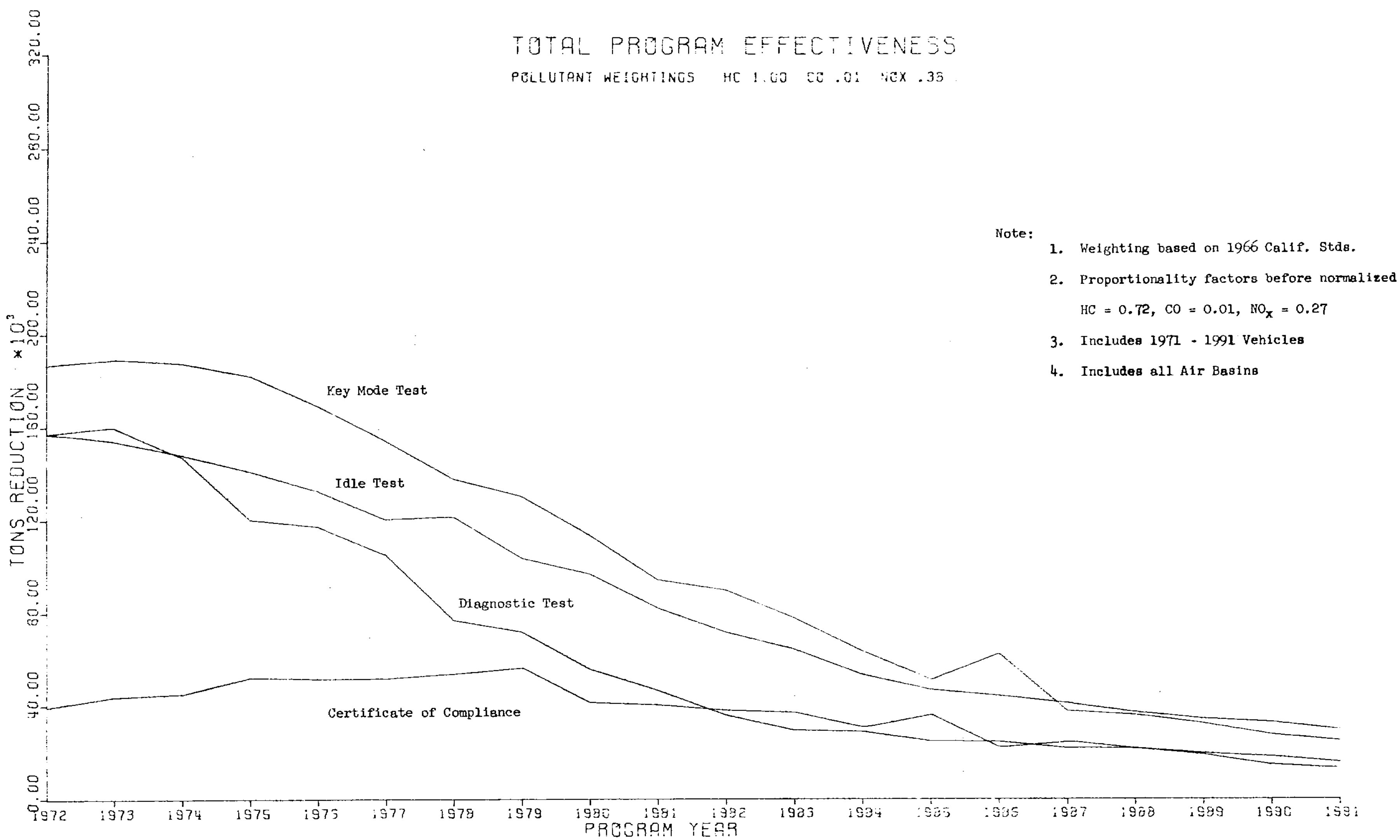

Figure 5-17. WEIGHTING BASED ON 1966 CALIFORNIA STANDARDS (MOD YR 1971-1991)

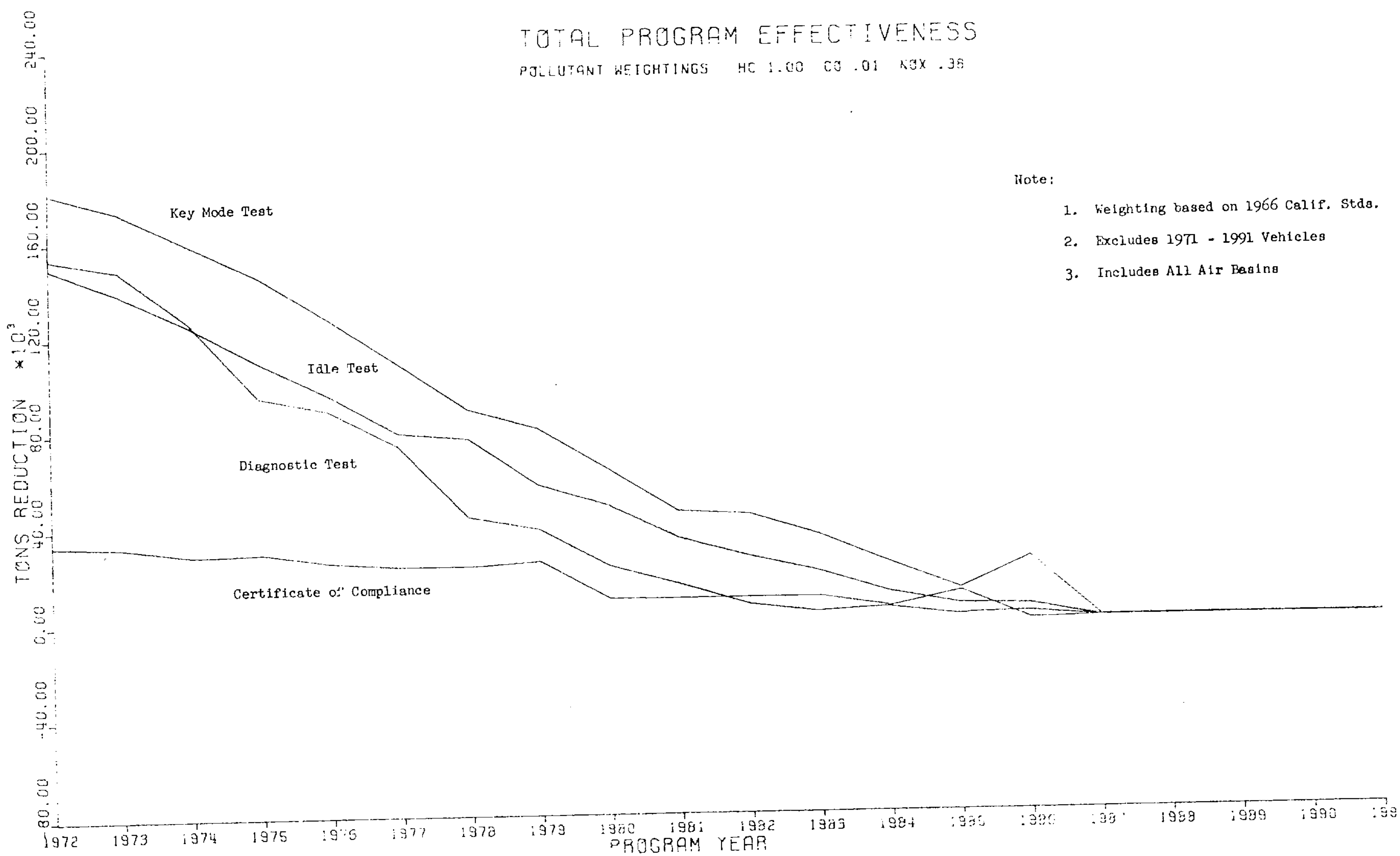

Figure 5-18. WEIGHTING BASED ON 1966 CALIFORNIA STANDARDS (MOD YR 1957-1970)

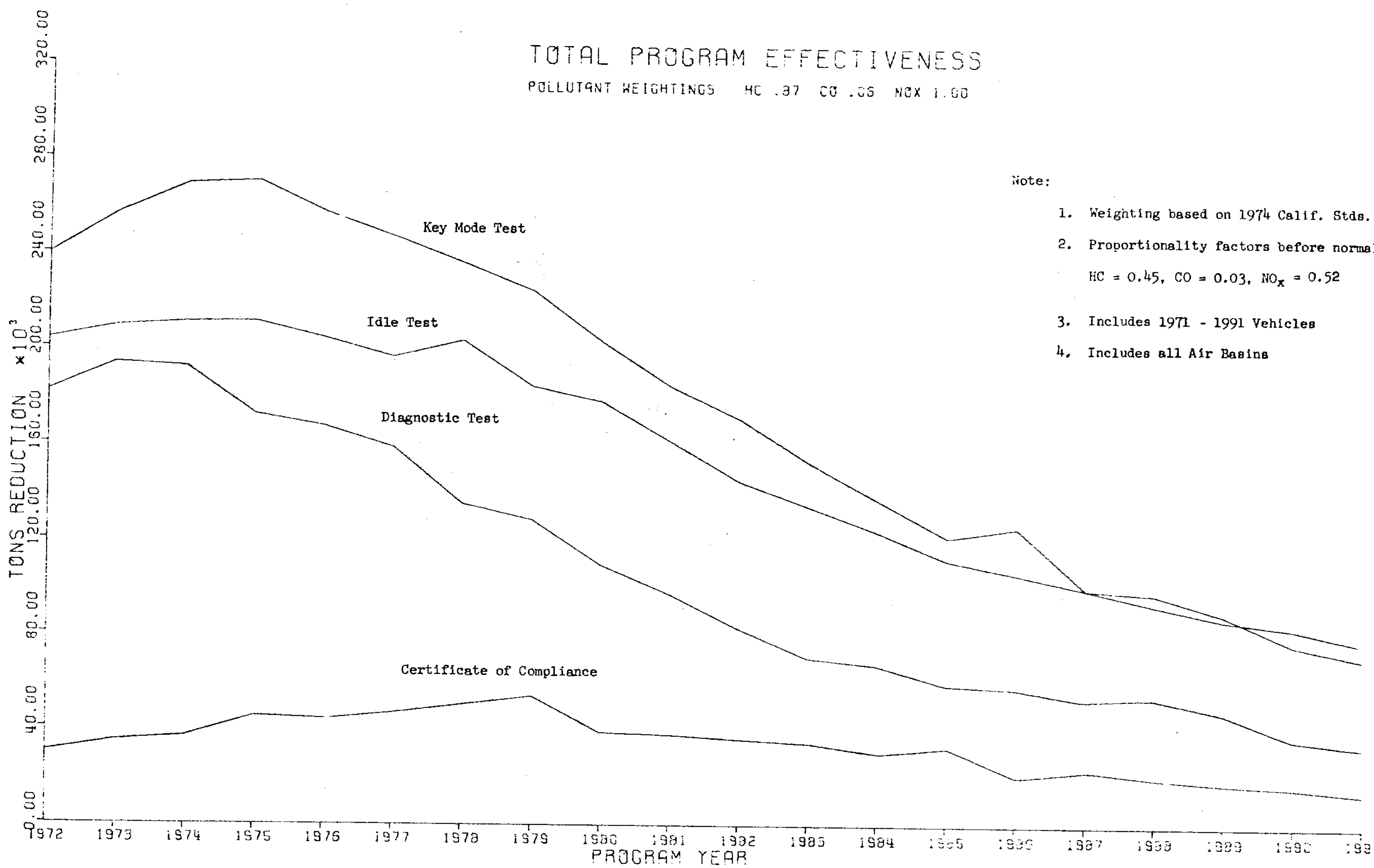

Figure 5-19. WEIGHTING BASED ON 1974 CALIFORNIA STANDARDS (MOD YR 1971-1991)

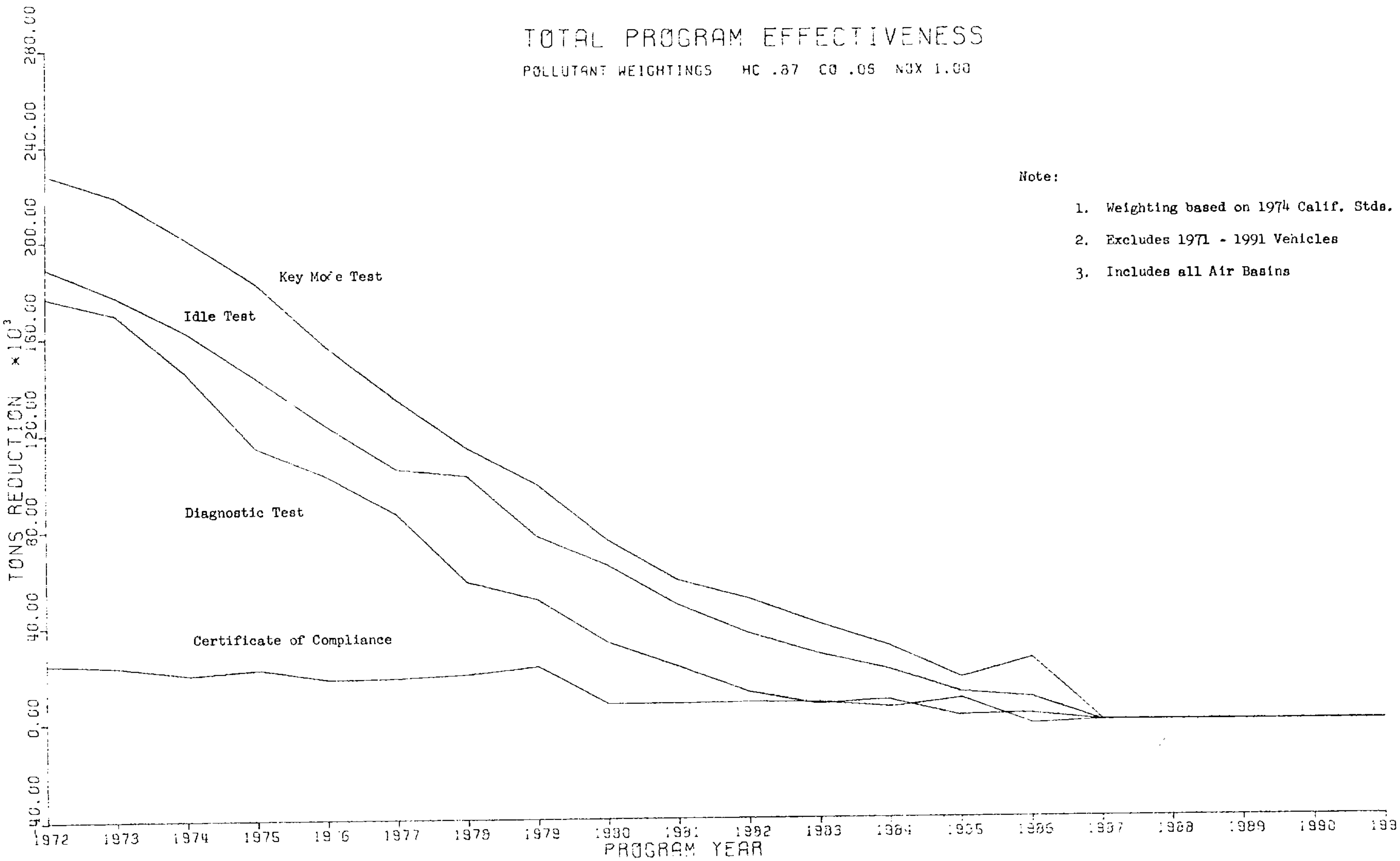

Figure 5-20. WEIGHTING BASED ON 1974 CALIFORNIA STANDARDS (MOD YR 1957-1970)

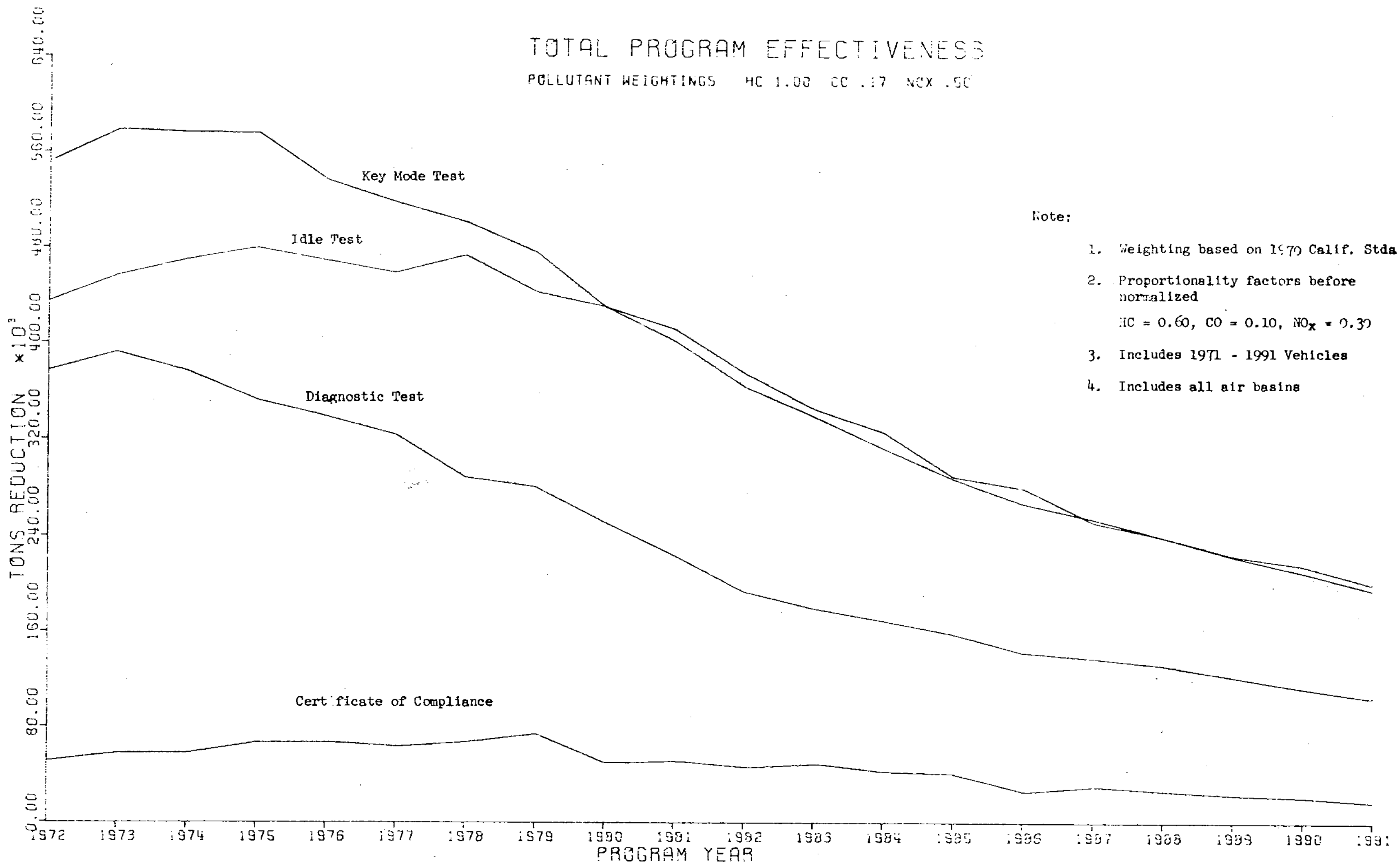

Figure 5-21. WEIGHTING BASED ON 1970 CALIFORNIA STANDARDS (MOD YR 1971-1991)

Figure 5-22 considers only the effects of 1957 through 1970 model-year vehicles as tested and serviced during the period 1972 to 1991. The figure indicates that Key Mode is relatively more effective than Idle test until 1980. From 1980 through 1986, they are essentially equal. After 1987, all test regimes will be, in essence, non-effective due to absence of 1957-1970 vehicles.

5.4.5 Effectiveness Comparison and Evaluation

The graphical data illustrates that Key Mode test is more effective than the other three test regimes during the first seven years of implementation. Depending on weighting factors considered, Idle test would become equally effective after the seventh year of operation. Diagnostic test appears to rank third consistently while Certificate of Compliance is definitely last.

It should be noted that regardless of weighting factor variations considered, the Key Mode test exhibited the greatest effectiveness, at least during the initial seven years of operation. The effects of including and excluding the estimated and projected emission reductions for 1971-1991 model-year vehicles did not alter the relative ranking of the alternatives.

Figure 5-23 illustrates the feasibility of instituting a given test regime on a maximum effects basis. In the example, which considers weighting based on 1971 standards Key Mode implemented in the two largest air basins, South Coast and San Francisco, would be as effective as Diagnostic or Certificate of Compliance in the total State, or Idle test in the four largest air basins.

5.5 EFFECTIVENESS OF REPEATED SERVICING

Paragraph 5.4 discussed briefly the effects of sending vehicles for additional servicing after initial service and retest. The data was presented in terms of "all" service and single service. Two tables of emission reductions were generated to be used as inputs to the effectiveness equation.

Table 5-24 covered the measured emission reductions for all service and included 1970 and older model-year vehicles. Similarily, Table 5-25 covered the same vehicles but included emission reductions based on single-service only. The differential reduction, based on an annual basis, is then plotted for each test regime and considers the different weighting factors.

5.5.1 Repeated Servicing Effects Based on Equal Weighting Factors

Figures 5-24 through 5-27 depict the effectiveness of repeated servicing for each of the test regimes. The figures, evaluated collectively, indicate that Idle test does not achieve a significant increase in the magnitude of emission reductions when multiple servicing is concerned. Conversely, Diagnostic test appears to realize the greatest improvement.

Interpreted another way and related to single service reduction, the Idle test realizes a majority of its reduction during the initial maintenance activity and little improvement is achieved by more than one servicing. On the other hand, Diagnostic testing benefits considerably more when additional service is performed. All test regimes decrease in overall emission reduction as the program progresses due to the diminishing vehicle population comprised of 1970 and older model-year vehicles.

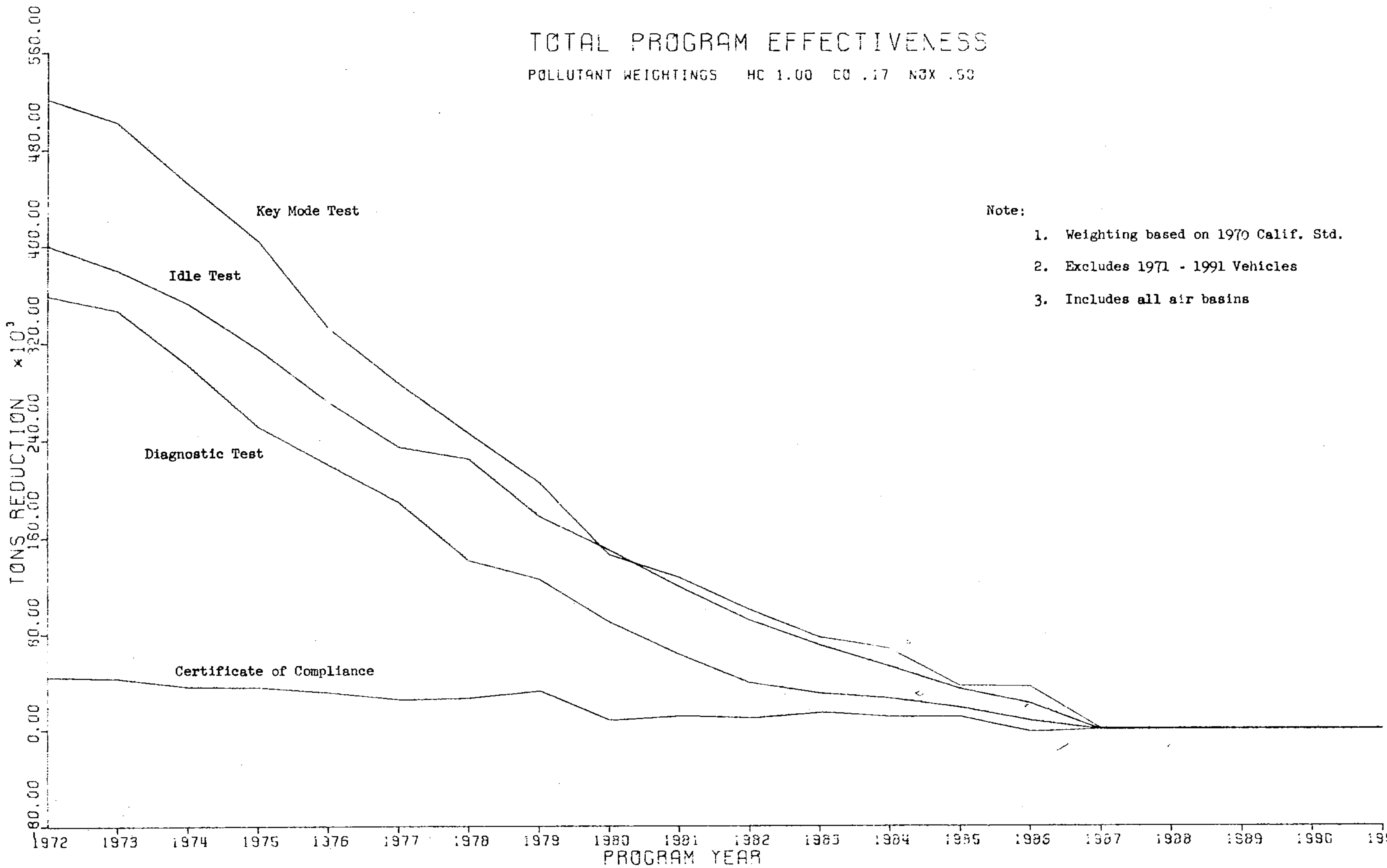

Figure 5-22. WEIGHTING BASED ON 1970 CALIFORNIA STANDARDS (MOD YR 1957-1970)

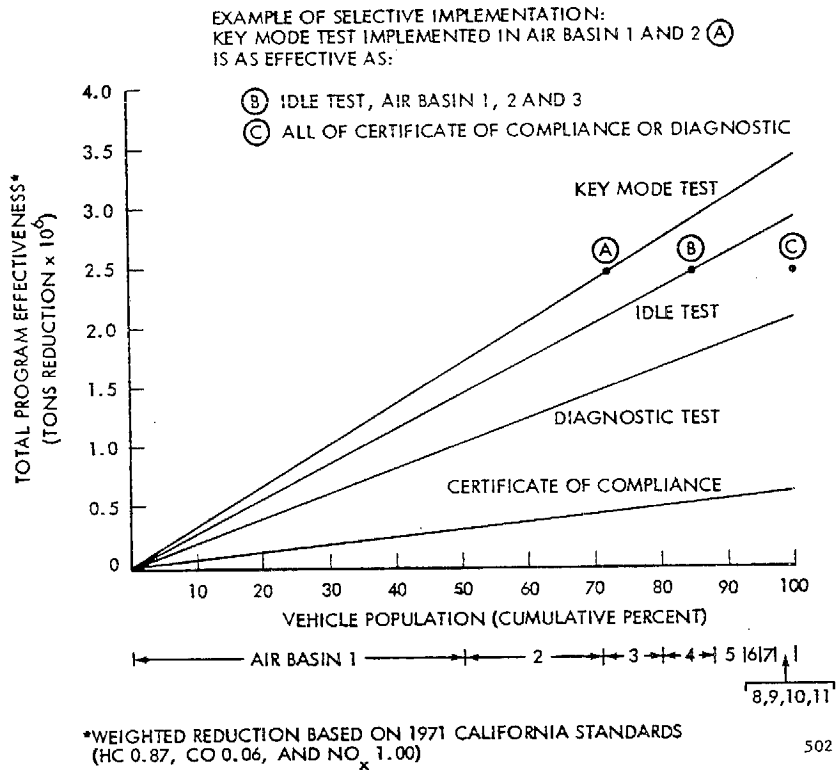

Figure 5-23. EFFECTIVENESS OF SELECTIVE IMPLEMENTATION BY AIR BASINS

5.5.2 Repeated Servicing Effects Based on 1966 California Standards

Figures 5-28 through 5-31 depict the effects of additional servicing as related to the four test regimes. The emissions of HC, CO, and NO_x are weighted according to the 1966 California Standards. Plotted as a function of calendar year, the emission reductions reflect the effects of additional services on the 1957 through 1970 model-year vehicles for which measured reductions are estimated. The effects on 1971 through 1991 model-year vehicles are not known nor included in the projections.

Figure 5-28 shows the single versus additional service effects for Certificate of Compliance vehicles. Additional servicing does provide an increased reduction over single service. Referring to the discussion under paragraph 5.4 on the reservicing of a 1963 Valiant, the effects of this vehicle, although averaged over the fleet, does impact on the total projection. Thus, when these model-year vehicles are phased out of the program, a dramatic drop in emission reduction is noted for the additional service fleet (1980).

Figure 5-29 shows the effects of additional service for the Idle test vehicles. Relatively little is gained by enforcing repeated servicing to assure meeting specified emission limits. It should be noted that the scaling of the ordinate of the plots (emission reduction) differs for each figure. This was a function of the computer plot routine which automatically adjusted the parameters to present maximum (intraregime) information. Unfortunately, this does not provide for easy comparison between test regimes. Figures to be provided later will present data for inter-regimes comparisons.

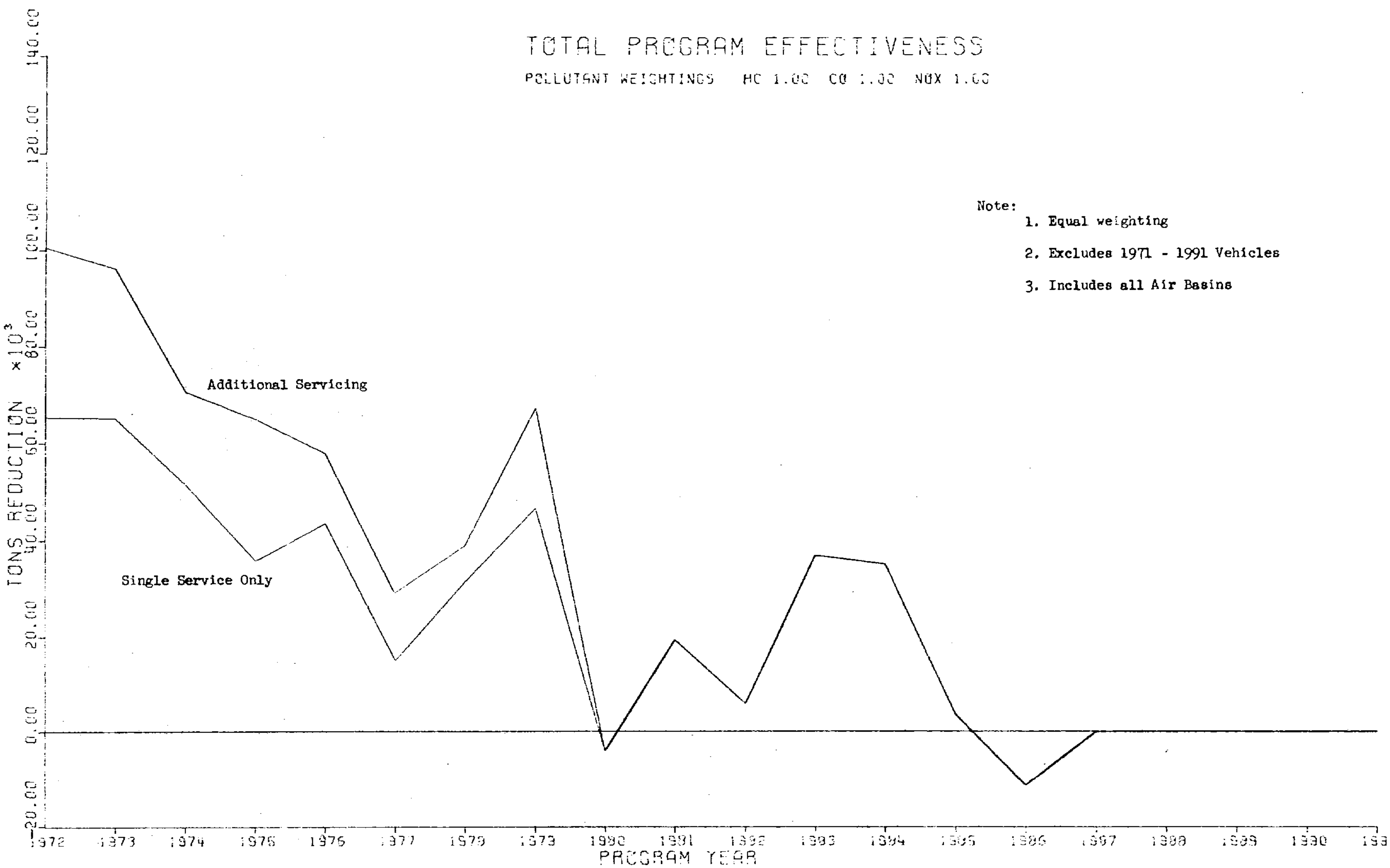

Figure 5-24. ADDITIONAL SERVICING EFFECTS, CERTIFICATE OF COMPLIANCE

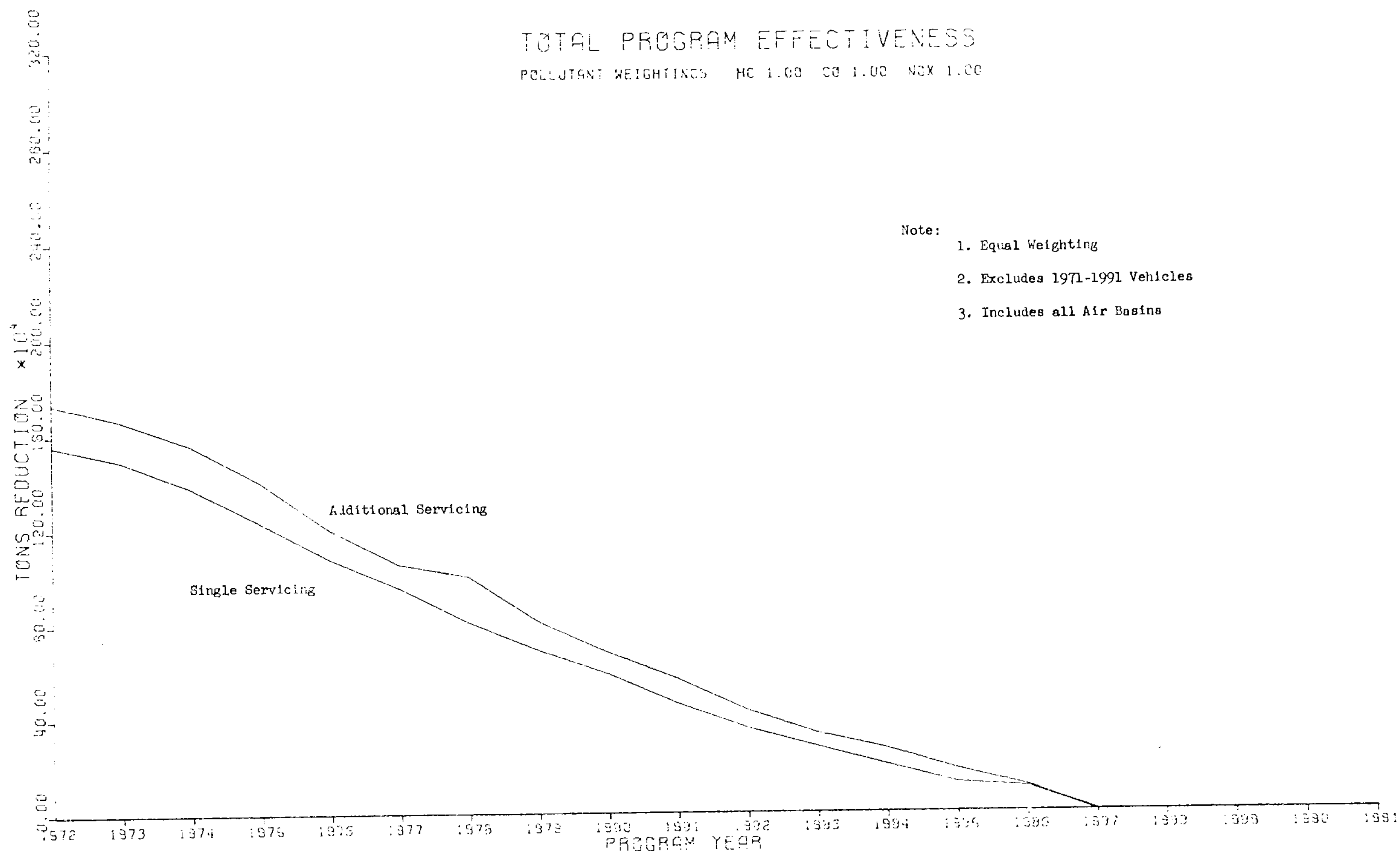

Figure 5-25. ADDITIONAL SERVICING EFFECTS, IDLE TEST

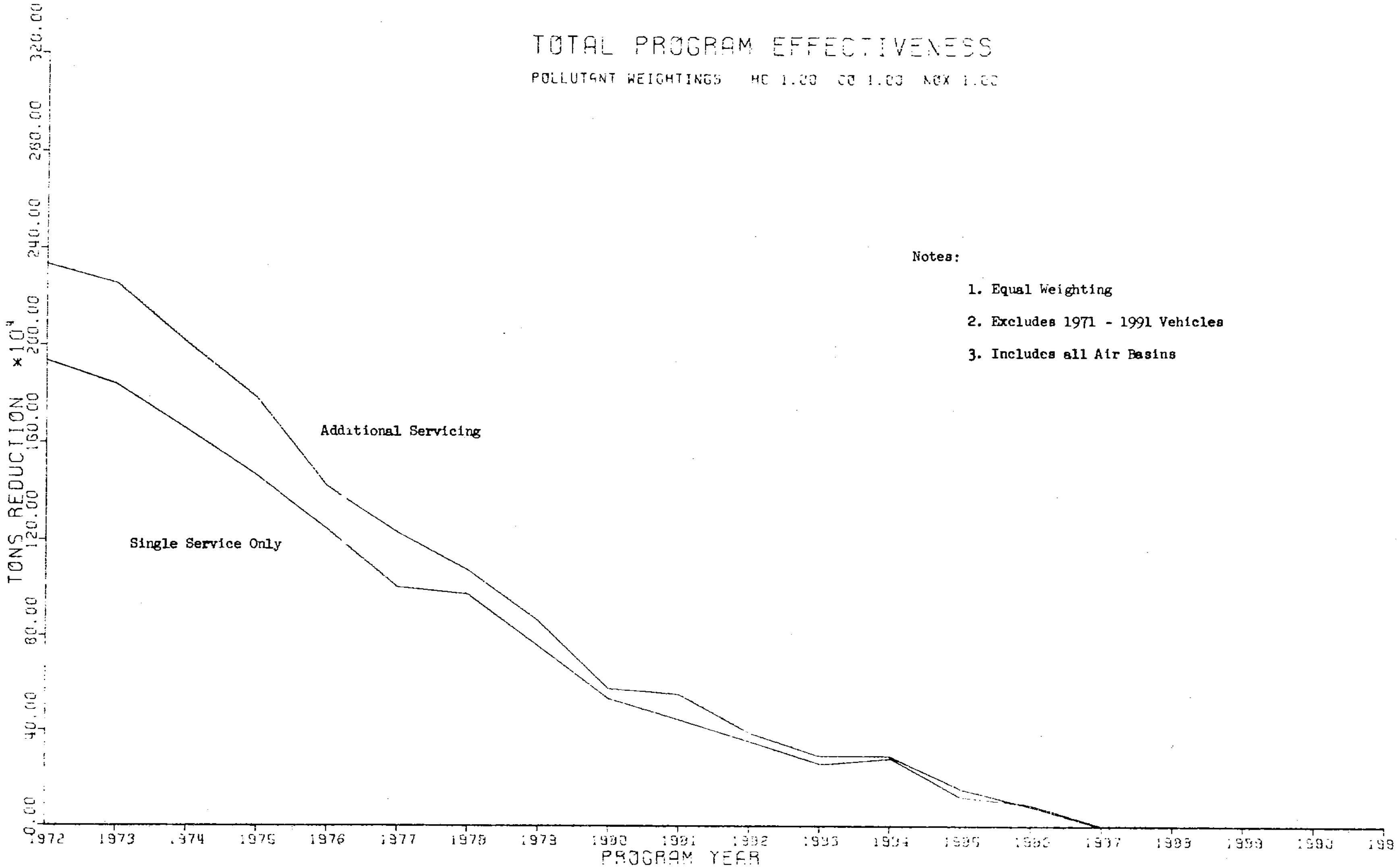

Figure 5-26. ADDITIONAL SERVICING EFFECTS, KEY MODE

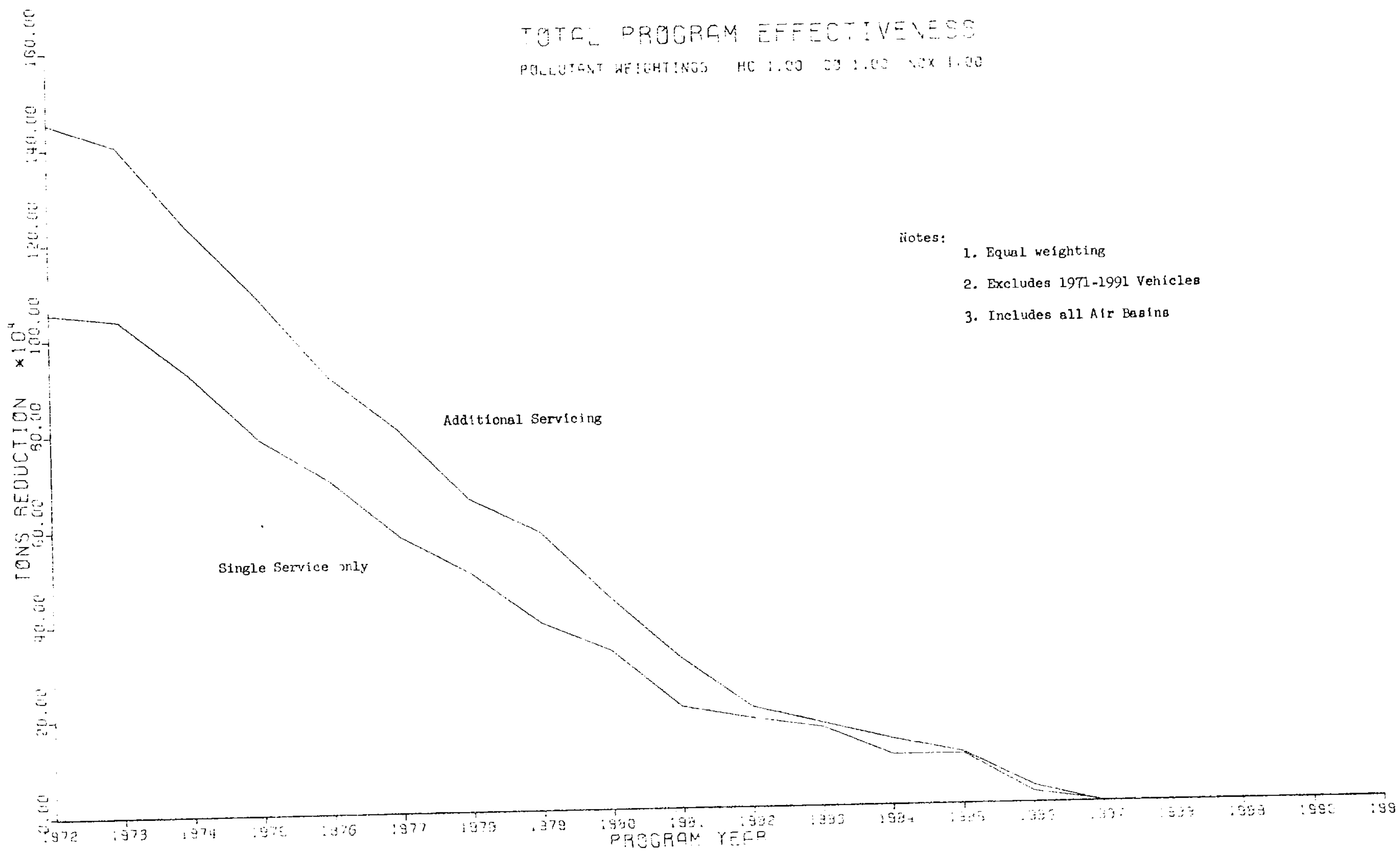

Figure 5-27. ADDITIONAL SERVICING EFFECTS, DIAGNOSTIC TEST

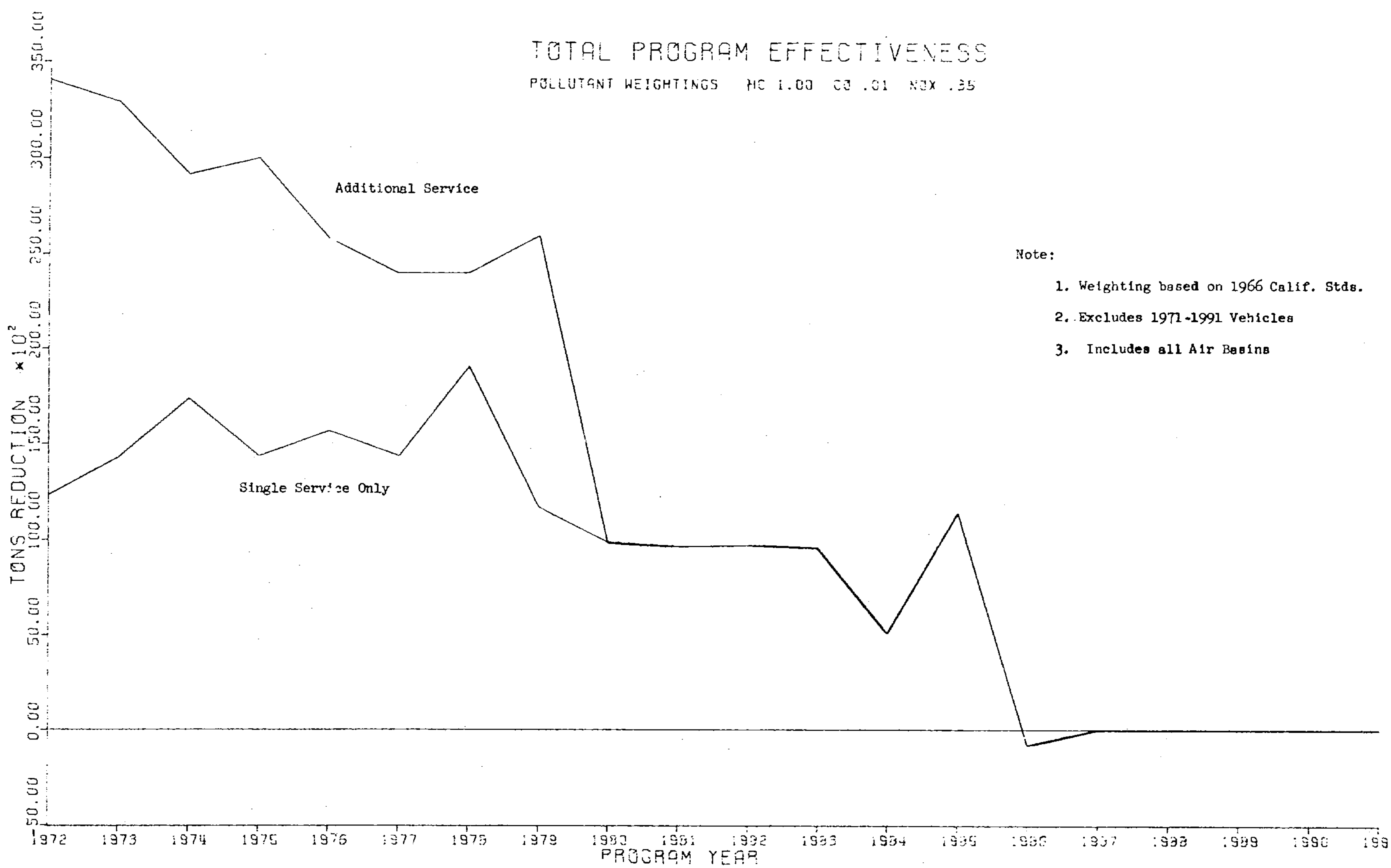

Figure 5-28. SINGLE VERSUS ADDITIONAL SERVICE - CERTIFICATE OF COMPLIANCE (1966 CALIFORNIA STANDARDS)

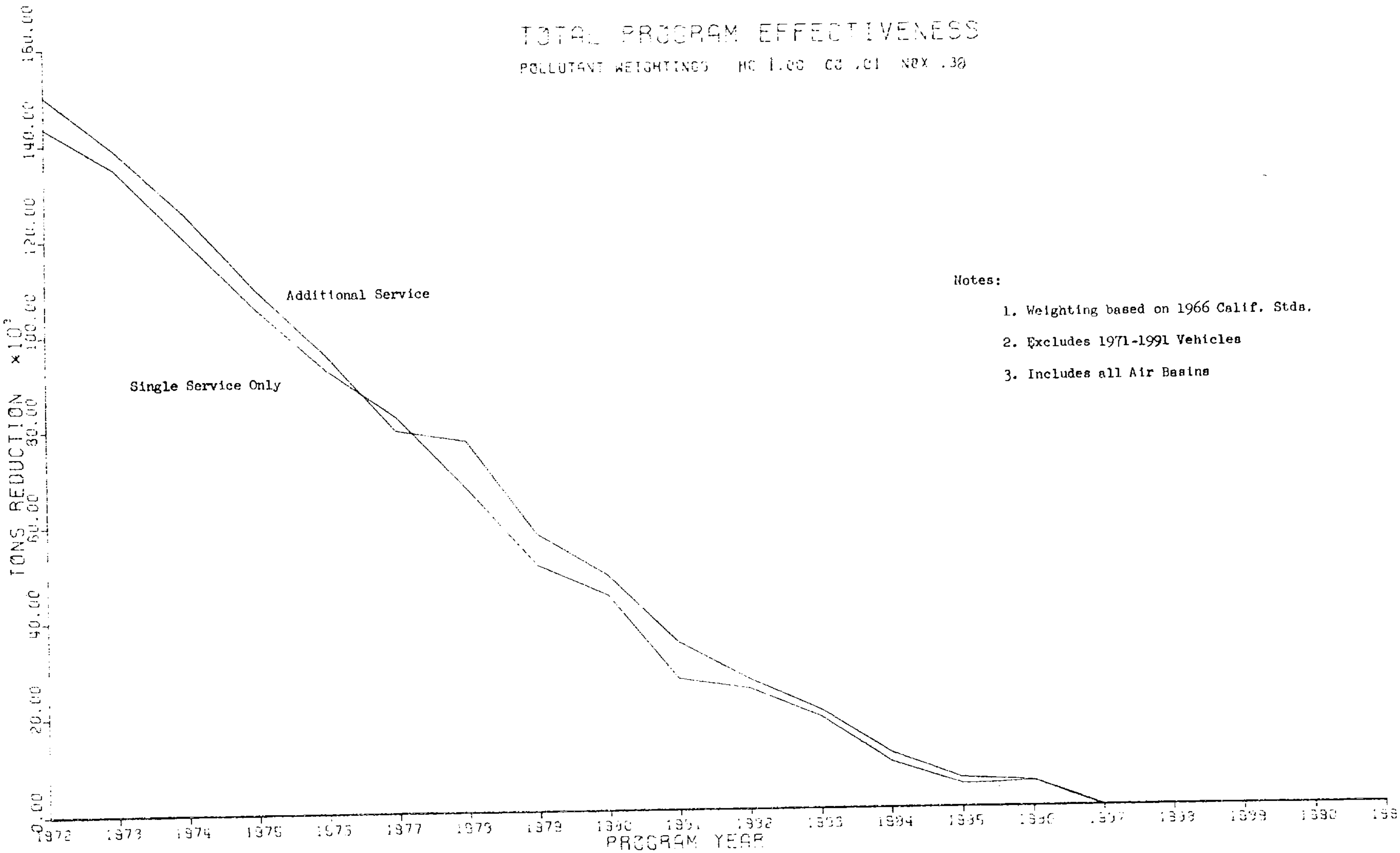

Figure 5-29. SINGLE VERSUS ADDITIONAL SERVICE, IDLE TEST (1966 CALIFORNIA STANDARDS)

Figure 5-30 depicts the advantages of multiple service for Key Mode vehicles. Relative to Idle test, Key Mode does benefit slightly more by performing service beyond the initial. Beyond 1978 little is gained by requiring additional service on 1970 and older vehicles.

Diagnostic test vehicles appear to benefit significantly during the earlier program years as shown in Figure 5-31. The large discontinuity in the single service curve can be attributed to the 1960-1961 model-year vehicles which received considerable service initially and thus required little additional service. After 1982, the advantage of multiple servicing is relatively negligible. This is due to the diminishing vehicle population.

5.5.3 Repeated Servicing Effects Based on 1974 California Standards

The 1971 California Standards are the first to emphasize and regulate NO_x emissions. Based on the weighting factors derived from these standards, Figures 5-32 through 5-35 were generated to display the effects of additional servicing.

The Certificate of Compliance, Figure 5-32, shows a marked improvement when the vehicles are returned for additional servicing. Ordinarily, this test regime does not require servicing beyond the initial one. However, in a few limited cases, the vehicles obviously needed further work and were thus sent out for recertification.

The figure shows that after 1980 there are no advantages to multiple servicing. This can be attributed to the nonexistence of uncontrolled vehicles (pre-1966 model-year vintage) on which the earlier differences are largely based.

Figure 5-33 shows the effects of additional servicing as related to the Idle test regime. It appears that additional servicing does not affect NO_x and HC readings (weightings of 1.00 and 0.87) too greatly as noted by the relatively small difference between the two curves. In essence, Idle test was very effective during initial servicing.

Figures 5-34 and 5-35 illustrate the additional servicing effects as experienced by Key Mode and Diagnostic tests, respectively. Key Mode realizes some increased emission reductions early in program life when additional service is performed on marginal vehicles. Similarly, Diagnostic test vehicles benefit from more than one servicing, especially in earlier years. After 1981, neither would realize an advantage by requiring additional service. This can be attributed to the diminishing vehicle population and the distribution (1957-1970 model years).

5.5.4 Repeated Servicing Effects Based on 1970 California Standards

Using the 1970 California emissions standards, a new set of curves are generated and shown in Figures 5-36 through 5-39 for each of the four test regimes. This mix of weighting factors favors HC, and NO_x to a lesser extent. The figures again show that Idle test is least affected by additional servicing followed by Key Mode test. Both Diagnostic and Certificate of Compliance appear to benefit from additional servicing during the early years of the program.

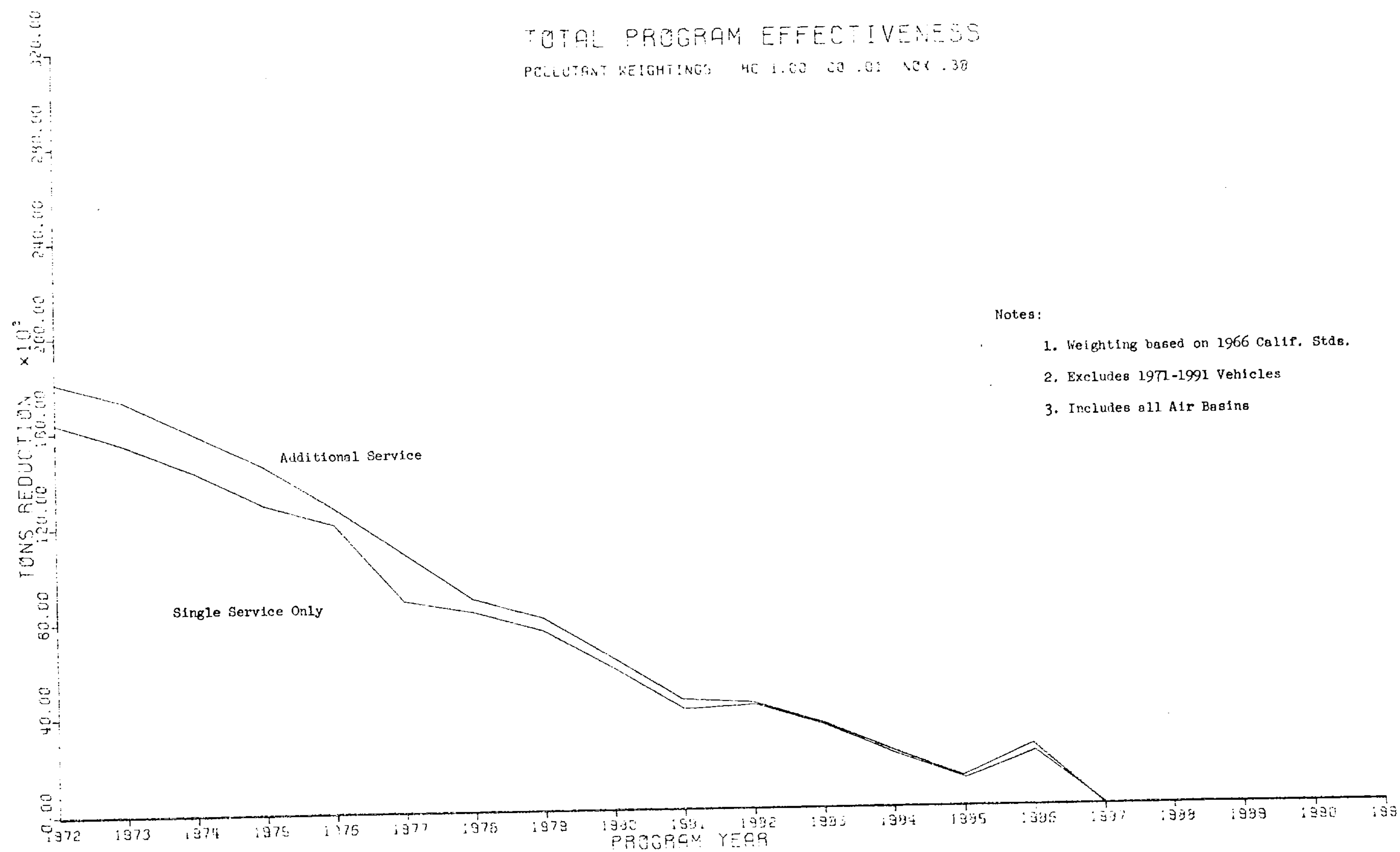

Figure 5-30. SINGLE VERSUS ADDITIONAL SERVICE, KEY MODE TEST (1966 CALIFORNIA STANDARDS)

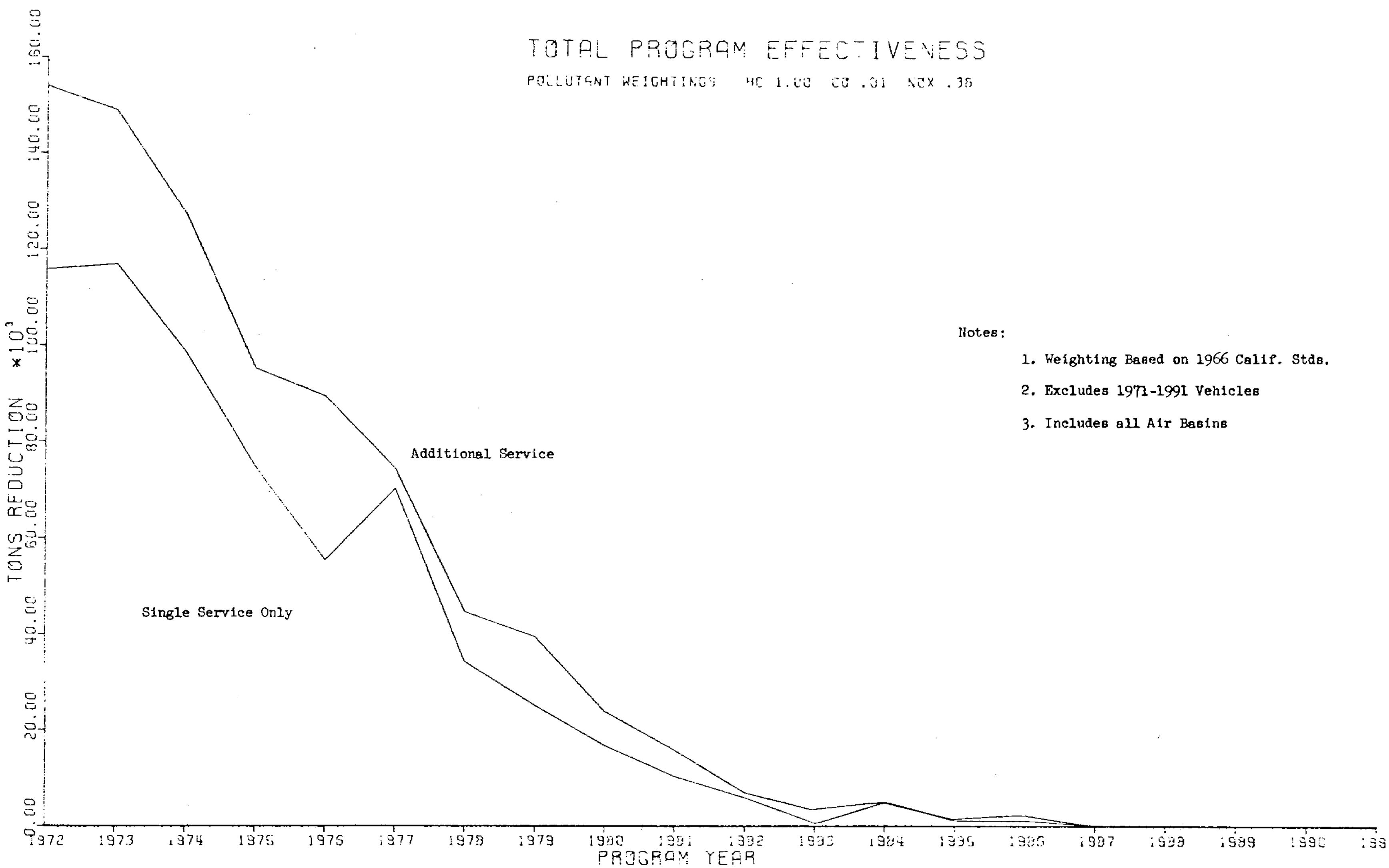

Figure 5-31. SINGLE VERSUS ADDITIONAL SERVICE, DIAGNOSTIC TEST (1966 CALIFORNIA STANDARDS)

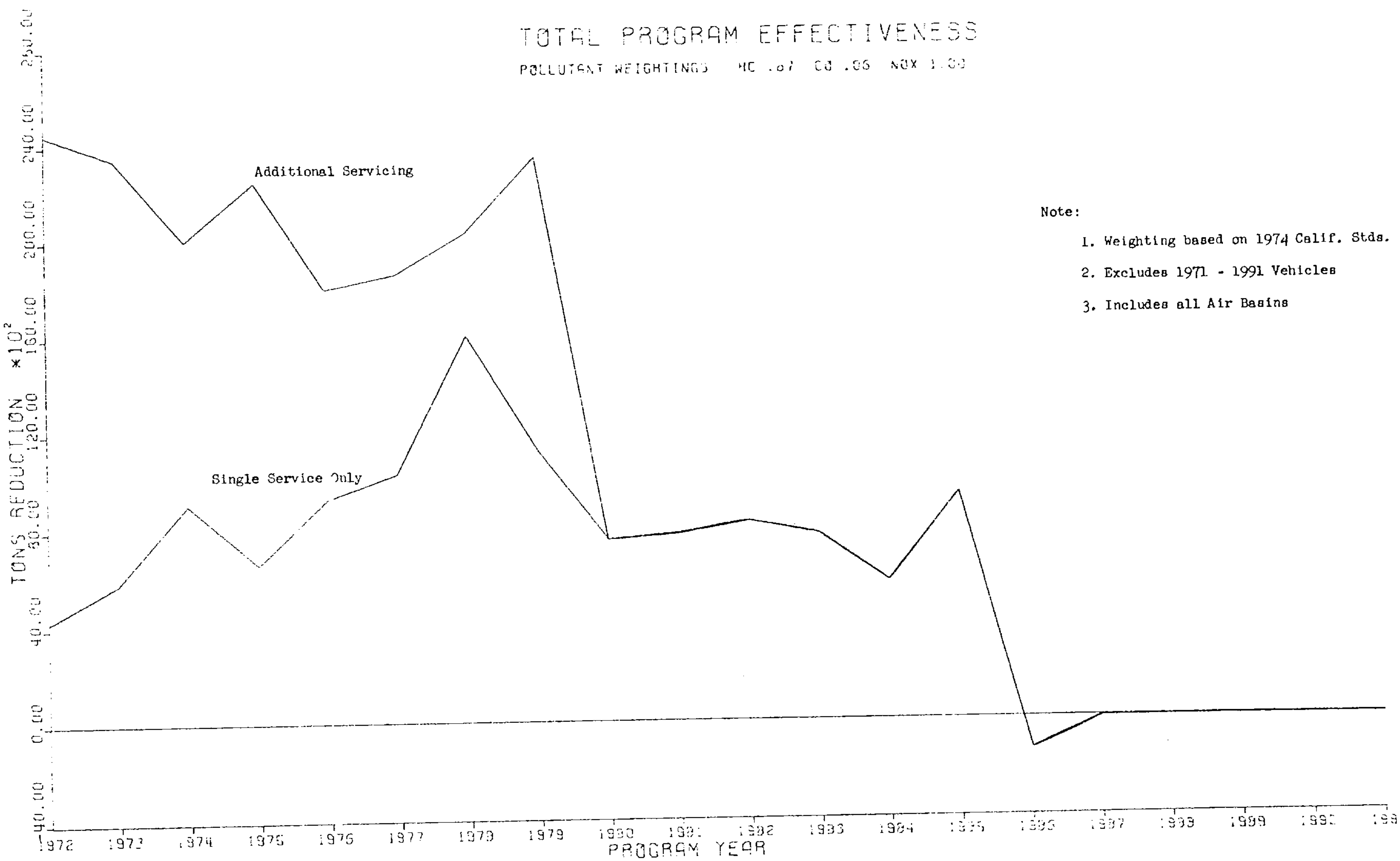

Figure 5-32. CERTIFICATE OF COMPLIANCE ADDITIONAL SERVICING EFFECTS (1974 CALIFORNIA STANDARDS)

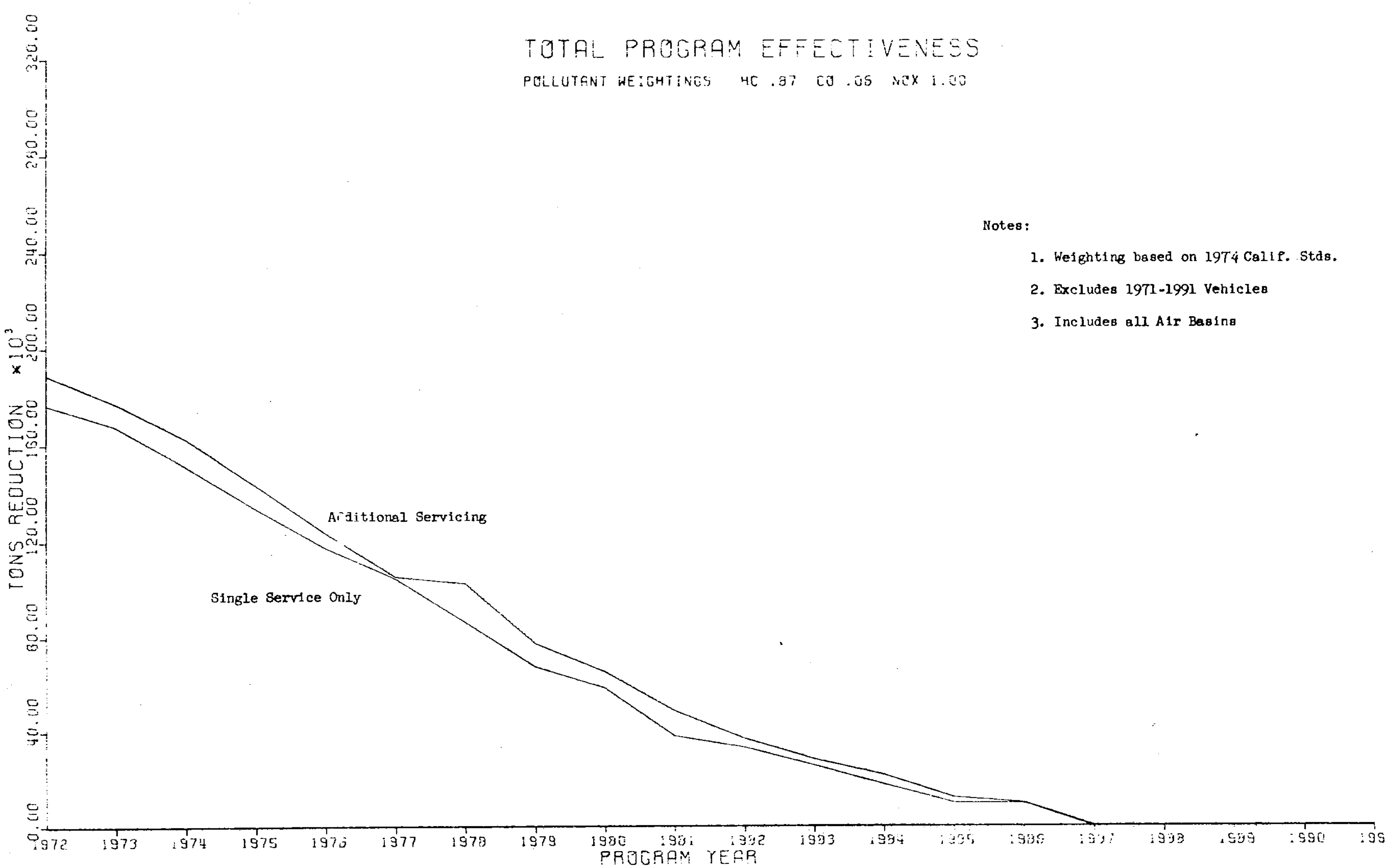

Figure 5-33. IDLE TEST ADDITIONAL SERVICING EFFECTS (1974 CALIFORNIA STANDARDS)

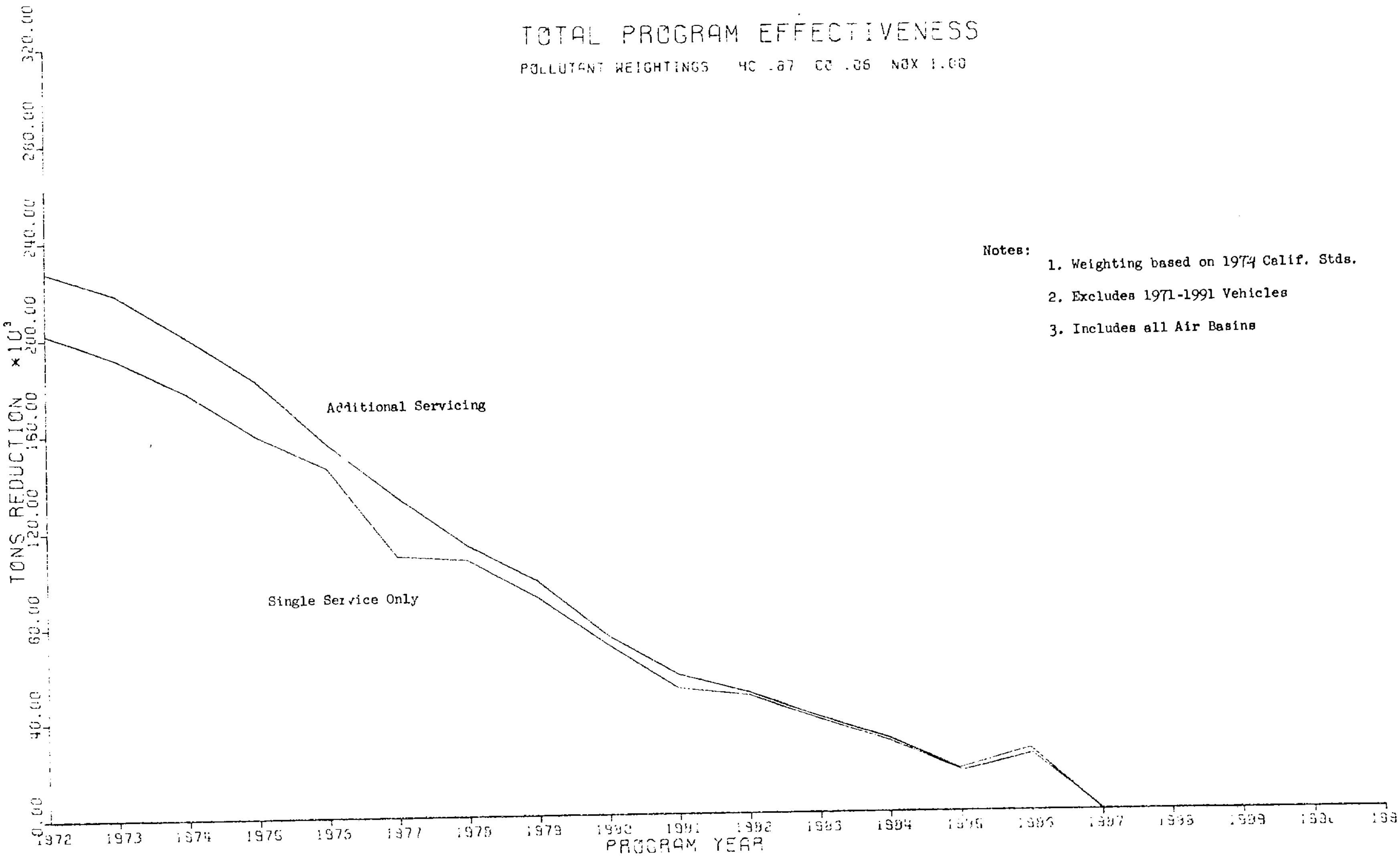

Figure 5-34. KEY MODE TEST ADDITIONAL SERVICING EFFECTS (1974 CALIFORNIA STANDARDS)

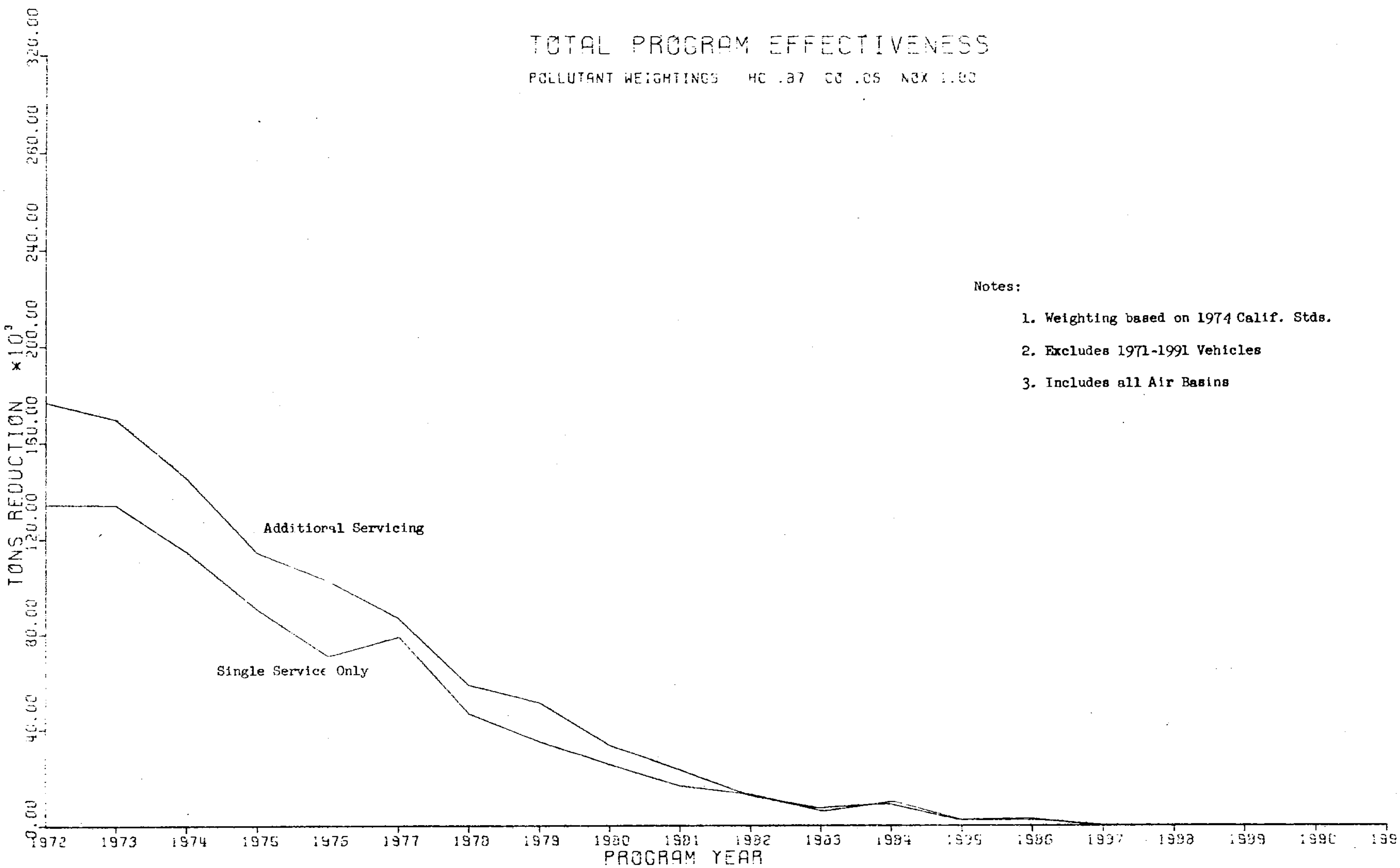

Figure 5-35. DIAGNOSTIC TEST ADDITIONAL SERVICING EFFECTS (1974 CALIFORNIA STANDARDS)

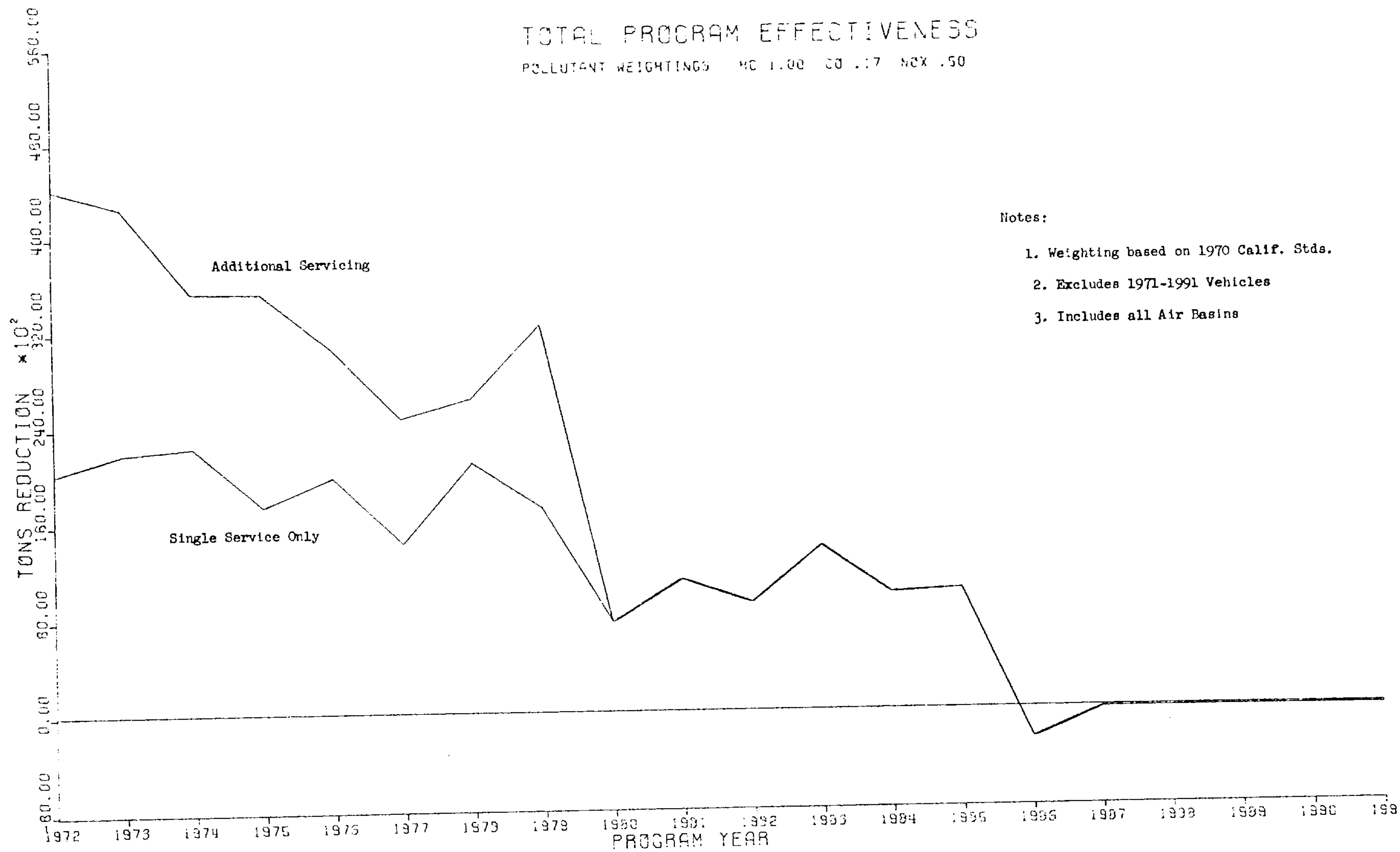

Figure 5-36. ADDITIONAL VERSUS SINGLE SERVICE, CERTIFICATE OF COMPLIANCE (1970 CALIFORNIA STANDARDS)

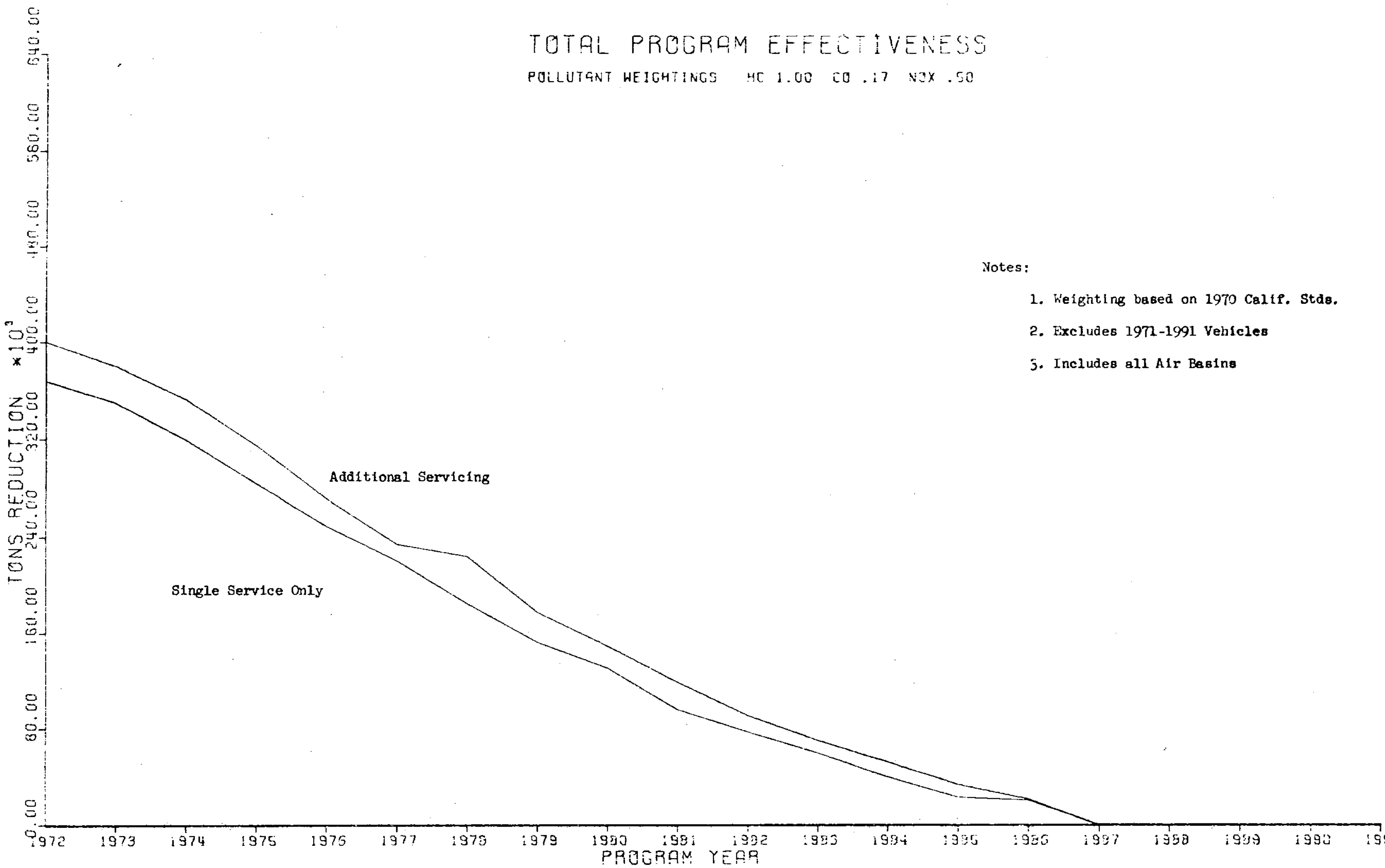

Figure 5-37. ADDITIONAL VERSUS SINGLE SERVICE, IDLE TEST (1970 CALIFORNIA STANDARDS)

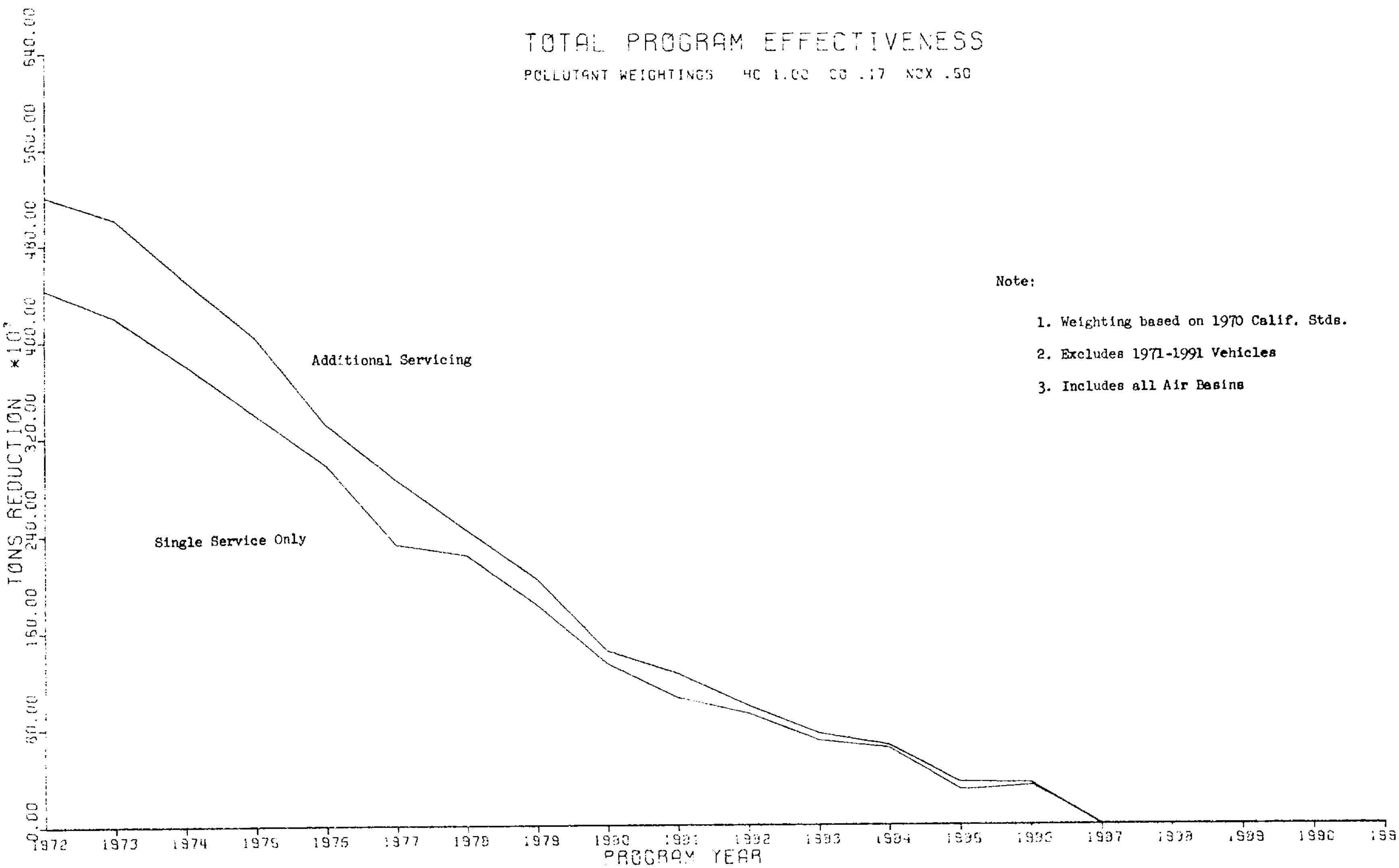

Figure 5-38. ADDITIONAL VERSUS SINGLE SERVICE, KEY MODE TEST (1970 CALIFORNIA STANDARDS)

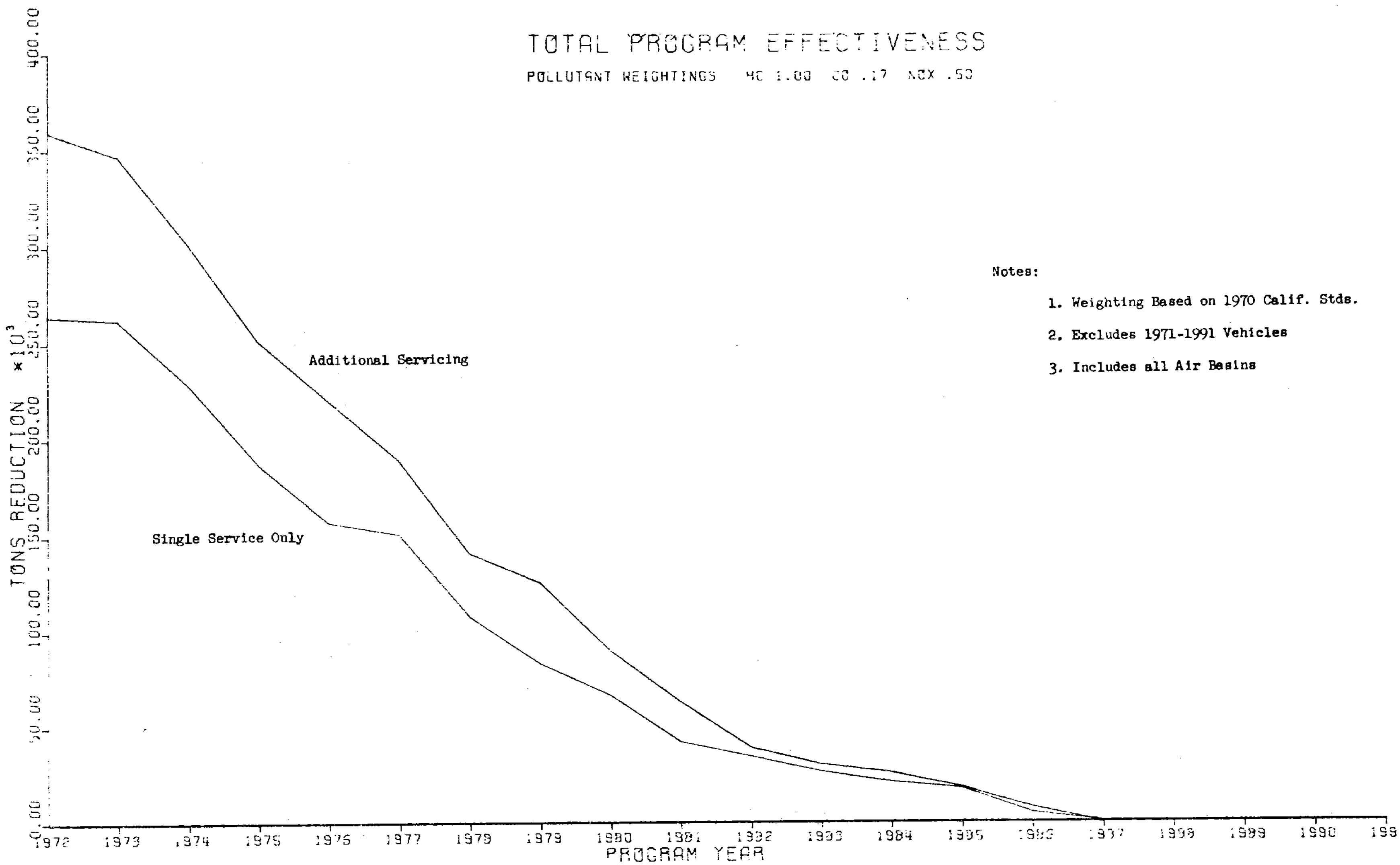

Figure 5-39. ADDITIONAL VERSUS SINGLE SERVICE, DIAGNOSTIC TEST (1970 CALIFORNIA STANDARDS)

5.5.5 Comparison of Test Regimes Based on Single Service Effects

The previous paragraphs have evaluated the relative effects of additional service for the individual test regimes using the various proportional weighting factors. In Figures 5-40 through 5-43, the test regimes are evaluated and compared collectively, again based on the different weighting factors.

The figures show that regardless of weighting factors considered, the Key Mode test regime is relatively superior to the other three. Figure 5-40 shows that with equal weighting of the three pollutants, Idle test is essentially equal to Key Mode, beginning in 1980, and even surpasses it in 1984 for a brief period.

Using the 1966 California Standards, the emphasis is on HC emissions reduction. Figure 5-41 shows that Key Mode test remains the most effective up to 1985 when Diagnostic appears to be the best of the four regimes. Figure 5-42 shows the single service effectiveness of the four test regimes with weighting factors based on 1970 California emission standards. Key Mode test remains the most effective in achieving emission reduction.

The 1971 California emission standards emphasizes NO_x. Using these standards for the weighting factors, Figure 5-43 compares the four test regimes. Key Mode test maintains a relative dominance over the other three test regimes.

5.5.5.1 Evaluation of Single Service Effects - The figures show that the Key Mode test regime realizes the greatest emission reduction of the four test regimes regardless of the set of weighting factors considered. Its closest competitor, in every case, was Idle test, followed by Diagnostic and Certificate of Compliance.

5.6 PROGRAM EFFECTS ON FUTURE YEARS

The projected vehicle emission test program effects on future years in California is shown in Figures 5-44 through 5-47, illustrating the trend in California vehicle emission levels as a function of test regimes and various chronological emission standards. These projections are based on 50 percent inspection rejection and without emission degradation after service. As mentioned in other sections of this report, emission degradation effects are currently being assessed and are not available for inclusion within the calculated projections. All 1971-1991 vehicles, together with the 1957-1970 vehicles have been considered in the estimates.

Figure 5-44 shows the projections for emission levels with and without periodic vehicle emission inspection. The absolute difference between each test regime curve and the "without periodic vehicle inspection" curve have been previously calculated and plotted as effectiveness data. Whereas Figure 5-44 provides the true or unweighted emissions, Figures 5-45, 5-46, and 5-47 indicate the trends in emission as a function of 1966, 1974, and 1970 California standards, respectively.

The 1970 Annual Report of the Air Resources Board, dated January 1971 , contains three figures of interest. These figures, 8, 9, and 10, show the trends in HC, CO, and NO_x respectively, attributable to motor vehicles in the South Coast Basin. It is noted that approximately 1000 tons of HC, 3000 tons of CO, and 150 tons of NO_x were emitted on an average year 1940 day in that locale. This was calculated to be approximately 1.5 million tons per year for the South Coast Basin, or 3 million tons per year for the total state (South Coast constitutes slightly over 50 percent of the total vehicle population).

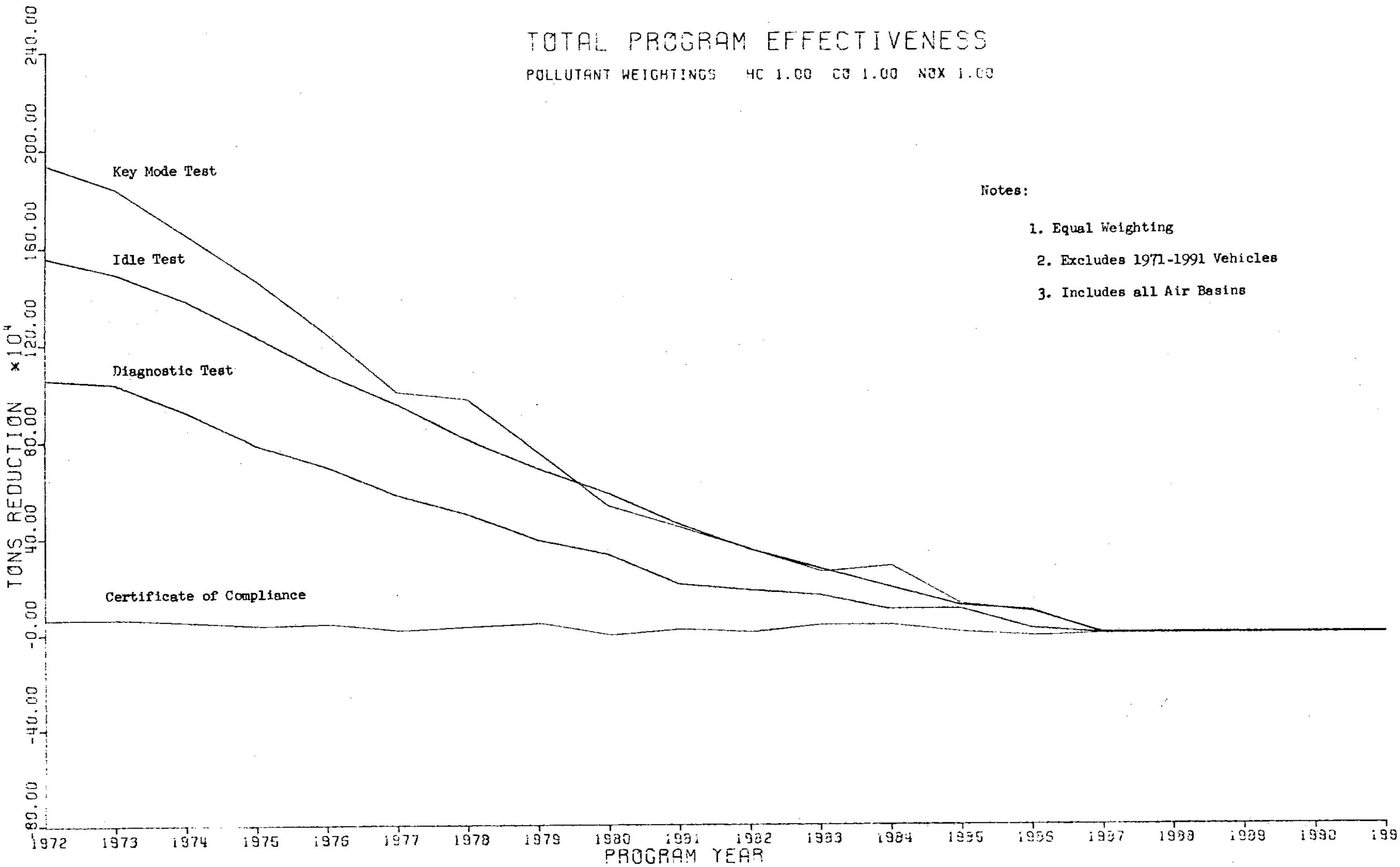

Figure 5-40. SINGLE SERVICE COMPARISON, EQUAL WEIGHTING

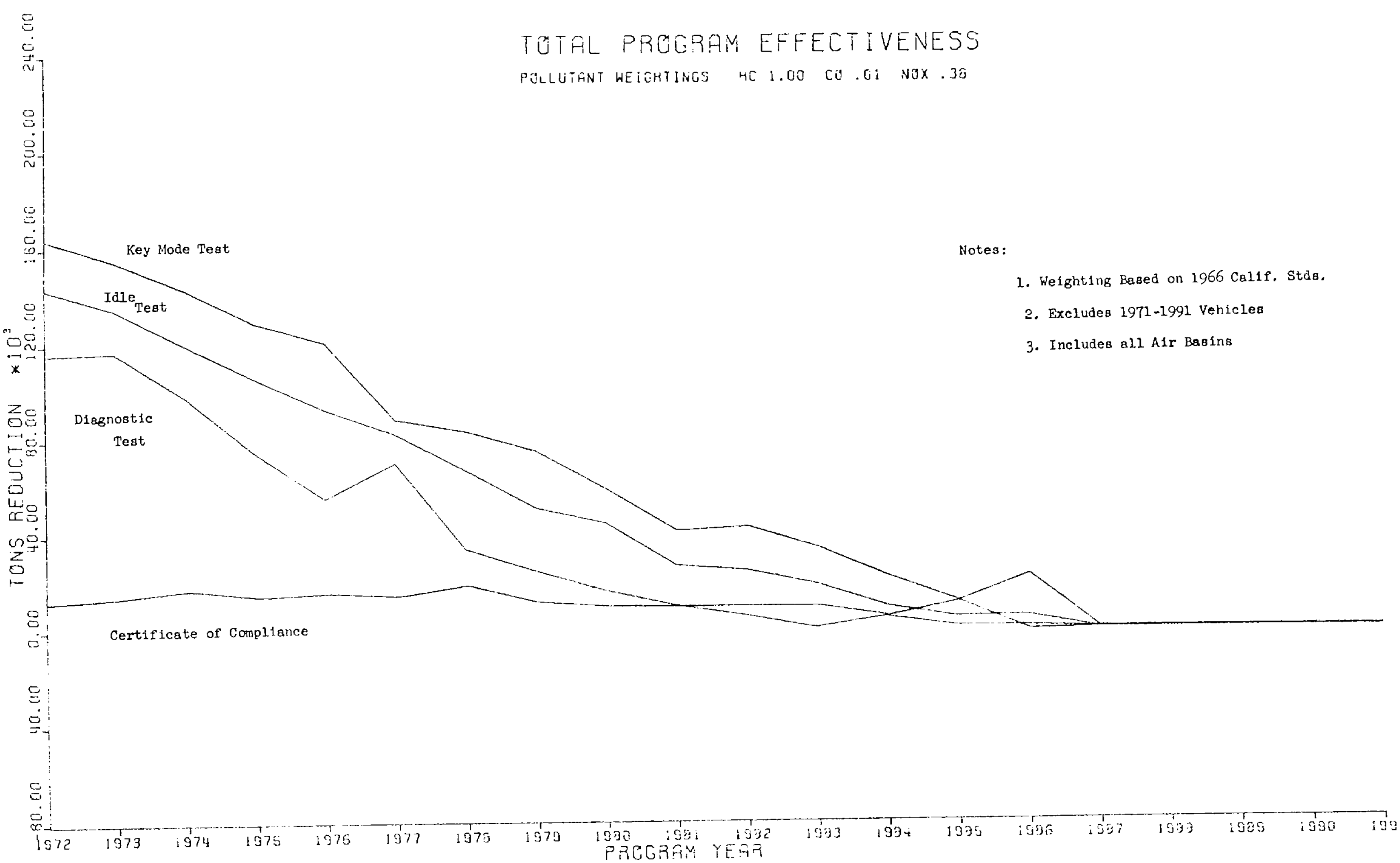

Figure 5-41. SINGLE SERVICE COMPARISON (1966 CALIFORNIA STANDARDS)

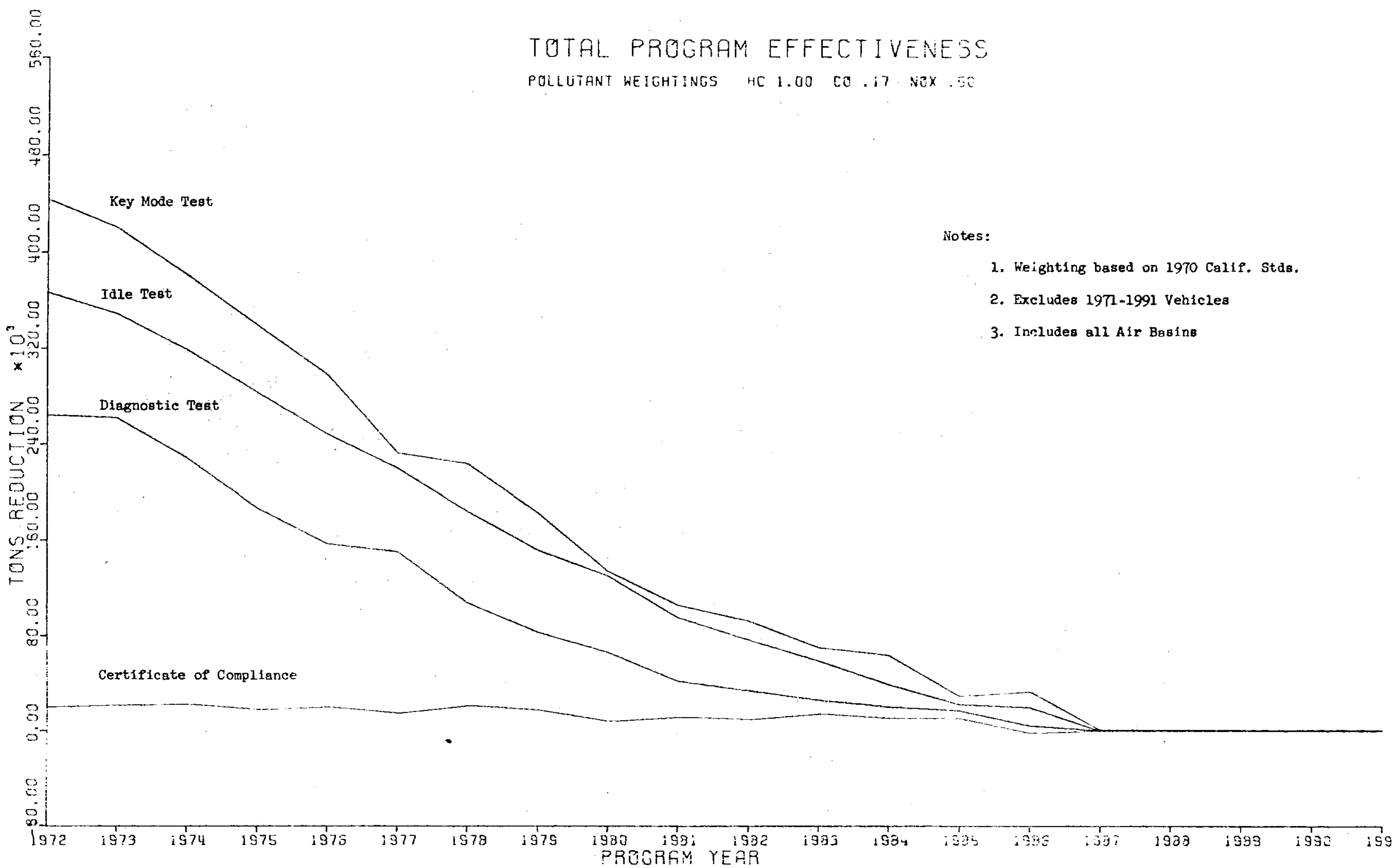

Figure 5-42. SINGLE SERVICE COMPARISON (1970 CALIFORNIA STANDARDS)

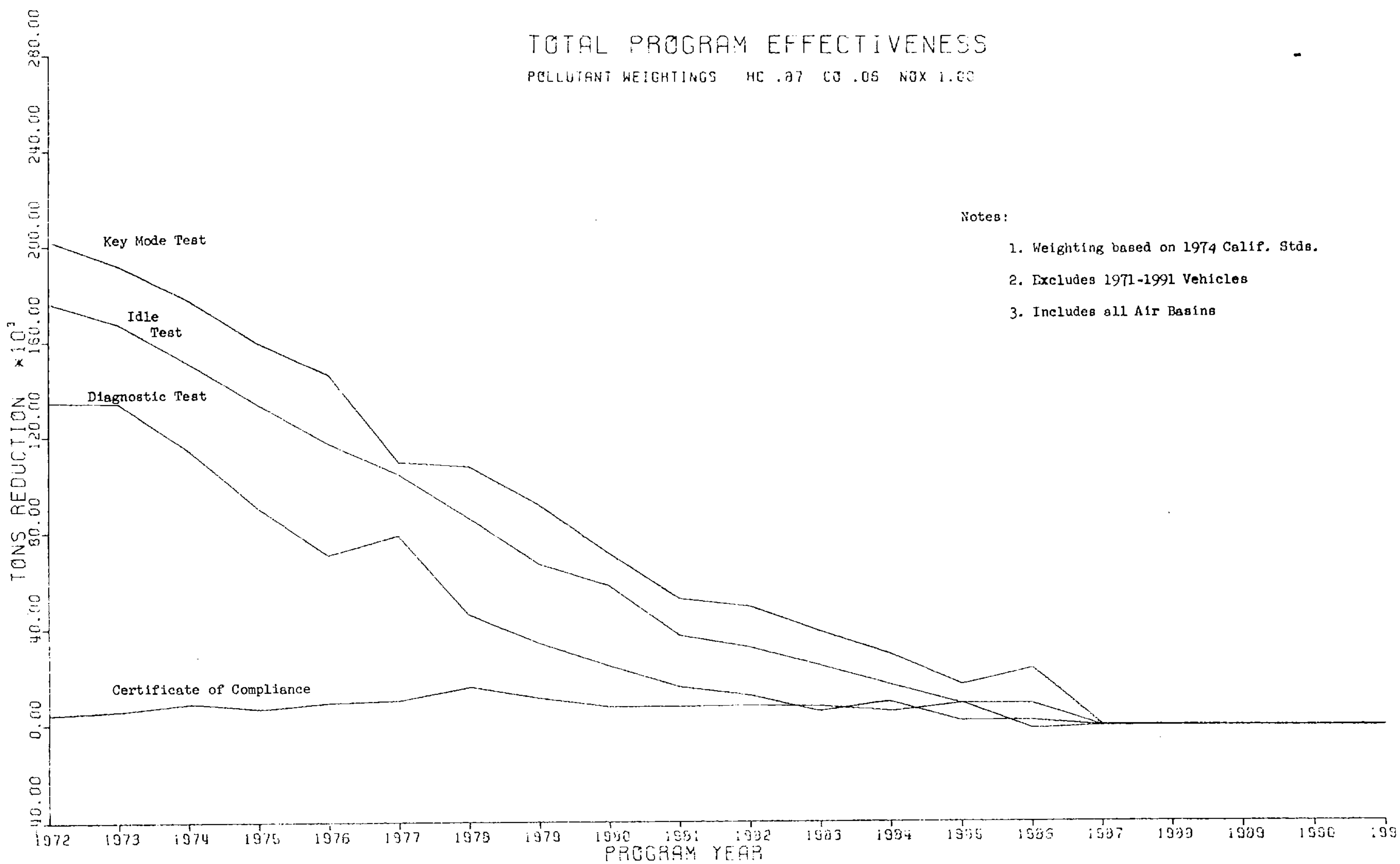

Figure 5-43. SINGLE SERVICE COMPARISON (1974 CALIFORNIA STANDARDS)

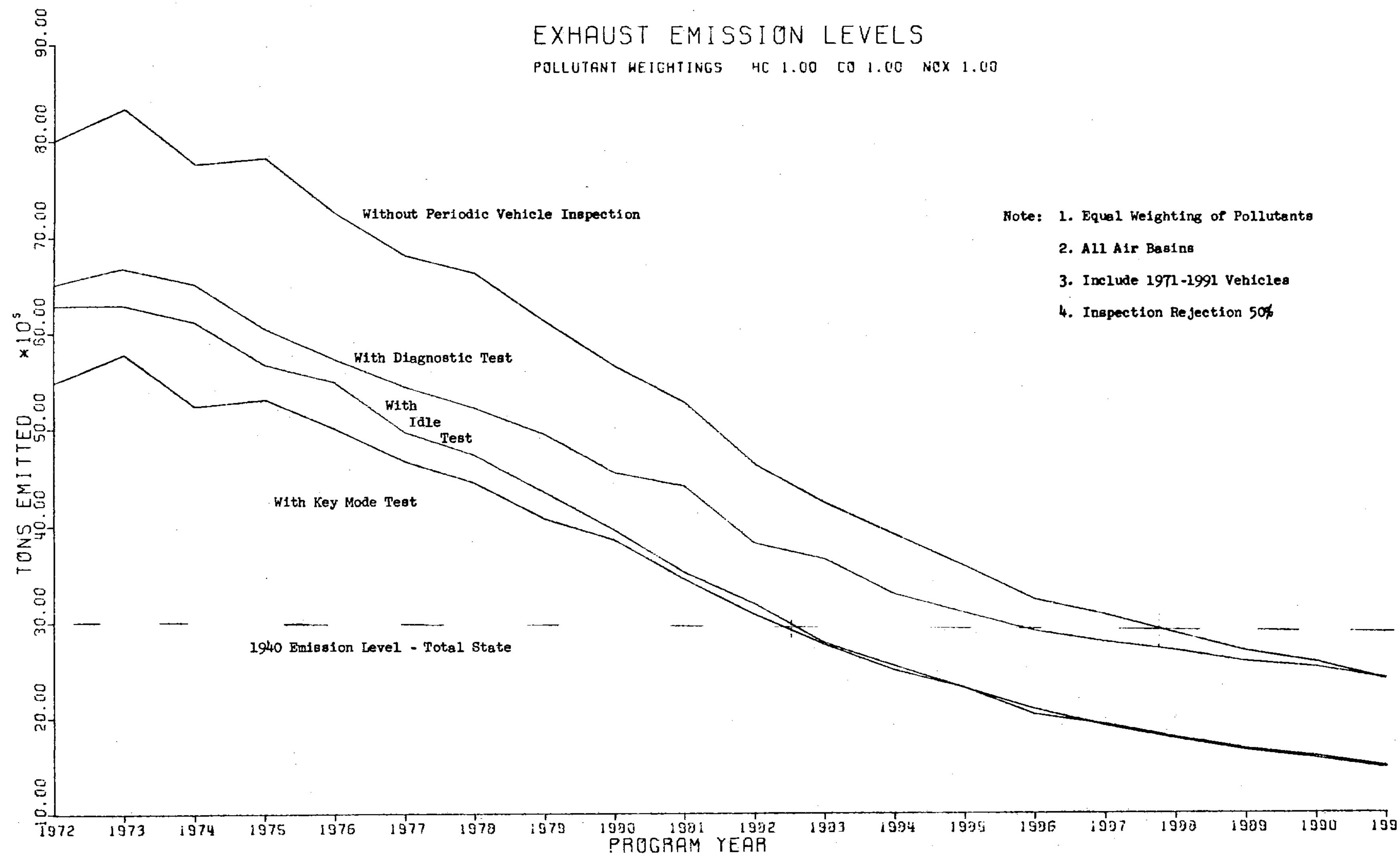

Figure 5-44. TRENDS IN EMISSION LEVELS

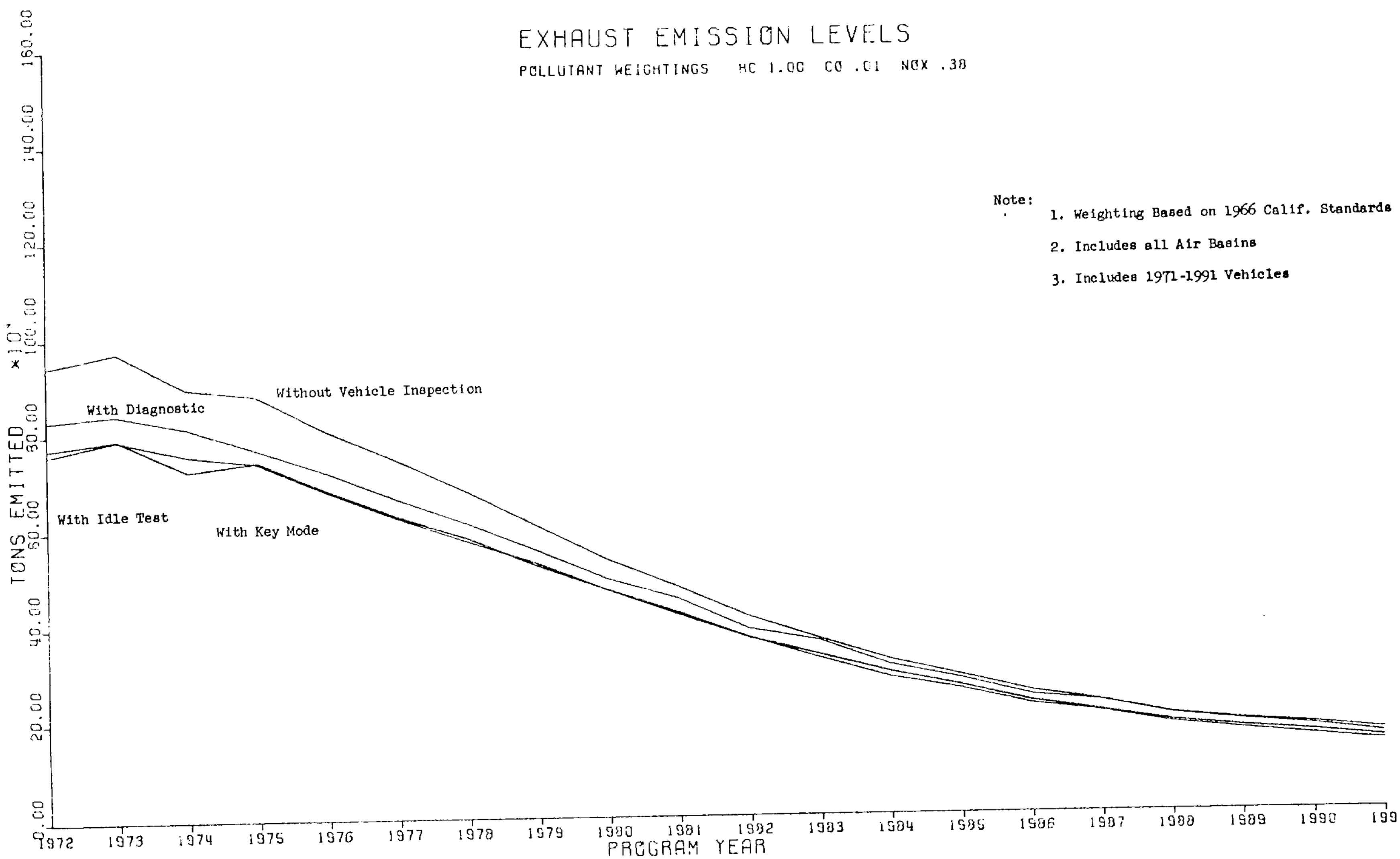

Figure 5-45. TRENDS IN EMISSION LEVELS - 1966 CALIFORNIA STANDARDS WEIGHTING

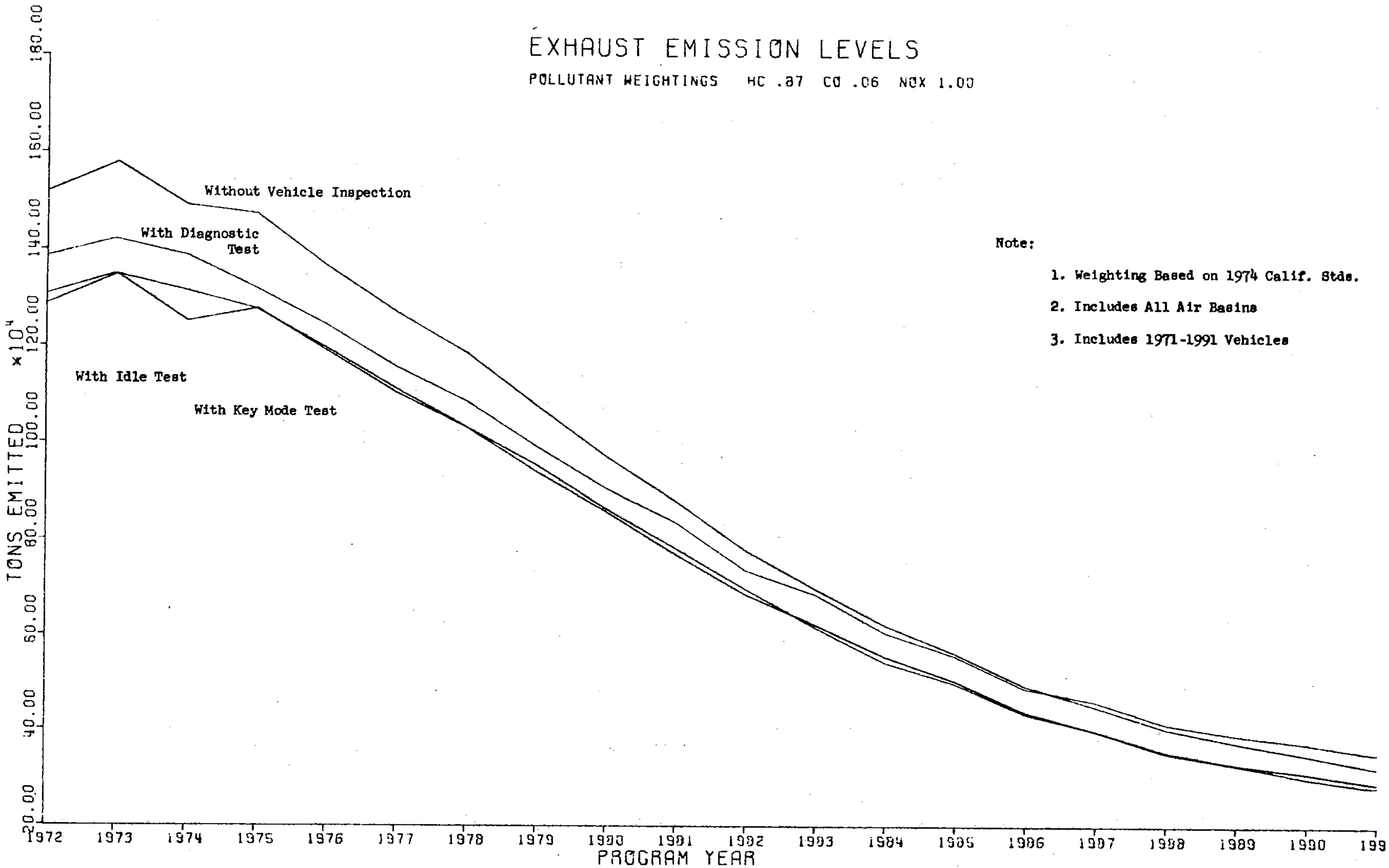

Figure 5-46. TRENDS IN EMISSION LEVELS - 1974 CALIFORNIA STANDARDS WEIGHTING

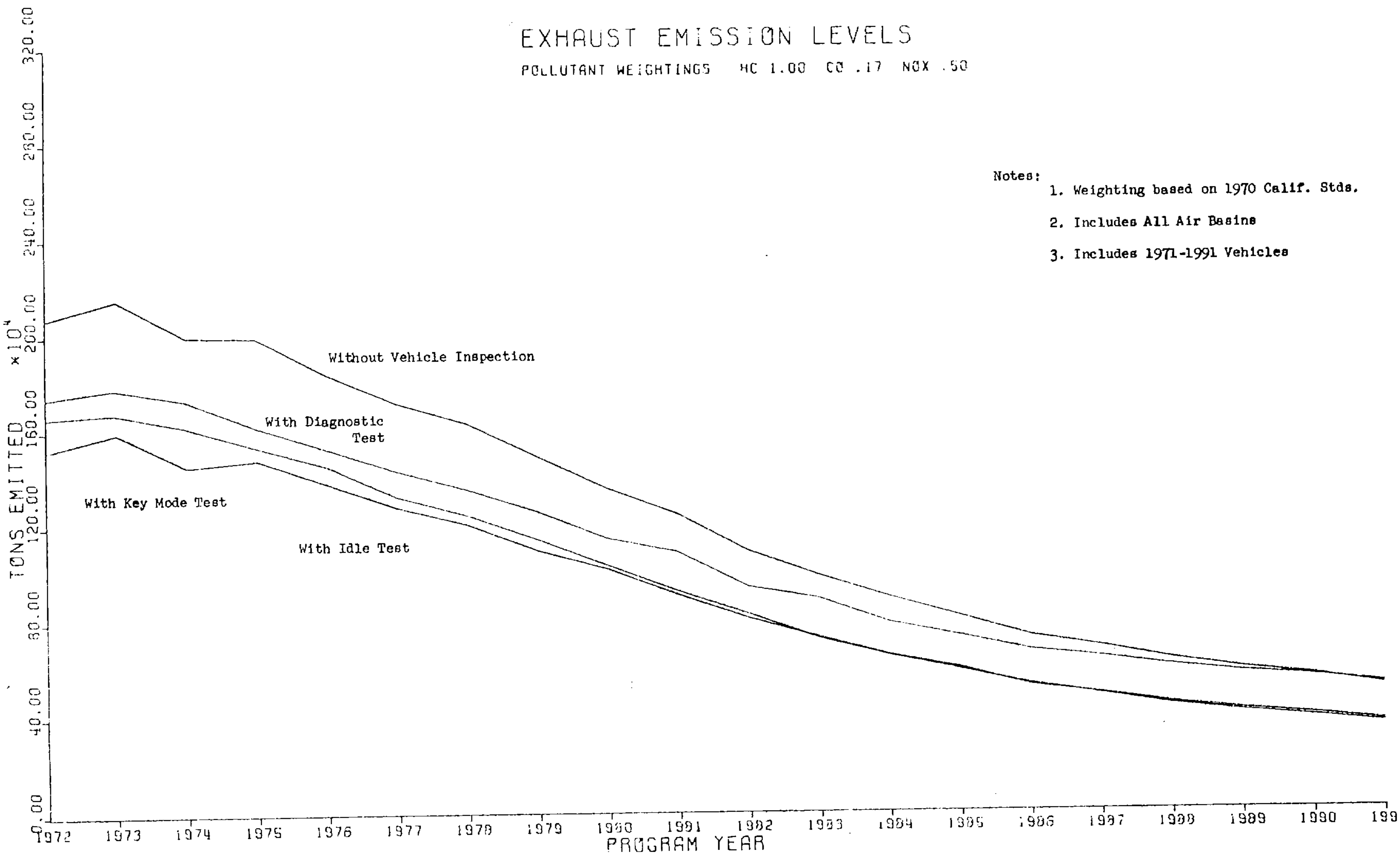

Figure 5-47. TRENDS IN EMISSION LEVELS - 1970 CALIFORNIA STANDARDS WEIGHTING

This three million ton level is shown dotted to depict a hypothetical program goal. Based on this quantity, the State would realize this goal during 1987 without any inspection program. This would result from the normal attrition of older vehicles and the introduction of newer and better controlled vehicles designed to meet stricter regulations. The projections include normal attrition and a 3.6 percent annual increase in total vehicle population.

With the implementation of an inspection program, this same goal could be realized during 1982, using either Key Mode or Idle test. Diagnostic test would reach this hypothetical goal in 1985.

5.6.1 Exhaust Emission Levels

Figures 5-48 through 5-50 show the individual anticipated reductions for HC, CO, and NO_x, respectively, as a function of program calendar year. The effectiveness of each test regime except Certificate of Compliance is shown and evaluated against the 1940 emission levels as calculated from the Air Pollution Control 1970 Annual Report.

Figure 5-48 indicates that each of three test regimes, if implemented, would lower the HC levels below the calculated 1940 year level shown. This lower emission level would be realized immediately upon implementation and would continue through program duration. Without an inspection program, the 1940 level would be reached in year 1975.

Figure 5-49 shows the estimated and projected emission levels for CO as a function of program calendar year and test regime, again not including Certificate of Compliance. Both Idle and Key Mode test regimes will achieve 1940 year levels of emission by year 1984, whereas, Diagnostic test does not achieve this level at anytime of its program life. Similarly, without periodic vehicle inspection this previous level of approximately 2.2 million tons per year will not be achieved before year 1991. It is interesting to note that the cited annual report indicates to the contrary, and that 1940 emissions of CO attributable to motor vehicles will indeed be met by about year 1982. Reconciling the two figures is beyond the scope of this report. However, a few of the reasons could be small differences in estimated vehicle population growth rate, model-year distribution, average miles driven, and emission characteristics of future vehicles.

Figure 5-50 presents the estimated levels of oxides of nitrogen (NO_x) as a function of test regimes and program calendar year. Certificate of Compliance is not included. The data shows that each of the test regimes causes an increase in NO_x levels. Without any periodic emission inspection, the existing and proposed standards should have sufficient influence to cause the total emission level of NO_x to closely approximate the 1940 year levels by 1990. From the figure, it appears that none of the test regimes exhibits an advantage over the others. In fact, they seem to be equally ineffective. Thus, a fair assumption would be that the increase is not due to test regimes but could be more the fault of the vehicles not being amenable to optimum NO_x emission adjustment. This has been validated in studies mentioned in Section 2 of this report.

The study was limited to pre-1970 model year vehicles which were not required to meet either State or Federal regulations of emitted NO_x. However, the years 1971 through 1991 will have NO_x emission standards imposed on them. Consequently, it is anticipated that the test regimes would be more effective on these future vehicles than that experienced on the older vehicles.

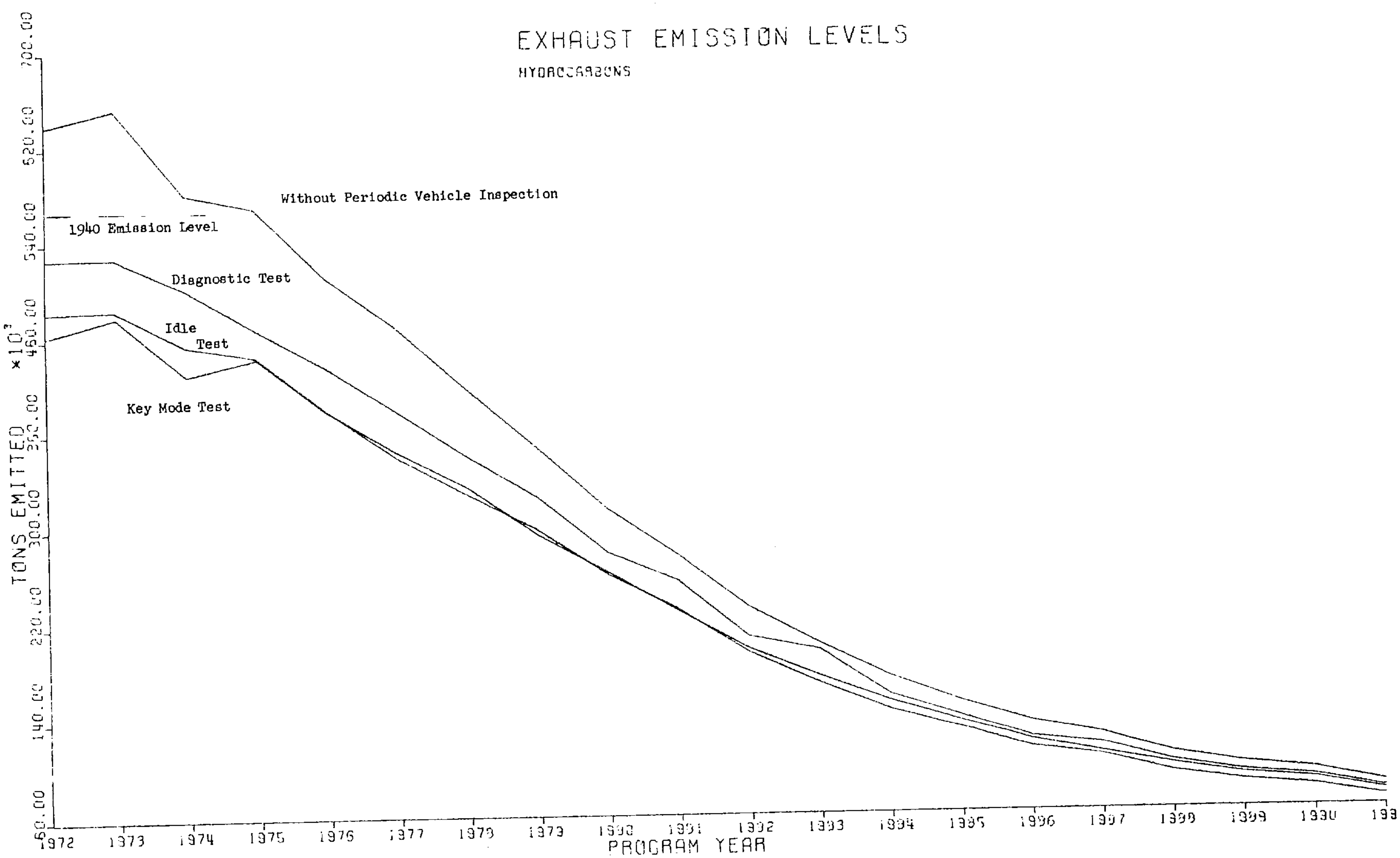

Figure 5-48. ESTIMATED HYDROCARBON EMISSION LEVELS

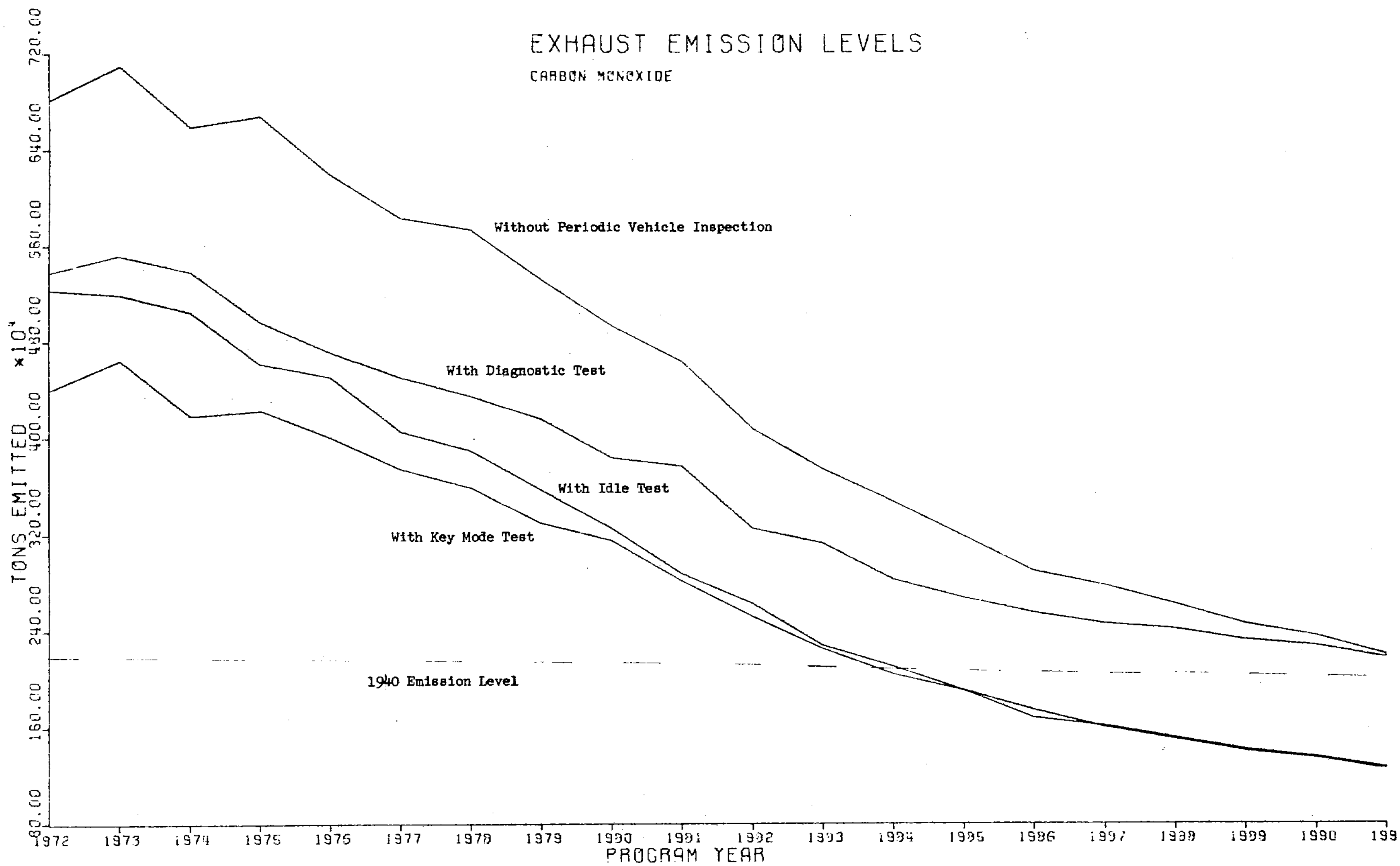

Figure 5-49. ESTIMATED CARBON MONOXIDE EMISSION LEVELS

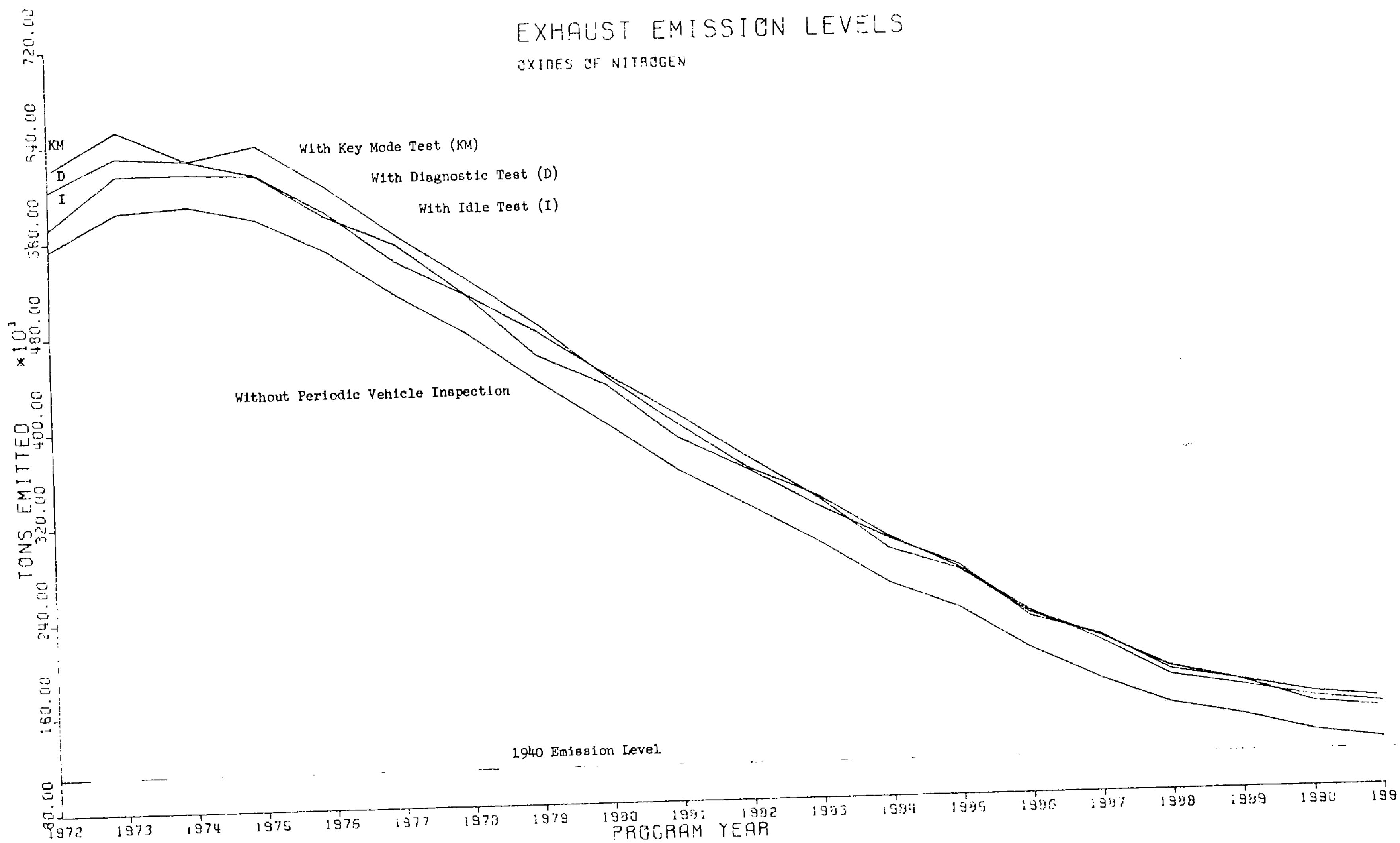

Figure 5-50. ESTIMATED OXIDES OF NITROGEN EMISSION LEVELS