4.4 EMISSION DEGRADATION

Approximately 50 percent of all vehicles used during the main test phase were subjected to a retest at about 3 to 8 months after their respective original test. The purpose of the retest phase was to determine the emission degradation for serviced and unserviced vehicles as a function of mileage.

There were 552 vehicles retested during this phase. An attempt was made to obtain a representative mix of the test regimes and of serviced and unserviced vehicles. Figure 4-11 shows the distribution of the vehicles being tested.

As the experiment design did not discriminate which vehicles were to be retested, some of the vehicles received normal engine service by the owner or his selected garage. Approximately 25 percent received some sort of engine maintenance and, if included, would have biased the results. To obtain a meaningful evaluation of emission degradation, only those vehicles which had no subsequent engine work performed were considered in this analysis. The following paragraphs document the results of the retest phase.

4.4.1 Test Results

A computer program was developed to search through the raw emission data to obtain the mean and standard deviation for before and after emission profiles as a function of mileage. The changes, both in magnitude and percent, were obtained and are summarized in Tables 4-28 through 4-41, and the percent of degradation plotted versus mileages are in Figures 4-12 through 4-25.

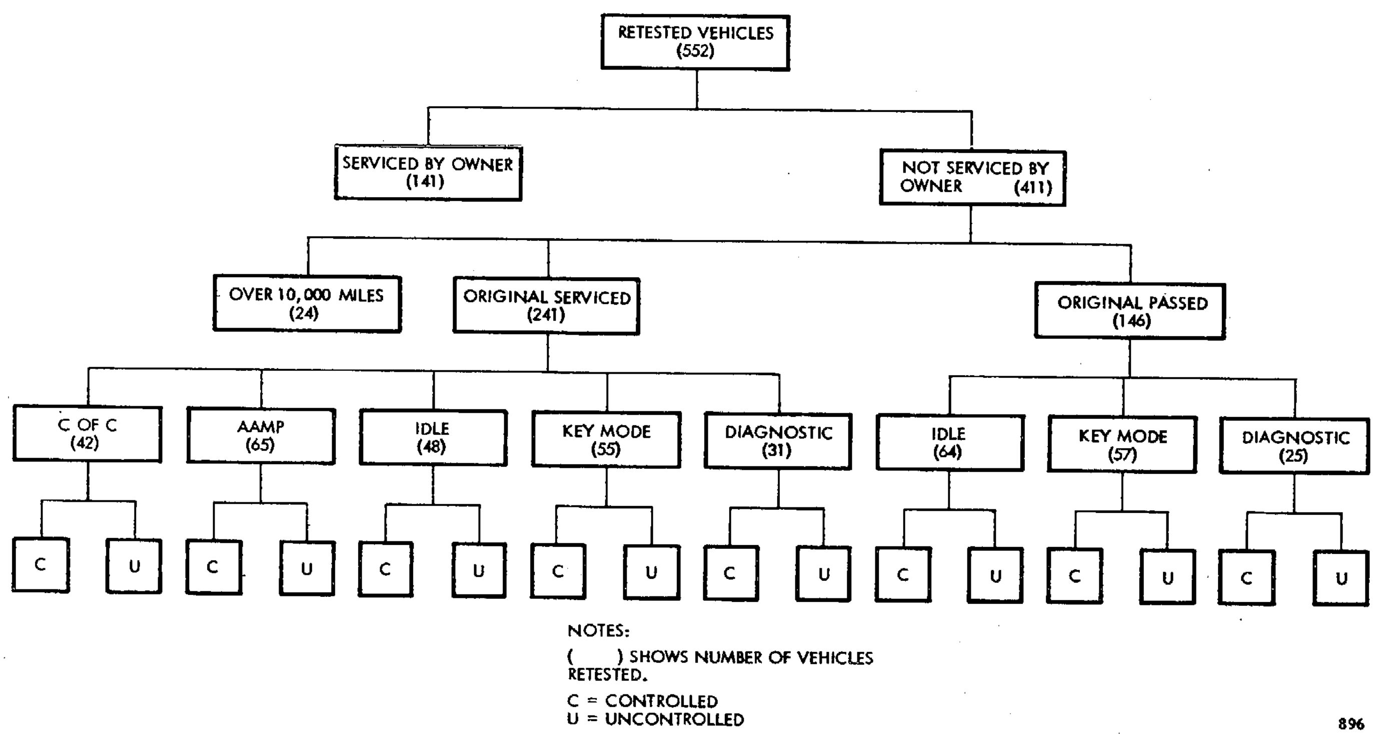

Figure 4-11. DISTRIBUTION OF RETESTED VEHICLES

Since degradation is the emission increase, the reduction in emission is shown as a negative value. It was determined that the overall emission degradation after 10,000 miles was 25 percent for hydrocarbon, 44 percent for carbon monoxide and -17 percent for oxides of nitrogen.

4.4.2 Originally Passed Vehicles

All vehicles which passed the original test and did not receive any service are included in this category. Vehicles in Certificate of Compliance and AAMP test regimes are defined in this program as requiring service during their original testing and therefore are not included.

Since only limited quantities of vehicles were available within each mileage range for each different test regime, insufficient data were obtained for correlation and conclusion. The results shown in Figure 4-12 through 4-14 are quite unpredictable. Emission degradations fluctuate significantly. However, the curves behave in such a way that a positive degradation trend for HC and CO and a negative degradation trend for NO_x can be visualized.

4.4.3 Originally Serviced Vehicles

All vehicles failing the original tests of either Idle, Key-Mode, or Diagnostic were dispatched to selected service facilities to receive the required maintenance. By intent, all vehicles processed by Certificate of Compliance and AAMP were serviced. For the same reason of insufficient data, the results shown in Figures 4-15 through 4-19 are also scattered. However, it can be seen that the emission degradation is generally higher in this group than the originally passed vehicles.

4.4.4 Originally Passed and Originally Serviced Vehicles

Attempts were made to combine the data for the originally passed and the originally serviced vehicles from all the test regimes which included both the controlled and uncontrolled vehicles. This would provide a larger data base to perform a more meaningful analysis.

First, the originally passed and originally serviced vehicles were combined for each of the Certificate of Compliance, Idle, Key-Mode and Diagnostic test regimes. The results are presented in Tables 4-36 through 4-39 and Figures 4-20 through 4-23. The results show that Idle Test has the highest degradation both in HC and CO, whereas the emission level of Certificate of Compliance remains relatively constant regardless of mileage. As for the NO_x level, no significant changes were observed in all test regimes.

Since all test regimes show similar patterns of behavior in emission degradation, the next task was to combine the Certificate of Compliance, Idle, Key-Mode and Diagnostic test regimes (totaling 322 vehicles) into two groups: i.e., controlled and uncontrolled vehicles. The results are shown in Table 4-40 and plotted in Figure 4-24. Thus, the data then reflected a clear trend of increase in degradation for HC and CO and a decrease in degradation for NO_x.

A clearer indication of the data trend was formed after combining emission measurements of controlled and uncontrolled vehicles as shown in Figure 4-25. The least square method was utilized to linearize the degradation results and are shown as dotted lines. The overall degradation based on this linearized method for 10,000 miles was determined to be 25 percent for HC, 44 percent for CO, and -17 percent for NOx.

Note that all curves presented an initial degradation at zero mile. This is because of the repeatability of the test result and the fact that several vehicles which were questionable in mileage were considered in the less than 500 miles range. Therefore, the first couple of data points may be questionable. The final result would be much improved if the questionable data were neglected. For example, the HC emission test Y-intercept would be 8 percent instead of the present 20 percent and the resulting slope would then be 20 percent in 10,000 miles instead of the present 5 percent. However, the final degradation at 10,000 miles does not change significantly.

This analysis shows that the degradation of an automobile is not fully dependent on mileage driven; it also depends on how the car was driven and how well it was operating, etc. Further statistical analysis showed that a maximum of 66 percent correlation exists between emission degradation and mileage driven, thus showing that other factors also contribute to the degradation.

Table 4-28. DEGRADATION FOR ORIGINAL PASSED CARS IN IDLE TEST REGIME

Pollutant / Mileage	Controlled Fleet Degradation Unit						No. of Cars Tested	Uncontrolled Fleet Degradation Unit						No. of Cars Tested
	Grams/Mile			Percent				Grams/Mile			Percent			
	HC	CO	NO_x	HC	CO	NO_x		HC	CO	NO_x	HC	CO	NO_x	
0-500	-0.20	-4.82	-0.30	-9	-20	-5	1	-0.43	-2.07	-0.21	-6	-4	-3	2
500-1,000	-	-	-	-	-	-	0	-0.12	22.81	1.04	-2	48	18	2
1,000-1,500	0.21	-2.19	2.14	8	-9	35	3	0.26	14.53	-0.11	7	26	-3	6
1,500-2,000	1.30	-0.78	0.99	58	-3	27	5	-0.05	-7.13	0.48	-1	-14	9	3
2,000-2,500	-0.16	-10.98	1.82	-8	-57	29	1	-0.01	3.72	-0.28	0	8	-7	7
2,500-3,000	-0.05	0.73	-0.08	-2	8	-1	1	0.58	16.44	0.32	13	36	9	3
3,000-4,000	0.29	2.95	1.36	16	12	26	5	1.25	27.14	0.57	30	60	14	4
4,000-5,000	-0.33	3.53	-1.07	-12	32	-18	4	-0.09	5.34	-0.27	-3	12	-6	3
5,000-6,000	0.42	4.63	1.44	25	16	32	4	-0.73	13.56	-0.38	-14	34	-12	1
6,000-7,000	1.45	83.02	-2.94	52	276	-65	2	-1.44	-19.70	0.30	-22	-21	10	3
7,000-8,000	0.62	11.33	0.74	64	47	44	2	-	-	-	-	-	-	0
8,000-9,000	0.75	41.38	-1.28	45	119	-30	2	-	-	-	-	-	-	0
9,000-10,000	-	-	-	-	-	-	0	-	-	-	-	-	-	0

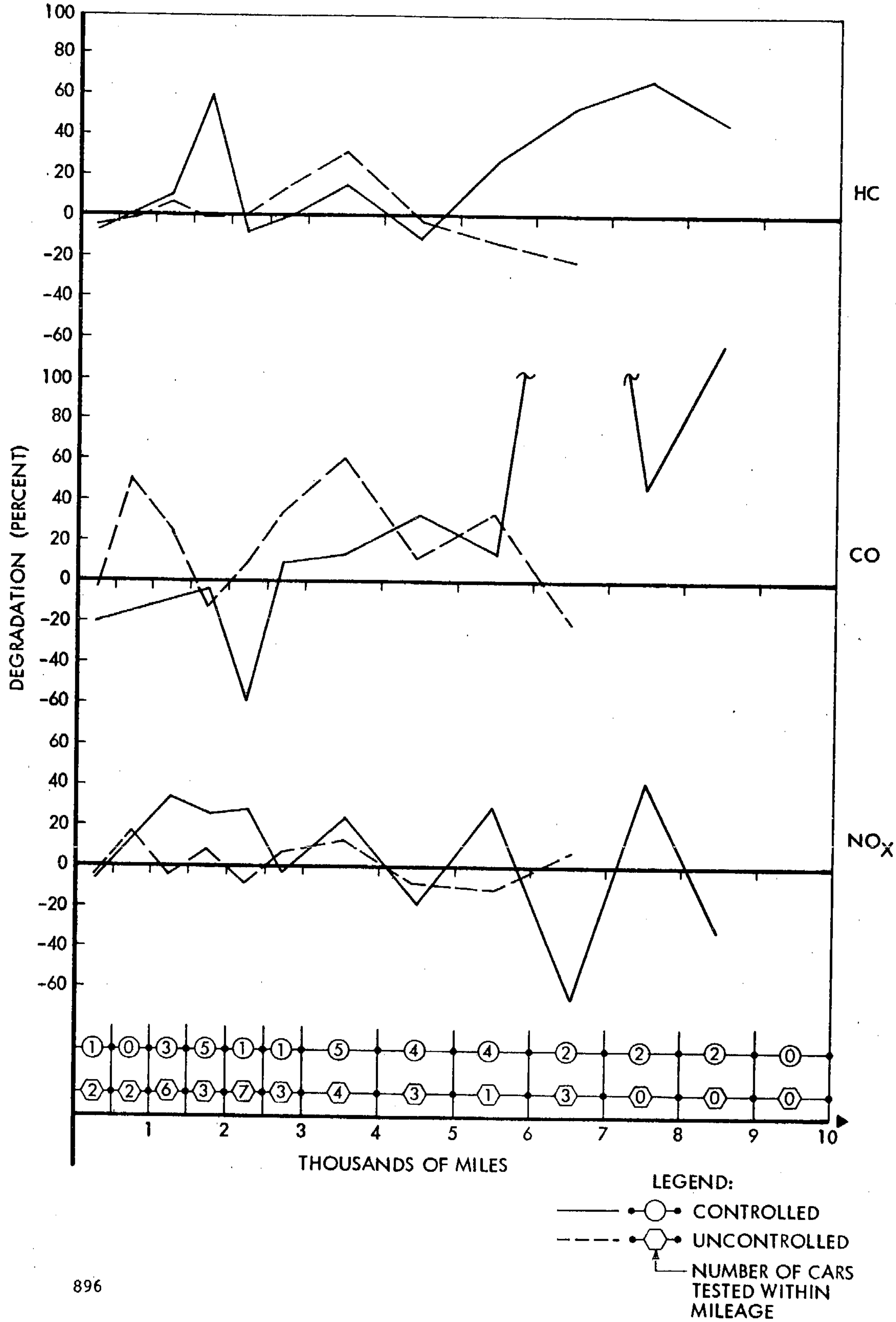

Figure 4-12. DEGRADATION FOR ORIGINAL PASSED CARS IN IDLE TEST REGIME

Table 4-29. DEGRADATION FOR ORIGINAL PASSED CARS IN KEY-MODE TEST REGIME

Pollutant / Mileage	Controlled Fleet Degradation Unit						No. of Cars Tested	Uncontrolled Fleet Degradation Unit						No. of Cars Tested
	Grams/Mile			Percent				Grams/Mile			Percent			
	HC	CO	NO_x	HC	CO	NO_x		HC	CO	NO_x	HC	CO	NO_x	
0-500	-1.49	2.24	0.72	-67	25	19	1	-0.60	13.97	-0.73	-7	25	-18	1
500-1,000	-	-	-	-	-	-	0	0.04	-5.42	1.18	1	-11	72	1
1,000-1,500	0.06	-0.52	0.86	3	-2	28	2	-0.07	-5.57	-0.38	-1	-21	-7	1
1,500-2,000	-0.87	0.15	0.11	-44	2	4	1	0.63	8.48	0.08	11	12	2	7
2,000-2,500	0.53	-2.90	-0.55	24	-10	-14	4	-0.26	6.74	0.68	-5	15	18	2
2,500-3,000	-0.07	1.50	0.01	-4	5	0	1	-1.98	-32.19	0.67	-23	-25	48	1
3,000-4,000	-0.41	8.27	-0.17	-17	42	-3	10	0.41	1.56	-0.77	10	4	-14	4
4,000-5,000	-0.01	9.06	-0.66	0	78	-9	3	7.15	6.96	-0.03	136	15	-1	4
5,000-6,000	0.34	4.57	0.16	25	28	4	2	2.34	-2.67	-0.69	51	-4	-33	1
6,000-7,000	-0.36	8.83	-1.21	-24	44	-26	1	2.42	11.85	1.05	57	31	39	1
7,000-8,000	0.11	0.69	-0.94	5	2	-14	2	2.35	65.83	-0.91	44	87	-39	2
8,000-9,000	1.69	1.44	0.03	57	8	1	3	0.39	1.60	0.18	8	5	3	2
9,000-10,000	-	-	-	-	-	-	0	-	-	-	-	-	-	0

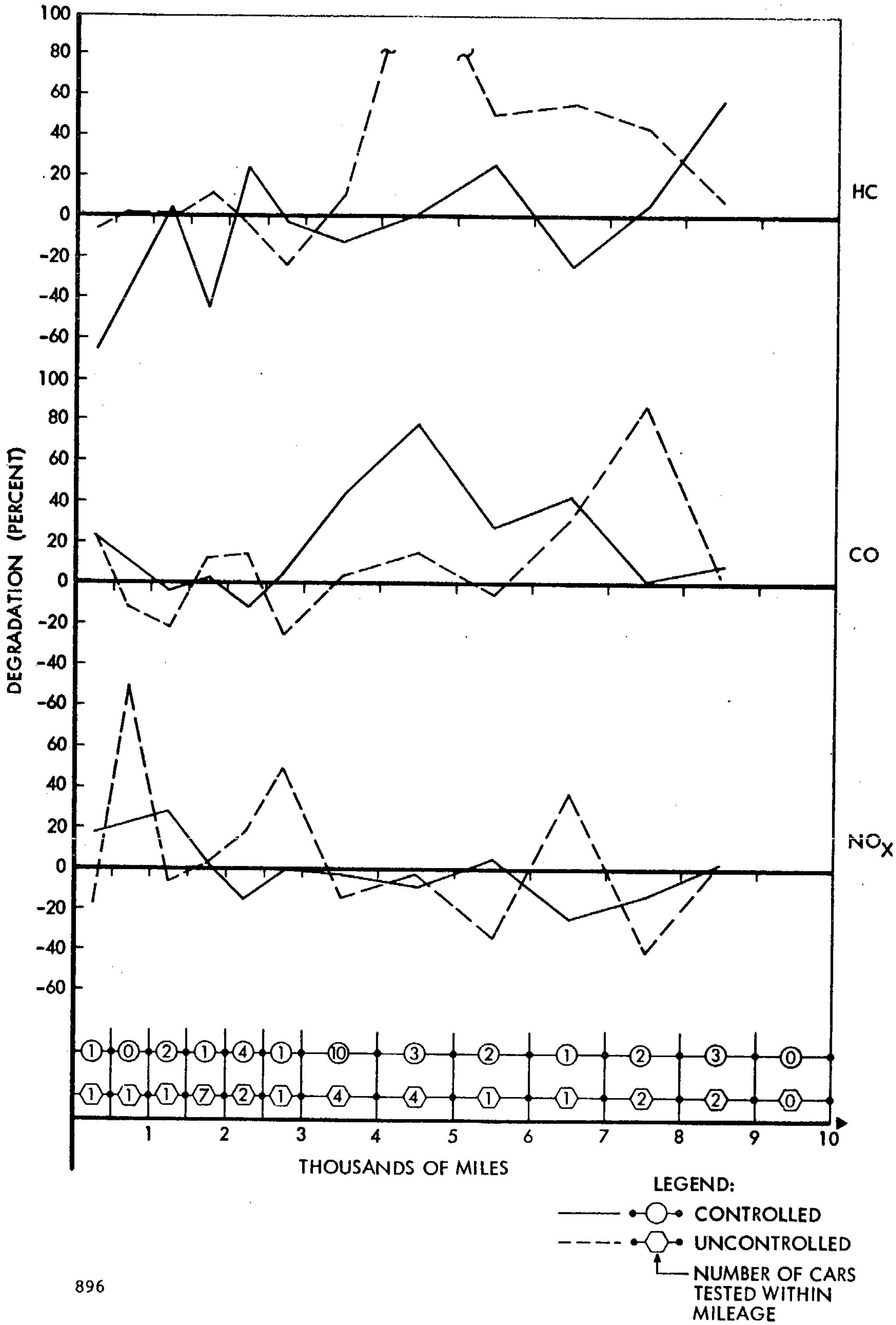

Figure 4-13. DEGRADATION FOR ORIGINAL PASSED CARS IN KEY-MODE TEST REGIME

Table 4-30. DEGRADATION FOR ORIGINAL PASSED CARS IN DIAGNOSTIC TEST REGIME

Pollutant / Mileage	Controlled Fleet Degradation Unit						No. of Cars Tested	Uncontrolled Fleet Degradation Unit						No. of Cars Tested
	Grams/Mile			Percent				Grams/Mile			Percent			
	HC	CO	NO_x	HC	CO	NO_x		HC	CO	NO_x	HC	CO	NO_x	
0-500	-	-	-	-	-	-	0	-	-	-	-	-	-	0
500-1,000	-	-	-	-	-	-	0	-	-	-	-	-	-	0
1,000-1,500	-	-	-	-	-	-	0	-0.51	25.64	0.65	-9	46	13	2
1,500-2,000	-	-	-	-	-	-	0	-	-	-	-	-	-	0
2,000-2,500	-	-	-	-	-	-	0	0.56	11.74	-0.24	18	43	-4	2
2,500-3,000	1.05	0.96	-0.59	58	7	-16	2	1.02	-2.43	0.13	25	-3	11	1
3,000-4,000	0.03	0.28	0.40	1	1	9	5	-	-	-	-	-	-	0
4,000-5,000	0.25	-0.38	0.12	7	-1	2	1	-	-	-	-	-	-	0
5,000-6,000	-0.15	11.08	-0.26	-6	48	-6	3	-	-	-	-	-	-	0
6,000-7,000	0.04	2.39	0.60	2	9	11	4	2.56	21.77	0.61	68	46	14	2
7,000-8,000	1.03	4.47	-0.68	46	26	-13	1	-	-	-	-	-	-	0
8,000-9,000	0.47	19.04	0.72	16	79	9	1	-	-	-	-	-	-	0
9,000-10,000	1.79	30.06	-2.16	79	128	-32	1	-	-	-	-	-	-	0

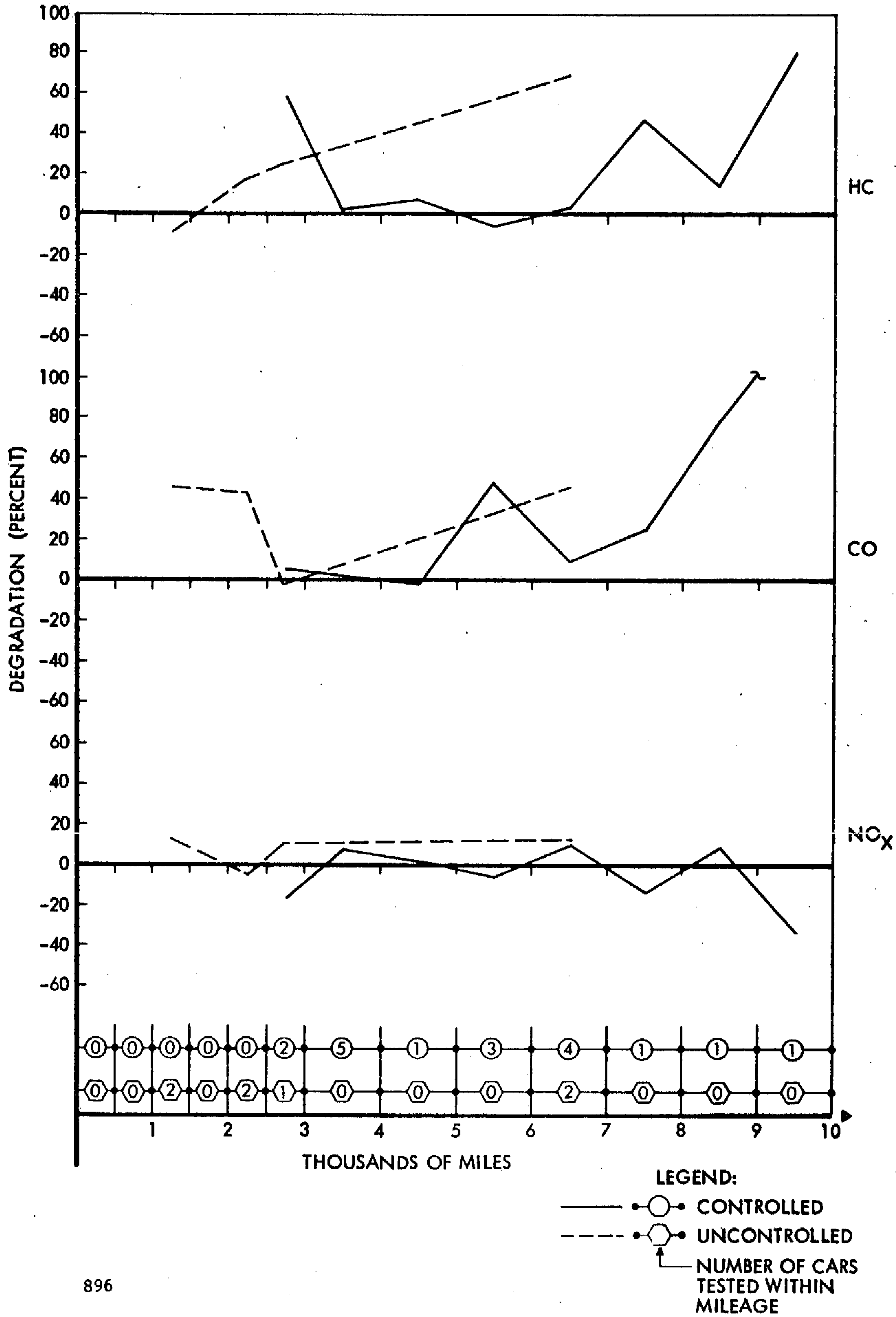

Figure 4-14. DEGRADATION FOR ORIGINAL PASSED CARS IN DIAGNOSTIC TEST REGIME

Table 4-31. DEGRADATION OF ORIGINAL SERVICED CARS IN AAMP TEST REGIME

Pollutant / Mileage	Controlled Fleet Degradation Unit						No. of Cars Tested	Uncontrolled Fleet Degradation Unit						No. of Cars Tested
	Grams/Mile			Percent				Grams/Mile			Percent			
	HC	CO	NO_x	HC	CO	NO_x		HC	CO	NO_x	HC	CO	NO_x	
0-500	-0.75	-15.99	1.52	-34	-43	37	3	2.03	-29.36	1.82	31	-39	85	4
500-1,000	-0.43	-11.32	0.34	-11	-14	13	1	5.49	-4.04	0.14	92	-5	7	9
1,000-1,500	-0.27	-6.43	0.24	-11	-42	4	3	-0.29	-9.65	0.41	-4	-15	11	9
1,500-2,000	0.05	-3.8	0.52	3	-9	20	2	0.19	-4.3	1.17	3	-6	36	7
2,000-2,500	0.13	-5.98	2.48	4	-18	101	2	12.03	-18.39	1.75	224	-24	61	5
2,500-3,000	-1.09	-11.69	0.16	-31	-28	3	5	3.20	13.38	2.15	54	23	73	1
3,000-4,000	-0.31	-1.67	-0.67	-10	-7	-10	4	0.08	-15.35	0.30	2	-25	12	2
4,000-5,000	-0.29	-2.78	2.19	-22	-14	83	1	2.60	42.49	-0.45	63	74	-13	1
5,000-6,000	-	-	-	-	-	-	0	-	-	-	-	-	-	0
6,000-7,000	-0.69	2.81	0.27	-23	14	4	2	-1.76	-24.59	0.43	-21	-41	10	1
7,000-8,000	-0.74	-4.46	-1.31	-58	-59	-36	1	-	-	-	-	-	-	0
8,000-9,000	-	-	-	-	-	-	0	0.09	-39.48	1.29	2	50	48	1
9,000-10,000	-2.25	-5.49	1.75	-46	-23	34	1	-	-	-	-	-	-	0

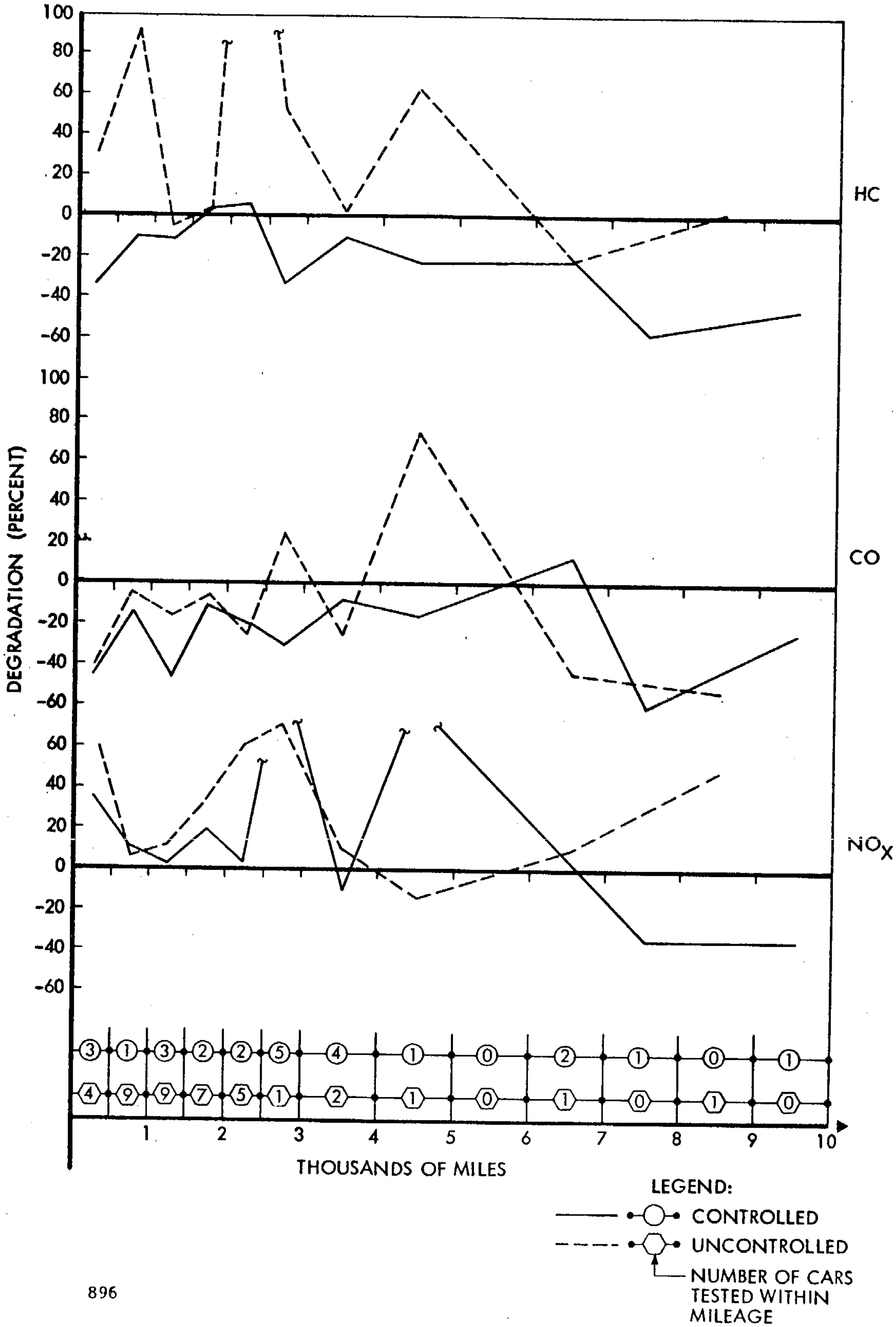

Figure 4-15. DEGRADATION FOR ORIGINAL SERVICED CARS IN AAMP TEST REGIME

Table 4-32. DEGRADATION FOR ORIGINAL SERVICED CARS IN CERTIFICATE OF COMPLIANCE TEST REGIME

Pollutant / Mileage	Controlled Fleet Degradation Unit						No. of Cars Tested	Uncontrolled Fleet Degradation Unit						No. of Cars Tested
	Grams/Mile			Percent				Grams/Mile			Percent			
	HC	CO	NO_x	HC	CO	NO_x		HC	CO	NO_x	HC	CO	NO_x	
0-500	-	-	-	-	-	-	0	-0.83	-8.90	-0.33	-12	-14	-7	3
500-1,000	-	-	-	-	-	-	0	0.46	19.04	0.24	10	37	4	1
1,000-1,500	-	-	-	-	-	-	0	1.71	18.02	-0.33	40	44	-8	3
1,500-2,000	-	-	-	-	-	-	0	-0.03	18.62	-0.32	0	23	-12	3
2,000-2,500	-	-	-	-	-	-	0	1.79	3.44	-0.66	63	8	-16	3
2,500-3,000	0.03	9.12	-0.03	2	39	-1	1	2.31	14.25	-0.24	67	58	-6	2
3,000-4,000	0.74	7.45	-0.42	54	52	-10	4	1.70	1.17	1.80	43	2	53	2
4,000-5,000	0.27	-18.82	1.06	8	-27	17	1	1.33	32.94	-2.17	27	71	-46	4
5,000-6,000	1.00	-5.13	0.29	31	-9	4	1	2.10	4.37	-0.02	28	5	-1	5
6,000-7,000	0.29	13.21	1.04	13	36	31	5	-	-	-	-	-	-	0
7,000-8,000	-	-	-	-	-	-	0	0.81	9.54	-7.45	22	21	-61	1
8,000-9,000	-0.47	3.12	-1.25	-13	6	-24	3	-	-	-	-	-	-	0
9,000-10,000	-	-	-	-	-	-	0	-	-	-	-	-	-	0

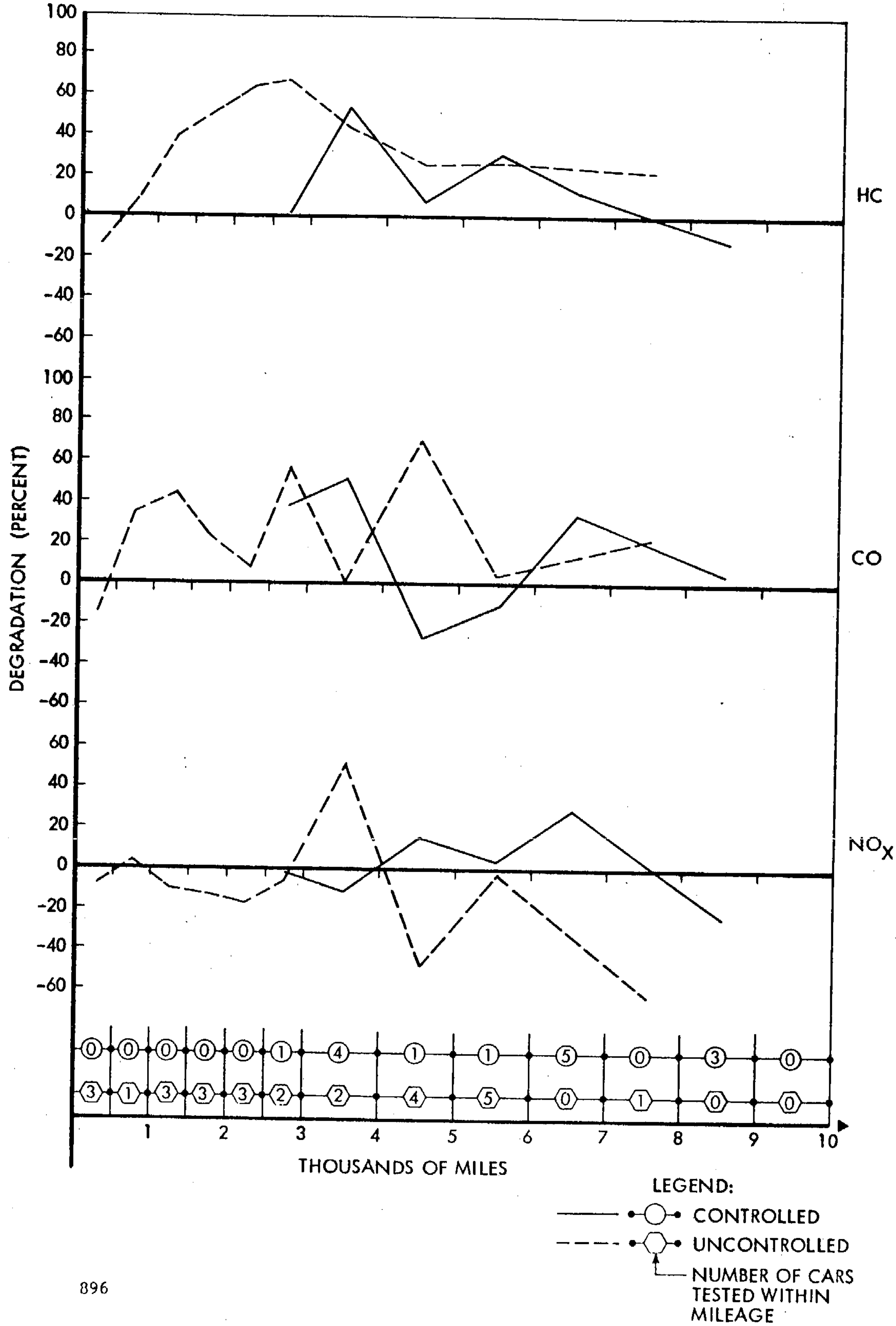

Figure 4-16. DEGRADATION FOR ORIGINAL SERVICED CARS IN CERTIFICATE OF COMPLIANCE TEST REGIME

Table 4-33. DEGRADATION FOR ORIGINAL SERVICED CARS IN IDLE TEST REGIME

Pollutant / Mileage	Controlled Fleet Degradation Unit						No. of Cars Tested	Uncontrolled Fleet Degradation Unit						No. of Cars Tested
	Grams/Mile			Percent				Grams/Mile			Percent			
	HC	CO	NO_x	HC	CO	NO_x		HC	CO	NO_x	HC	CO	NO_x	
0-500	-	-	-	-	-	-	0	4.11	-7.47	0.37	76	-10	16	6
500-1,000	-	-	-	-	-	-	0	-0.45	12.81	-0.26	-8	34	-7	2
1,000-1,500	-	-	-	-	-	-	0	-1.95	-12.61	-0.01	-36	-21	-1	3
1,500-2,000	-	-	-	-	-	-	0	-0.17	22.65	1.05	-2	30	56	3
2,000-2,500	-	-	-	-	-	-	0	0.63	2.35	-0.60	14	7	-12	7
2,500-3,000	-1.25	-4.88	1.22	-49	-18	145	1	1.60	21.80	-0.35	29	47	-8	5
3,000-4,000	-0.08	8.27	-1.48	-3	31	-26	5	0.20	4.42	0.51	4	8	19	4
4,000-5,000	2.05	32.09	-1.84	54	92	-50	1	-0.40	-13.21	0.38	-6	-18	12	3
5,000-6,000	1.89	5.55	1.53	61	11	37	3	4.65	-4.72	0.23	70	-8	5	1
6,000-7,000	-	-	-	-	-	-	0	0.53	-0.87	0.34	15	-1	8	1
7,000-8,000	1.99	36.63	1.37	116	105.6	17	1	-	-	-	-	-	-	0
8,000-9,000	0.39	6.19	-0.92	20	61	-11	1	-	-	-	-	-	-	0
9,000-10,000	1.34	28.30	-3.42	48	84	-47	1	-	-	-	-	-	-	0

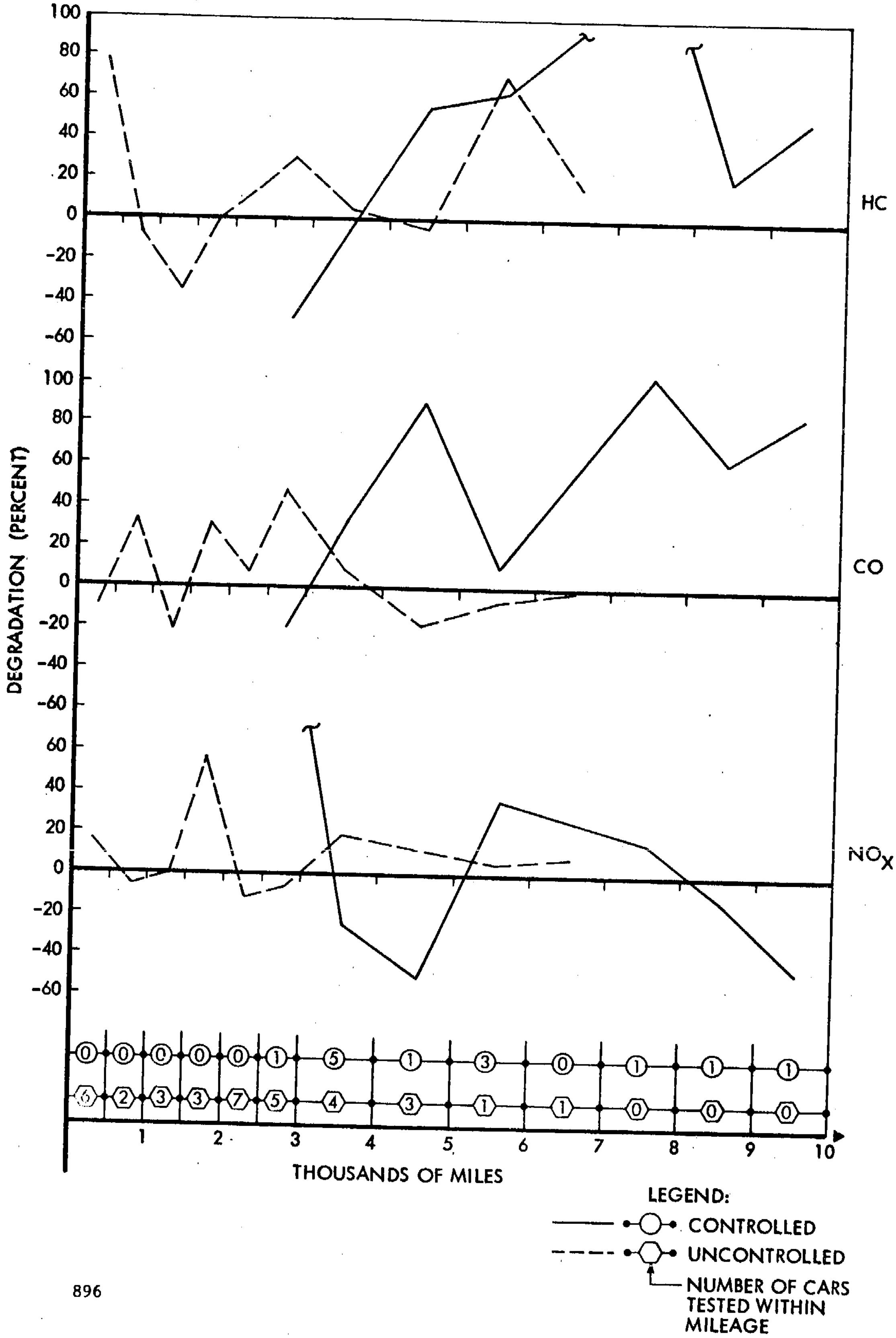

Figure 4-17. DEGRADATION FOR ORIGINAL SERVICED CARS IN IDLE TEST REGIME

Table 4-34. DEGRADATION FOR ORIGINAL SERVICED CARS IN KEY-MODE TEST REGIME

Pollutant / Mileage	Controlled Fleet Degradation Unit						No. of Cars Tested	Uncontrolled Fleet Degradation Unit						No. of Cars Tested
	Grams/Mile			Percent				Grams/Mile			Percent			
	HC	CO	NO_x	HC	CO	NO_x		HC	CO	NO_x	HC	CO	NO_x	
0-500	-	-	-	-	-	-	0	6.79	9.98	1.03	92	17	24	3
500-1,000	-	-	-	-	-	-	0	-1.44	-20.49	1.52	-25	-38	47	2
1,000-1,500	2.00	44.18	2.07	107	640	48	1	-1.55	11.31	-0.37	-20	20	-9	8
1,500-2,000	-	-	-	-	-	-	0	-0.08	19.74	-1.51	-2	45	-41	3
2,000-2,500	-	-	-	-	-	-	0	-0.10	8.24	-0.15	-2	38	-4	2
2,500-3,000	-0.61	12.49	-0.55	-20	65	-8	2	-0.45	7.68	0.28	-10	18	10	3
3,000-4,000	-0.46	0.81	0.73	-16	4	16	2	2.36	11.76	0.47	39	23	14	9
4,000-5,000	0.35	24.38	-1.59	12	104	-31	4	4.75	16.48	-1.36	109	41	-32	6
5,000-6,000	-	-	-	-	-	-	0	1.70	11.06	0.75	42	21	13	3
6,000-7,000	0.17	2.67	1.53	13	12	31	1	-0.08	5.86	-0.19	-1	11	-5	2
7,000-8,000	-	-	-	-	-	-	0	0.44	14.32	-0.22	8	28	-5	2
8,000-9,000	0.32	0.68	-0.01	17	5	0	2	-	-	-	-	-	-	0
9,000-10,000	-	-	-	-	-	-	0	-	-	-	-	-	-	0

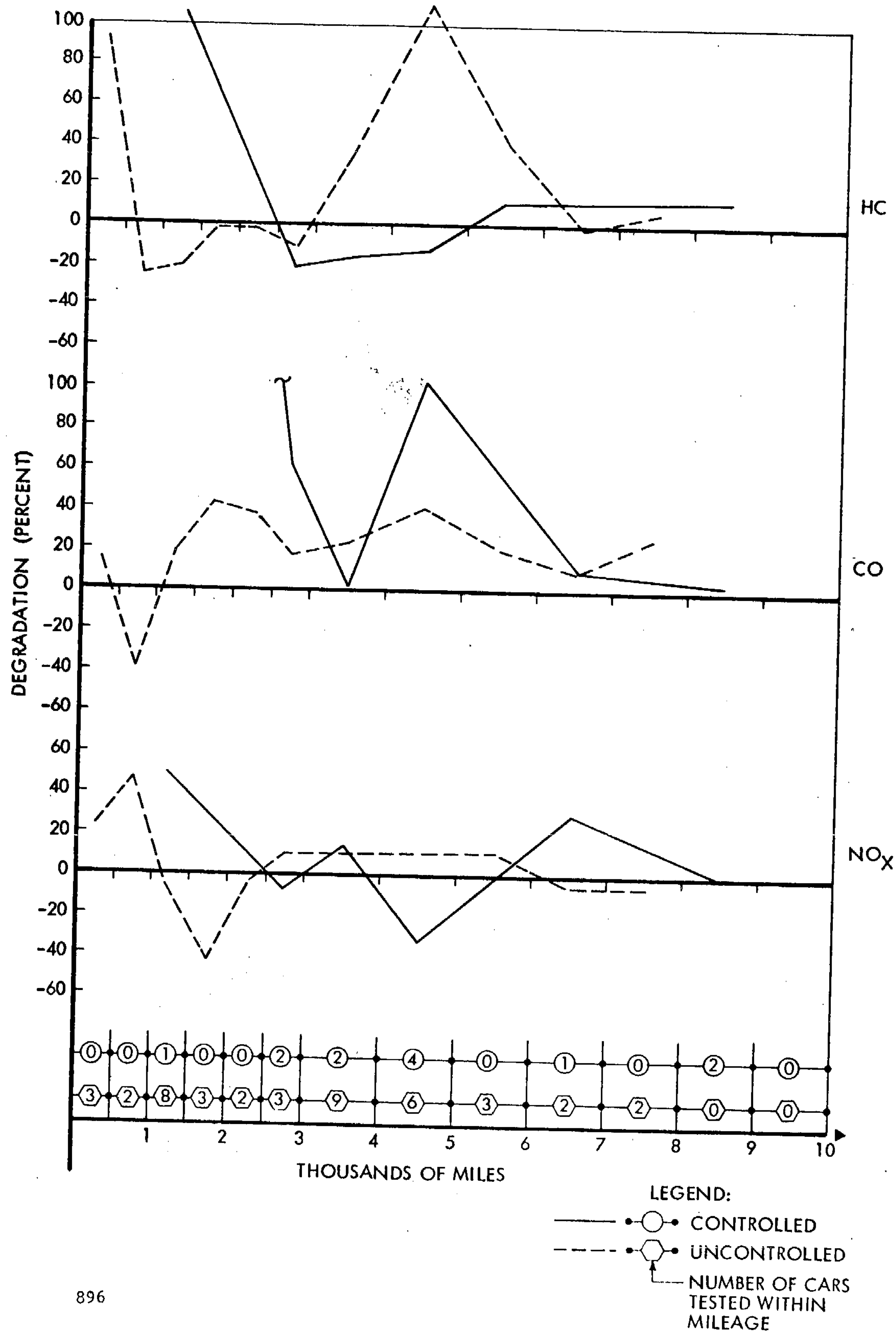

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Figure 4-18. DEGRADATION FOR ORIGINAL SERVICED CARS IN KEY-MODE TEST REGIME

Table 4-35. DEGRADATION FOR ORIGINAL SERVICED CARS IN DIAGNOSTIC TEST REGIME

Pollutant / Mileage	Controlled Fleet Degradation Unit						No. of Cars Tested	Uncontrolled Fleet Degradation Unit						No. of Cars Tested
	Grams/Mile			Percent				Grams/Mile			Percent			
	HC	CO	NO_x	HC	CO	NO_x		HC	CO	NO_x	HC	CO	NO_x	
0-500	-	-	-	-	-	-	0	2.13	69.08	-1.05	54	188	-32	1
500-1,000	-	-	-	-	-	-	0	10.33	-2.32	-0.17	240	-3	-7	2
1,000-1,500	-	-	-	-	-	-	0	3.65	-2.70	0.18	76	-4	5	1
1,500-2,000	-0.04	-12.87	0.49	-1	-30	13	1	0.63	17.54	0.16	12	20	11	1
2,000-2,500	1.61	5.80	1.76	63	21	54	2	0.71	6.03	0.04	17	14	1	3
2,500-3,000	0.12	2.66	0.18	5	9	3	1	0.27	-17.23	0.32	5	-22	8	1
3,000-4,000	2.28	1.31	0.70	84	4	19	5	0.83	22.13	-0.58	17	29	-18	2
4,000-5,000	0.72	-1.05	2.36	144	-12	109	1	-	-	-	-	-	-	0
5,000-6,000	-	-	-	-	-	-	0	1.31	14.98	-0.77	21	22	-13	2
6,000-7,000	-0.30	-4.11	-0.57	-15	-23	-7	1	3.07	19.63	0.24	78	18	49	1
7,000-8,000	-	-	-	-	-	-	0	2.01	26.30	0.22	66	50	10	1
8,000-9,000	0.63	20.05	0.53	19	76	9	2	-	-	-	-	-	-	0
9,000-10,000	-0.75	16.16	1.84	-20	66	-27	1	0.72	-3.64	-0.04	15	-7	-1	2

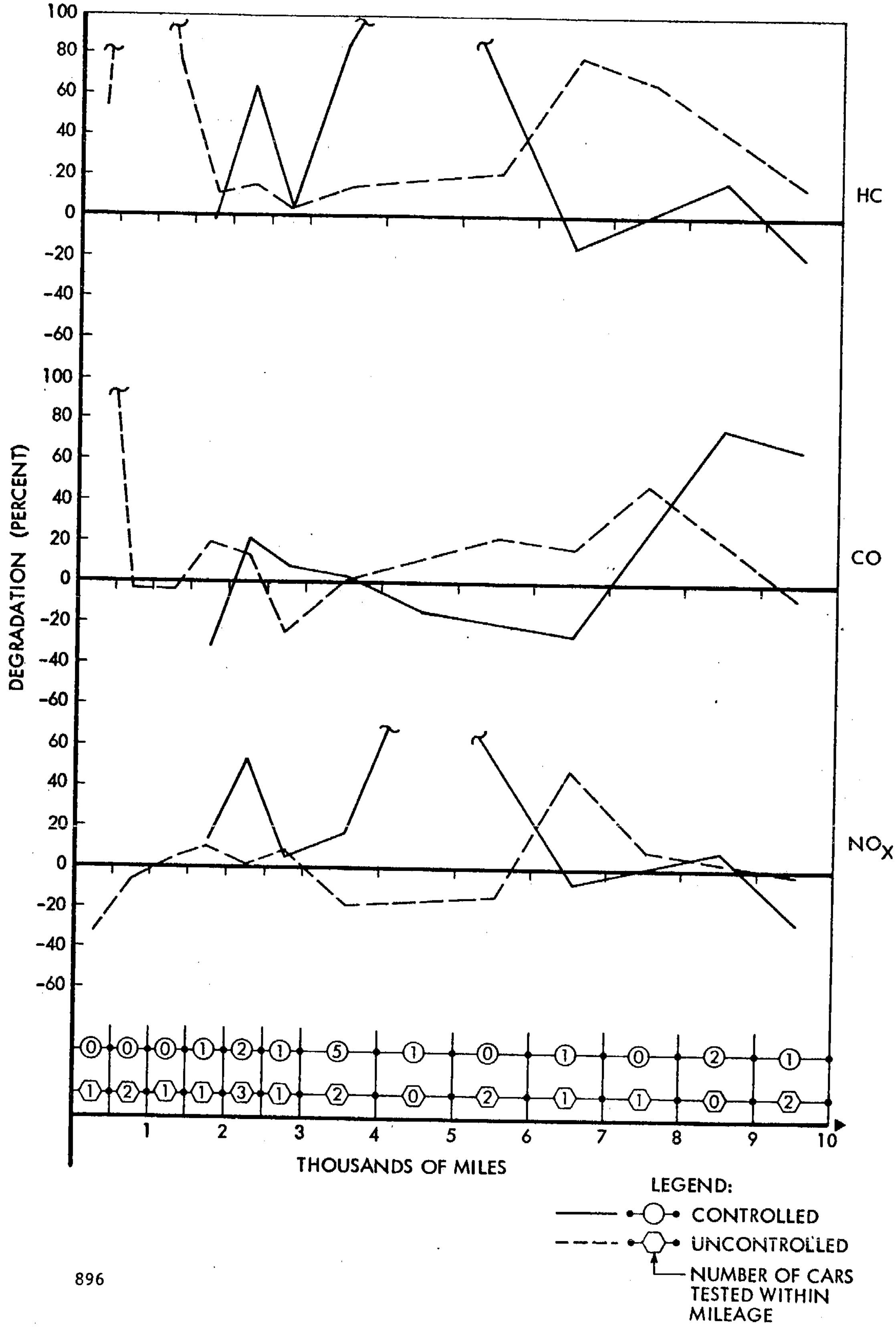

Figure 4-19. DEGRADATION FOR ORIGINAL SERVICED CARS IN DIAGNOSTIC TEST REGIME

Table 4-36. DEGRADATION FOR ORIGINAL PASSED AND ORIGINAL SERVICED CARS IN CERTIFICATE OF COMPLIANCE TEST REGIME

Pollutant / Mileage	Controlled Fleet Degradation Unit						No. of Cars Tested	Uncontrolled Fleet Degradation Unit						No. of Cars Tested
	Grams/Mile			Percent				Grams/Mile			Percent			
	HC	CO	NO_x	HC	CO	NO_x		HC	CO	NO_x	HC	CO	NO_x	
0-500	-	-	-	-	-	-	0	-0.83	-8.90	-0.33	-12	-14	-7	3
500-1,000	-	-	-	-	-	-	0	0.46	19.04	0.24	10	37	4	1
1,000-1,500	-	-	-	-	-	-	0	1.71	18.02	-0.33	40	44	-8	3
1,500-2,000	-	-	-	-	-	-	0	-0.03	18.62	0.32	0	23	-12	3
2,000-2,500	-	-	-	-	-	-	0	1.79	3.44	-0.66	63	8	-16	3
2,500-3,000	0.03	9.12	-0.03	2	39	-1	1	2.31	14.25	-0.24	67	58	-6	2
3,000-4,000	0.74	7.45	-0.42	54	52	-10	4	1.70	1.17	1.80	43	2	53	2
4,000-5,000	0.27	-18.82	1.06	8	-27	17	1	1.33	32.94	-2.17	27	71	-46	4
5,000-6,000	1.00	-5.13	0.29	31	-9	4	1	2.10	4.37	-0.02	28	5	-1	5
6,000-7,000	0.29	13.21	1.04	13	36	31	5	-	-	-	-	-	-	0
7,000-8,000	-	-	-	-	-	-	0	0.81	9.54	-7.45	22	21	-61	1
8,000-9,000	-0.47	3.12	-1.25	-13	6	-24	3	-	-	-	-	-	-	0
9,000-10,000	-	-	-	-	-	-	0	-	-	-	-	-	-	0

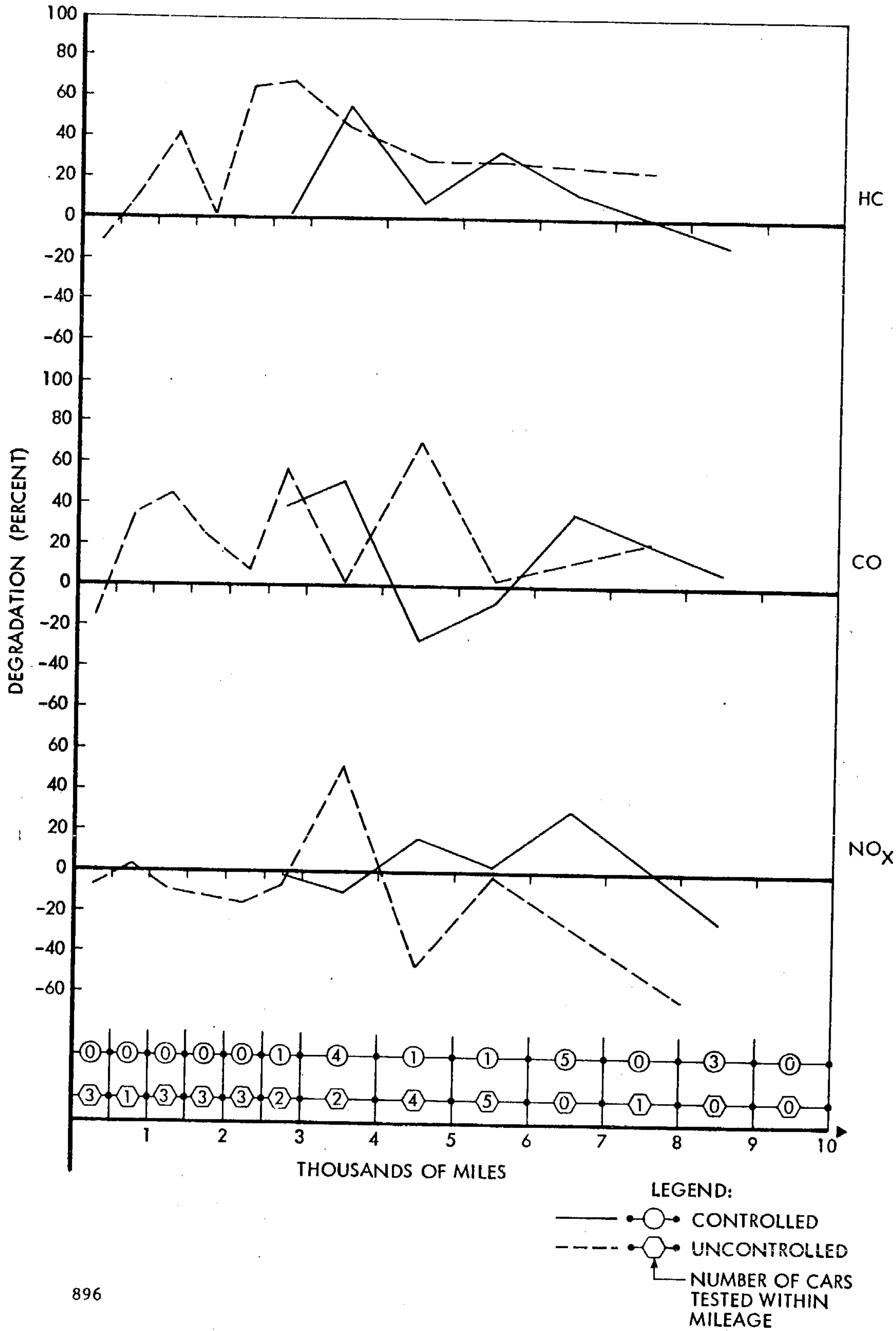

Figure 4-20. DEGRADATION FOR ORIGINAL PASSED AND ORIGINAL SERVICED CARS IN CERTIFICATE OF COMPLIANCE TEST REGIME

Table 4-37. DEGRADATION FOR ORIGINAL PASSED AND ORIGINAL SERVICED CARS IN IDLE TEST REGIME

Pollutant / Mileage	Controlled Fleet Degradation Unit						No. of Cars Tested	Uncontrolled Fleet Degradation Unit						No. of Cars Tested
	Grams/Mile			Percent				Grams/Mile			Percent			
	HC	CO	NO_x	HC	CO	NO_x		HC	CO	NO_x	HC	CO	NO_x	
0-500	-0.2	-4.82	-0.30	-9	-20	-5	1	2.98	-6.12	0.23	51	-9	7	8
500-1,000	-	-	-	-	-	-	0	-0.28	17.81	0.39	-5	42	8	4
1,000-1,500	0.21	-2.19	2.14	8	-9	35	3	-0.48	5.48	-0.08	-11	9	-3	9
1,500-2,000	1.30	-0.78	0.99	58	-3	27	5	-0.11	7.76	0.77	-2	12	21	6
2,000-2,500	-0.16	-10.98	1.82	-8	-57	29	1	0.31	3.03	-0.44	7	8	-10	14
2,500-3,000	-0.65	-2.08	0.57	-25	-12	15	2	1.22	19.80	-0.10	23	43	-3	8
3,000-4,000	0.10	5.61	-0.06	5	22	-1	10	0.73	15.78	0.54	15	31	16	8
4,000-5,000	0.15	9.24	-1.22	5	58	-23	5	-0.24	-3.93	0.06	-5	-7	2	6
5,000-6,000	1.05	5.02	1.48	46	13	34	7	1.96	4.42	-0.07	33	9	-2	2
6,000-7,000	1.45	83.02	-2.94	52	276	-65	2	-0.94	-14.99	0.31	-16	-17	10	4
7,000-8,000	1.07	19.76	0.95	88	116	25	3	-	-	-	-	-	-	0
8,000-9,000	0.63	29.65	-1.16	36	111	-20	3	-	-	-	-	-	-	0
9,000-10,000	1.34	28.30	-3.42	48	84	-47	1	-	-	-	-	-	-	0

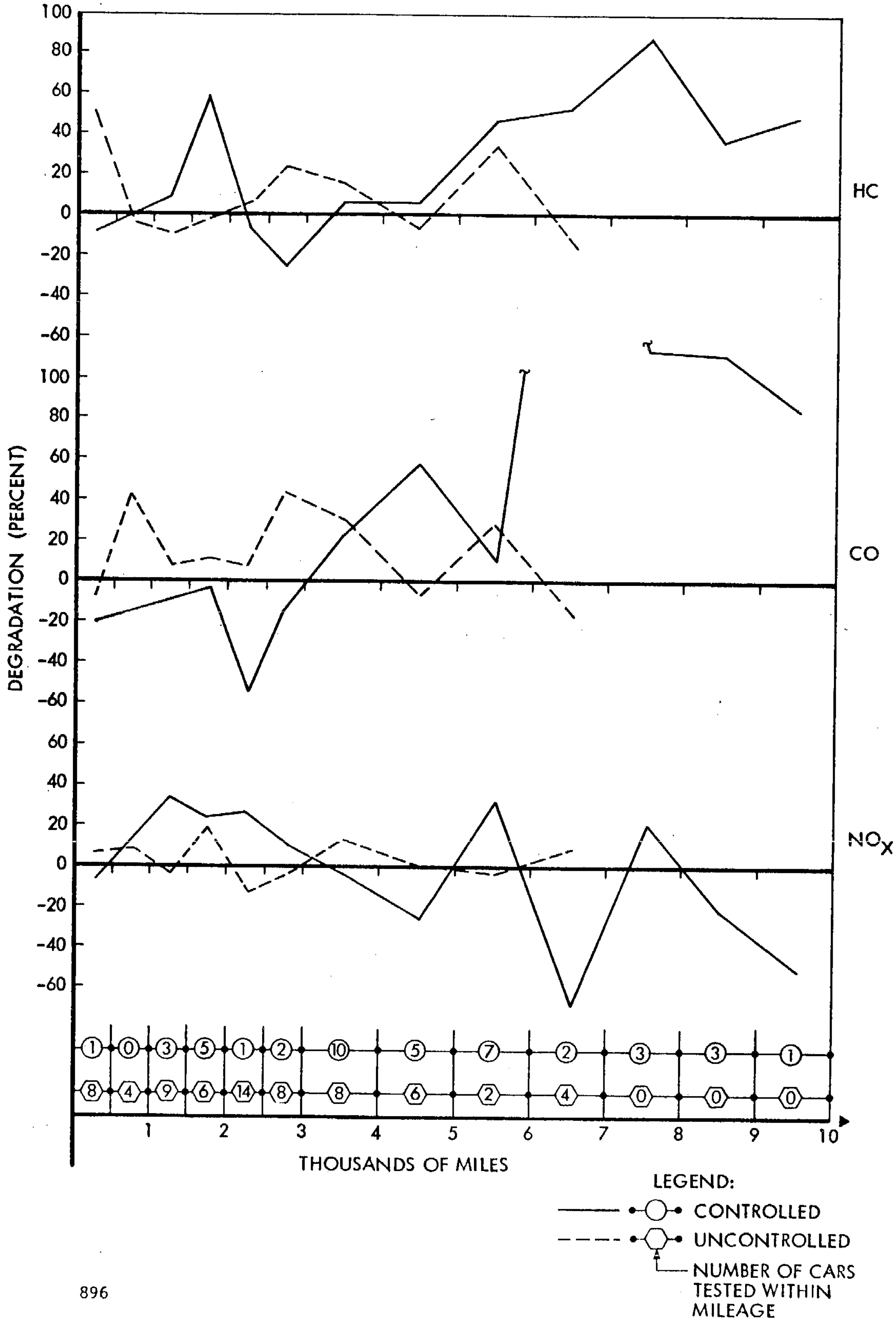

Figure 4-21. DEGRADATION FOR ORIGINAL PASSED AND ORIGINAL SERVICED CARS IN IDLE TEST REGIME

Table 4-38. DEGRADATION FOR ORIGINAL PASSED AND ORIGINAL SERVICED CARS IN KEY-MODE TEST REGIME

Pollutant / Mileage	Controlled Fleet Degradation Unit						No. of Cars Tested	Uncontrolled Fleet Degradation Unit						No. of Cars Tested
	Grams/Mile			Percent				Grams/Mile			Percent			
	HC	CO	NO_x	HC	CO	NO_x		HC	CO	NO_x	HC	CO	NO_x	
0-500	-1.49	2.24	0.72	-67	25	19	1	4.94	10.97	0.59	65	19	14	4
500-1,000	-	-	-	-	-	-	0	-0.95	-15.46	1.40	-19	-30	52	3
1,000-1,500	0.71	14.38	1.27	36	64	37	3	-1.38	9.43	-0.37	-18	17	-9	9
1,500-2,000	-0.87	0.15	0.11	-44	2	4	1	0.42	11.86	-0.40	8	18	-10	10
2,000-2,500	0.53	-2.90	-0.55	24	-10	-14	4	-0.18	7.49	0.26	-3	23	7	4
2,500-3,000	-0.43	8.83	-0.37	-17	39	-7	3	-0.83	-2.29	0.38	-15	-4	15	4
3,000-4,000	-0.42	7.02	-0.02	-17	35	0	12	1.76	8.62	0.08	32	18	2	13
4,000-5,000	0.19	17.81	-1.19	7	97	-20	7	5.71	12.67	-0.83	121	30	-19	10
5,000-6,000	0.34	4.57	0.16	25	28	4	2	1.86	7.63	0.39	44	13	8	4
6,000-7,000	-0.10	5.75	0.16	-7	28	3	2	0.75	7.86	0.23	11	16	7	3
7,000-8,000	0.11	0.69	-0.94	5	2	-14	2	1.39	40.07	-0.57	26	63	-16	4
8,000-9,000	1.15	1.14	0.01	45	7	0	5	0.39	1.60	0.18	8	5	3	2
9,000-10,000	-	-	-	-	-	-	0	-	-	-	-	-	-	0

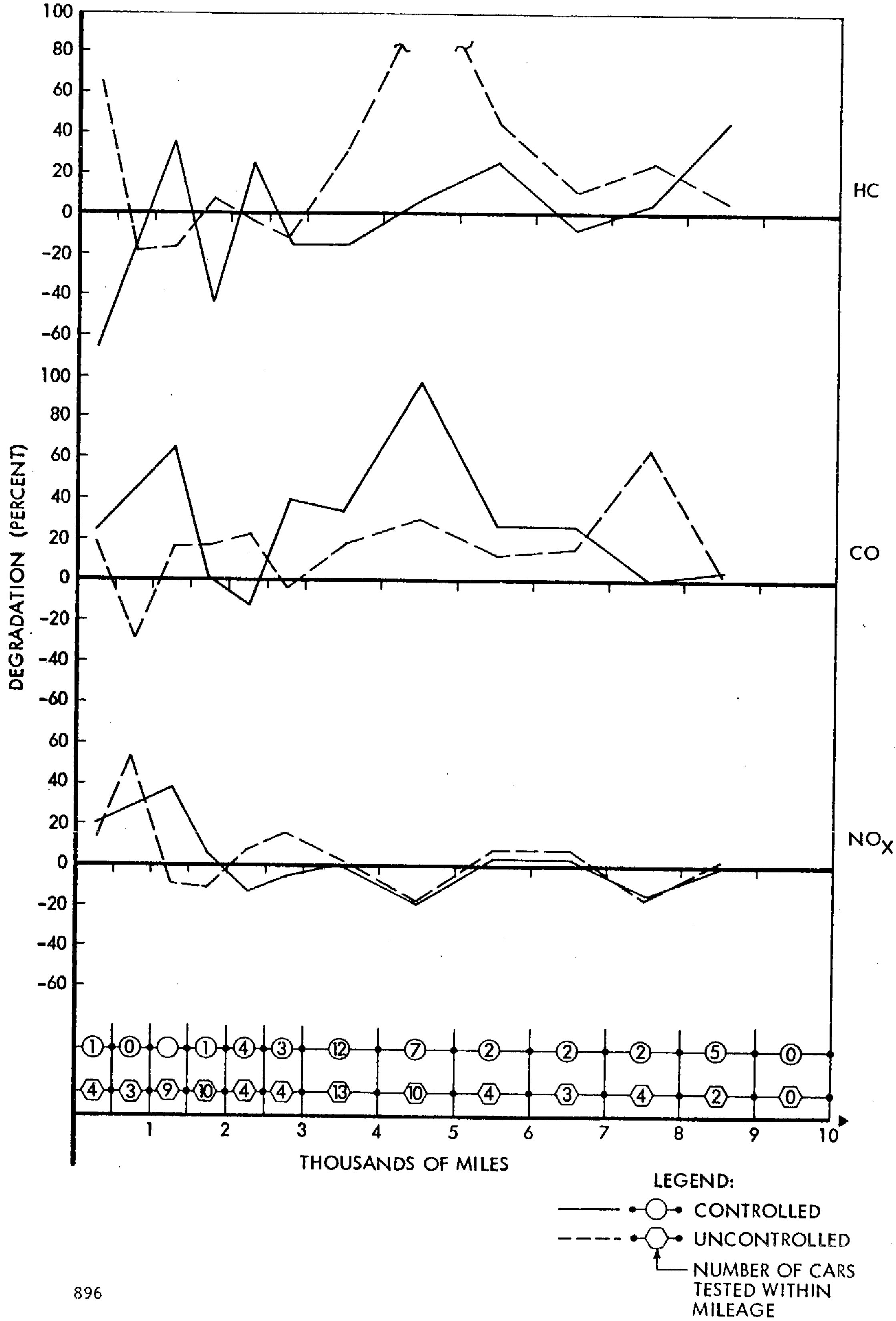

Figure 4-22. DEGRADATION FOR ORIGINAL PASSED AND ORIGINAL SERVICED CARS IN KEY-MODE TEST REGIME

Table 4-39. DEGRADATION FOR ORIGINAL PASSED AND ORIGINAL SERVICED CARS IN DIAGNOSTIC TEST REGIME

Pollutant / Mileage	Controlled Fleet Degradation Unit						No. of Cars Tested	Uncontrolled Fleet Degradation Unit						No. of Cars Tested
	Grams/Mile			Percent				Grams/Mile			Percent			
	HC	CO	NO_x	HC	CO	NO_x		HC	CO	NO_x	HC	CO	NO_x	
0-500	-	-	-	-	-	-	0	2.13	69.08	1.05	54	188	-32	1
500-1,000	-	-	-	-	-	-	0	10.33	-2.32	-0.17	240	-3	-7	2
1,000-1,500	-	-	-	-	-	-	0	0.88	16.20	0.49	16	27	11	3
1,500-2,000	-0.04	-12.87	0.49	-1	-30	13	1	0.63	17.54	0.16	12	20	11	1
2,000-2,500	1.61	5.80	1.76	63	21	54	2	0.65	8.31	0.07	17	23	-2	5
2,500-3,000	0.74	1.52	-0.33	35	8	-7	3	0.65	-9.83	0.22	13	-12	9	2
3,000-4,000	1.15	0.79	0.55	43	2	14	10	0.83	22.13	-0.58	17	29	-18	2
4,000-5,000	0.48	-0.71	1.24	23	-3	33	2	-	-	-	-	-	-	0
5,000-6,000	-0.15	11.08	-0.26	-6	48	-6	3	1.31	14.98	-0.77	21	22	-13	2
6,000-7,000	-0.03	1.09	0.36	-1	5	6	5	2.73	21.06	0.49	71	31	16	3
7,000-8,000	1.03	4.47	-0.68	46	26	-13	1	2.01	26.30	0.22	66	50	10	1
8,000-9,000	0.57	19.72	0.59	18	77	9	3	-	-	-	-	-	-	0
9,000-10,000	0.52	23.11	-2.00	18	96	-29	2	0.72	-3.64	-0.04	15	-7	-1	2

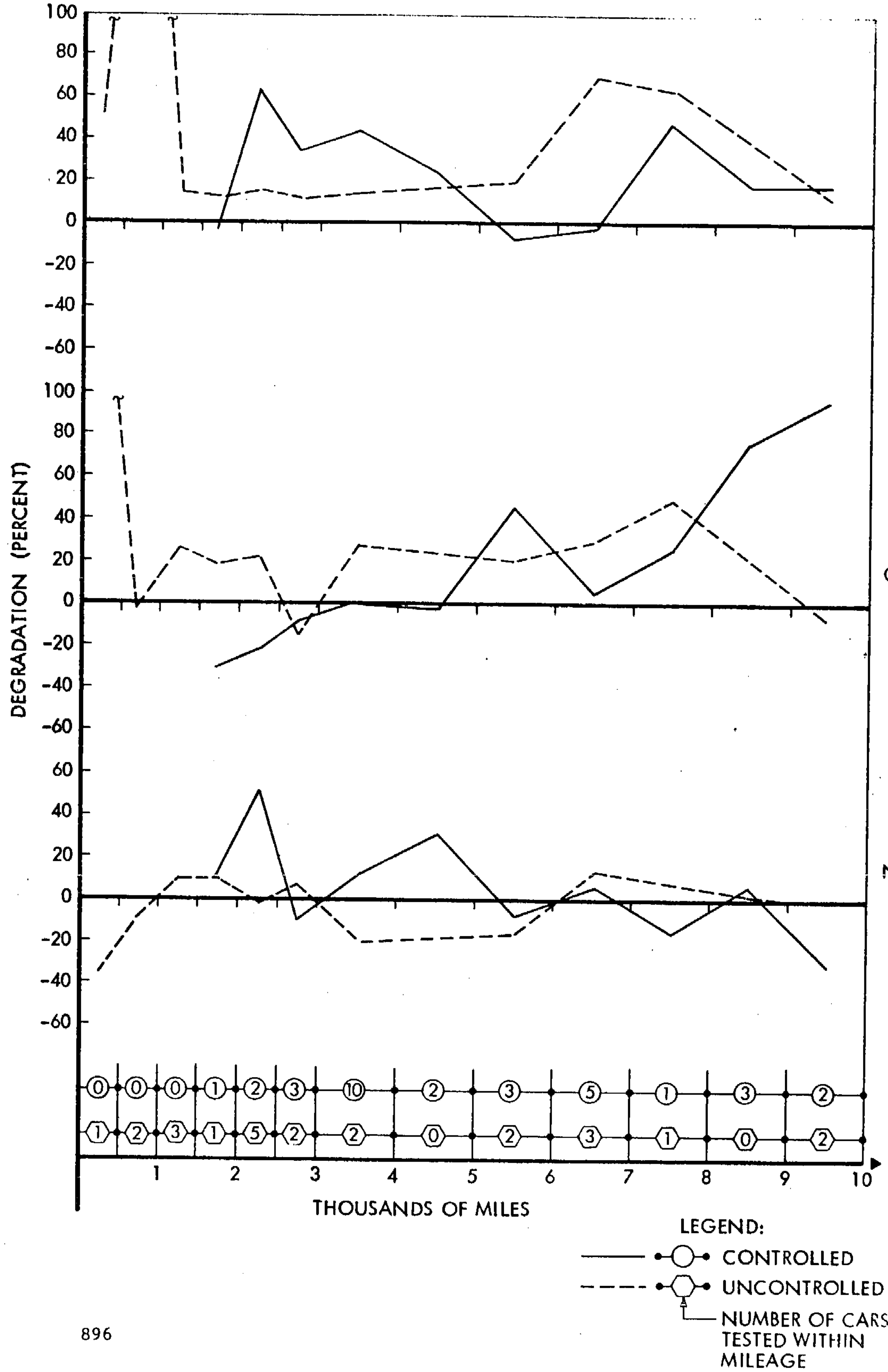

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Figure 4-23. DEGRADATION FOR ORIGINAL PASSED AND ORIGINAL SERVICED CARS IN DIAGNOSTIC TEST REGIME

Table 4-40. DEGRADATION FOR ORIGINAL PASSED AND ORIGINAL SERVICED CARS IN 4 COMBINED TEST REGIMES

Mileage \ Pollutant	Controlled Fleet Degradation Unit						No. of Cars Tested	Uncontrolled Fleet Degradation Unit						No. of Cars Tested
	Grams/Mile			Percent				Grams/Mile			Percent			
	HC	CO	NO_x	HC	CO	NO_x		HC	CO	NO_x	HC	CO	NO_x	
0-500	-0.84	-1.29	0.20	-38	-8	4	2	2.71	1.00	0.20	49	2	6	16
500-1,000	-	-	-	-	-	-	0	0.86	1.96	0.28	33	8	15	10
1,000-1,500	0.46	6.10	1.70	19	26	35	6	-0.54	8.34	-0.26	-10	17	-8	24
1,500-2,000	0.80	-2.38	0.79	34	-9	22	7	0.20	10.53	0.01	4	16	0	20
2,000-2,500	0.74	-1.57	0.44	32	-6	11	7	0.37	4.59	-0.25	9	13	-6	26
2,500-3,000	-0.04	4.00	-0.10	-2	20	-2	9	0.77	9.88	0.05	15	19	2	16
3,000-4,000	0.29	4.95	0.09	12	20	2	36	1.35	11.39	0.32	26	22	9	25
4,000-5,000	0.19	10.09	-0.81	7	50	-15	15	3.15	12.04	-0.82	66	25	-19	20
5,000-6,000	0.66	5.57	0.78	30	17	17	13	1.88	7.01	-0.02	31	10	-1	13
6,000-7,000	0.24	15.42	-0.09	14	68	-2	14	0.67	2.68	0.34	12	4	10	10
7,000-8,000	0.47	5.92	-0.18	33	35	-4	6	1.33	31.89	-0.96	30	59	-25	6
8,000-9,000	0.48	6.03	-0.19	26	36	-6	14	0.38	1.60	0.18	8	5	3	2
9,000-10,000	0.57	20.13	-1.90	24	92	-33	3	0.71	-3.74	-0.03	15	-7	-1	2

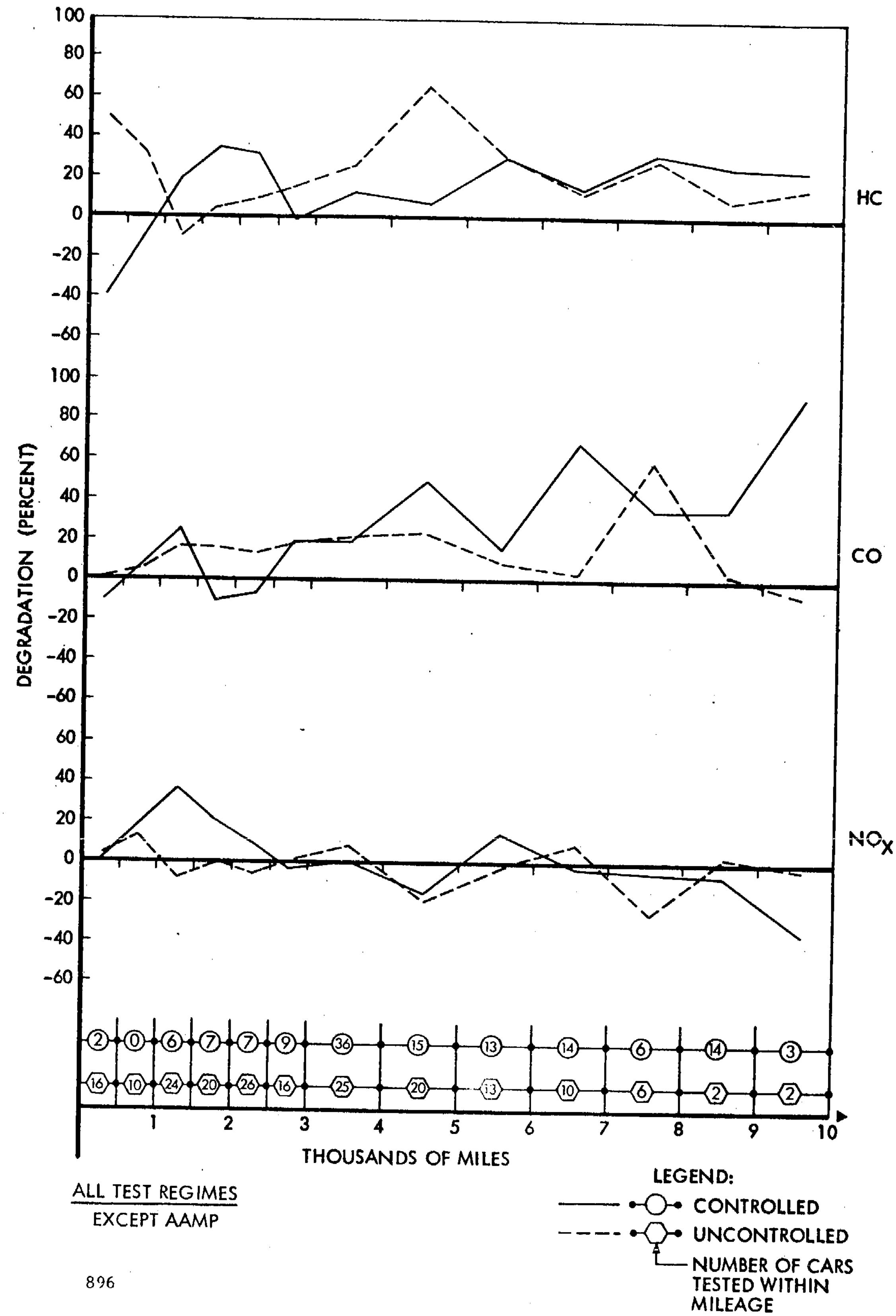

Figure 4-24. DEGRADATION FOR ORIGINAL PASSED AND ORIGINAL SERVICED CARS IN FOUR COMBINED TEST REGIMES

Table 4-41. DEGRADATION FOR ALL CARS NOT SERVICED BY OWNER (CONTROLLED AND UNCONTROLLED VEHICLES)

Mileage \ Pollutant	Degradation Unit						No. of Cars Used
	Grams/Mile			Percent			
	HC	CO	NO_x	HC	CO	NO_x	
0-500	2.31	1.93	0.15	39	3	4	18
500-1,000	0.86	1.96	0.28	33	8	15	10
1,000-1,500	-0.21	9.11	0.22	-4	18	5	30
1,500-2,000	0.35	8.22	0.20	7	14	6	27
2,000-2,500	0.52	3.34	-0.13	14	9	-3	33
2,500-3,000	0.48	7.76	-0.01	12	19	0	25
3,000-4,000	0.72	7.59	0.18	21	21	4	61
4,000-5,000	1.84	11.01	-0.79	47	30	-16	35
5,000-6,000	1.27	6.29	0.39	31	13	9	26
6,000-7,000	0.44	11.49	0.20	12	25	5	24
7,000-8,000	1.07	21.77	-0.76	35	55	-15	12
8,000-9,000	0.55	10.39	-0.32	18	37	-6	16
9,000-10,000	0.76	13.45	-1.50	21	36	-28	5

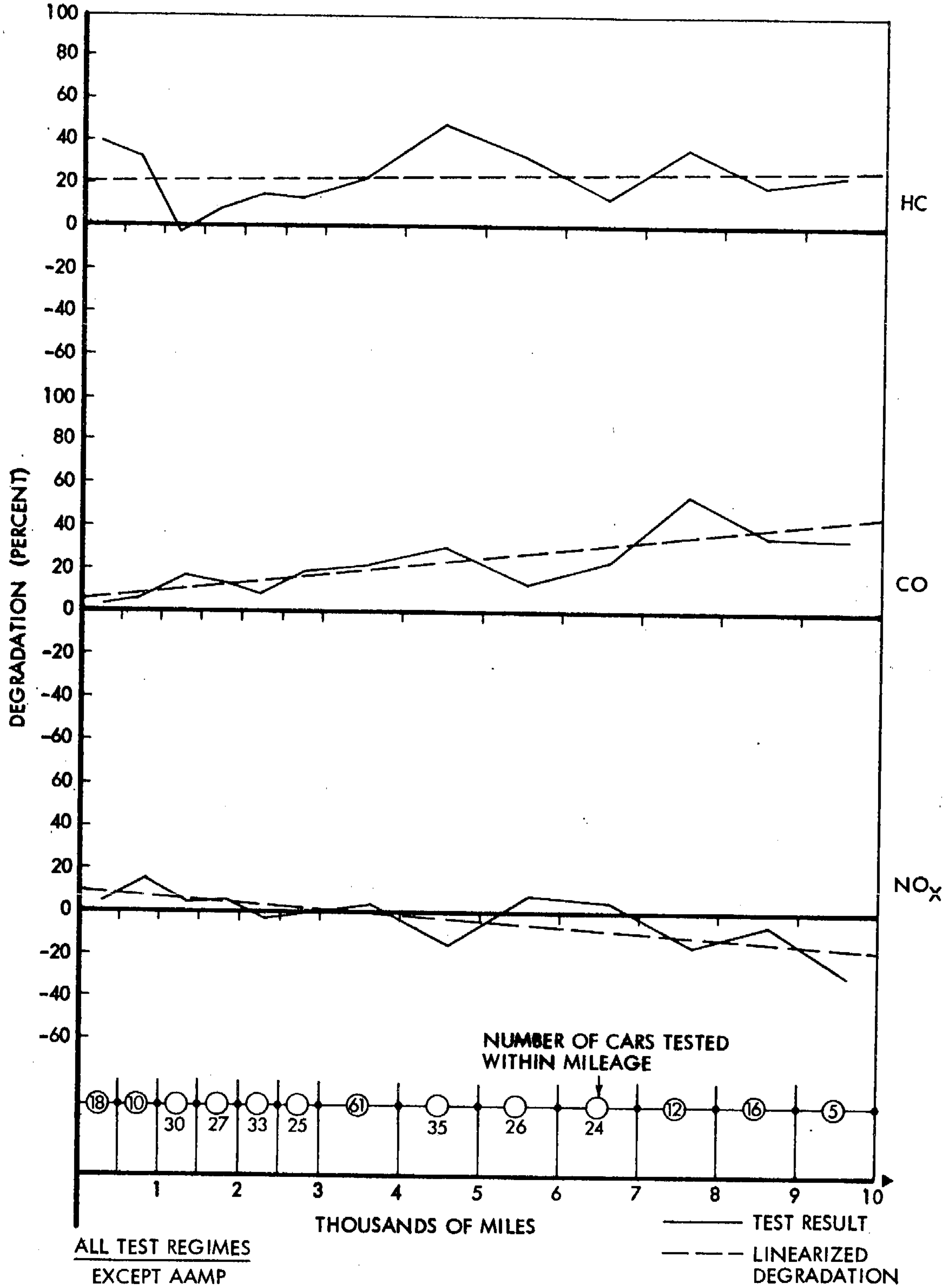

Figure 4-25. DEGRADATION FOR ALL CARS NOT SERVICED BY OWNER (CONTROLLED AND UNCONTROLLED VEHICLES)

4.5 STATISTICAL ANALYSIS OF THE EXPERIMENTAL RESULTS

Discussed in the following paragraphs are the statistical methods used to compare the effectiveness of the five test regimes in the reduction of emissions. A suitable statistical model is chosen and the analysis is based upon the experimental data. According to the test results of the statistical model, conclusions will be drawn about the effectiveness of the five test regimes.

Based on the experimental design, five groups of cars having similar characteristics (e.g., model years, vehicle size, make/model, etc.) were assigned to the five test regimes, one group per test regime. The sample sizes of the five groups were not the same, but the differences were small. Emission test measurements were taken before vehicle service and after service.

Statistical analysis of the experiment based only on the post-service results may not represent the true situation because the emission characteristics for each vehicle after service may be dependent upon the emission profile before services. The data show that the vehicles varied greatly with respect to their emission condition at the beginning of the experiment (before serviced). If the emission test results before service in the first group are relatively good while the third group are relatively bad, then the statistical result using only the after service data may favor the first test regime. Consequently, the differences among the effects of the five test regimes may or may not be significant. To determine if significant differences exist, necessary adjustments should be made on the emission test data before and after services. The analysis of covariance is a technique to adjust or correct the initial differences in emission condition and to achieve a lower experimental error and a more precise comparison among the five test regimes.

In the statistical test, certain suppositions are provisionally adapted to explain certain facts. A hypothesis of interest and an alternate hypothesis are defined before performing the test. From the statistical test result, conclusions can be drawn to determine whether the hypothesis of interest is accepted or rejected (accept the alternate hypothesis).

In conducting the statistical analysis, there will exist a probability α of rejecting the true hypothesis and a probability β of accepting the false hypothesis. α is chosen in advance, with 0.10, 0.05, and 0.01 being the most common choices. Then $1-\alpha$ is the probability of accepting a true hypothesis. In utilizing the analysis of covariance, the probability that the statistical test result indicates the acceptance of a true hypothesis is $1-\alpha$, which would be a large percentage.

4.5.1 Analysis Procedure

The completely randomized design of the analysis of covariance is used to compare the effectiveness of the five test regimes in the reduction of hydrocarbon, carbon monoxide, and oxides of nitrogen. The primary interest is on those vehicles which required service. The reduction of the three pollutants by the five test regimes are considered separately for the controlled and uncontrolled vehicles.

If the statistical test results indicate that the effectiveness of the five test regimes are the same, then each test regime is as good as the others. If the statistical test results indicate to the contrary, that is, the effectiveness of the five test regimes are different, then more tests were performed to identify which test regime is the best or which test regimes are significantly different from the others.

Scheffe's method for multiple comparisons was used for the linear combination of the effectiveness of two test regimes against the linear combination of the effectiveness of the other test regimes. For example, the effects of combining the first and third test regimes were compared against the combination of the second and fourth. Another test was to compare one test regime against each of the individual regimes. The results of these comparative testings identify the best regime, or those significantly better than the others. The probability that the analytical methods will provide the correct conclusions is $1-\alpha$.

4.5.2 Results of the Statistical Analysis

The method of analysis of covariance was applied to six groups: uncontrolled vehicles hydrocarbon, carbon monoxide, and oxide of nitrogen emissions; and controlled vehicles hydrocarbon, carbon monoxide, and oxides of nitrogen emissions. The primary objective of the analysis was to choose between the hypothesis that the test regimes effect on each pollutant are equal, or the alternative hypothesis that the test regime effects are not equal. The statistical test results are discussed in the following paragraphs.

4.5.2.1 Uncontrolled Vehicles Hydrocarbon Emission - The analysis of covariance table is:

Source	Sum of Square of x (SS_x)	Sum of Product (SP)	Sum of Square of y (SS_y)	SS'_y	Degree of Freedom (d.f.)	Mean Square (MS'_y)	F Ratio
Treat-ments	663.303	-98.065	27.928	86.151	4	21.538	2.626
Error	26509.963	5007.468	4489.070	3543.209	432	8.202	
Total	27153.266	4909.403	4516.997	3629.360			

$$\text{Where } SS'_{yT} = SS_{yT} - \frac{(SP_T)^2}{SS_{xT}} \text{ and } SS'_{yE} = SS_{yE} - \frac{(SP_E)^2}{SS_{xE}}.$$

The subscripts T and E are representations of treatments and error.

The equations used for the calculations of the table values were in accordance with the methods described in "Analysis of Variance" by Guenther, W. C., Prentice-Hall, Inc., 1964.

Choosing α equal to 0.10 (corresponding to a probability of accepting the true hypothesis is 90 percent), from the F-distribution table the following values are obtained:

$$F_{1-\alpha};\ r-1,\ N-r-1 = F_{.90};\ 4,432 = 1.94.$$

Since the value of the F ratio, 2.626 is greater than 1.94, the hypothesis that all test regimes have the same effect in reducing the emission of hydrocarbon is rejected. In other words, there are differences between the regimes.

The multiple comparison of the five test regimes by Scheffe (S-method) were performed to determine which test regime(s) caused the rejection of the hypothesis. The comparison of one test regime against each of the other test regimes results in 10 comparisons. The equations used in the multiple comparisons are based on Guenther, W. C., "Analysis of Variance," and Scheffe, H., "The Analysis of Variance."

$$\hat{L} = \sum_{j=1}^{r} C_j \bar{y}_{.j} - \frac{SP_E}{SS_{xE}} \sum_{j=1}^{r} C_j \bar{x}_{.j}$$

$$\hat{\sigma}^2_{\hat{L}} = MS'_{yE} \left[\sum_{j=1}^{r} \frac{C_j^2}{n_j} + \frac{\left(\sum_{j=1}^{r} C_j \bar{x}_{.j} \right)^2}{SS_{yE}} \right]$$

$$S^2 = (r-1)\, F_{1-\alpha;\, r-1,\, N-r-1}$$

If the calculated value of $\frac{\hat{L}^2}{\hat{\sigma}^2_{\hat{L}}} > S^2$, the two test regimes in comparison are significantly different from zero; therefore, one test regime is better than the other.

From the calculated results of the 10 comparisons of two test regimes at a time, only one result is greater than the value of S^2. The comparison showed that the Diagnostic Test is better than Certificate of Compliance. The other results are not significantly different from zero and no conclusion can be drawn about which test regime is better than the other.

More complicated comparison such as Key-Mode versus the other four test regimes, Key-Mode and Idle versus the other three test regimes, and Key-Mode, Idle, and AAMP versus the other two were performed. The results of the three comparisons do not provide any further information. Consequently, the conclusion drawn about the uncontrolled vehicles hydrocarbon emission testing is that the Diagnostic Test is better than Certificate of Compliance, whereas the others are not significantly different by comparison.

4.5.2.2 Uncontrolled Vehicles Carbon Monoxide Emission - The analysis of covariance table for the uncontrolled vehicles is:

Source	SS_x	SP	SS_y	SS'_y	d.f.	MS'_y	F Ratio
Treatments	58249.891	-15069.312	10290.697	33348.567	4	8337.142	12.738
Error	781923.326	349093.292	438613.324	282759.006	432	624.535	
Total	840173.217	334023.980	448904.021	316107.573			

CO testing appears below. The value of the F ratio (12.738) is greater than $F_{.90;\, 4,432} = 1.94$, therefore, the hypothesis that all test regimes have the same effect in reducing the emission of carbon monoxide is rejected.

Performing the multiple comparison tests, it was determined that 8 of 10 multiple comparisons between any two test regimes were significantly different from zero. The results are as follows:

Diagnostic is better than Certificate of Compliance
Key-Mode is better than Certificate of Compliance
Key-Mode is better than Idle
Key-Mode is better than Diagnostic
Key-Mode is better than AAMP.

Key-Mode is better than the other four test regimes. Therefore, it is the best test regime in achieving reduction of carbon monoxide for the uncontrolled vehicles.

4.5.2.3 Uncontrolled Vehicles Oxides of Nitrogen Emission - The analysis of covariance table for the uncontrolled vehicles NO_x reduction is:

Source	SS_x	SP	SS_y	SS'_y	d.f.	MS'_y	F Ratio
Treatments	65.938	-4.597	25.538	69.689	4	17.422	9.351
Error	1464.790	1127.615	1672.860	804.807	432	1.863	
Total	1530.728	1123.018	1698.398	874.496			

The value of the F ratio (9.351) is greater than $F_{.90}$; 4,432 = 1.94. Thus, the hypothesis of equal effectiveness of all five test regimes is rejected. The results from the multiple comparison which are significantly different from zero showed that:

Certificate of Compliance is better than Key-Mode
Idle is better than Key-Mode
AAMP is better than Key-Mode.

The above results indicate that the Key-Mode has the least effect in reducing NO_x emission from the uncontrolled vehicles. The other seven comparisons are not significantly different from zero; therefore, no further information can be obtained.

4.5.2.4 Controlled Vehicles Hydrocarbon Emission - The analysis of covariance table for this comparison test is:

Source	SS_x	SP	SS_y	SS'_y	d.f.	MS'_y	F Ratio
Treatments	137.413	6.633	3.040	2.780	4	0.695	0.557
Error	6451.767	448.174	330.500	299.367	240	1.247	
Total	6589.180	454.807	333.540	302.147			

The value of the F ratio (0.557) is less than the value of $F_{.90}$; 4,240 = 1.94, hence, the hypothesis that the test regime effectiveness is the same is accepted. In other words, each test regime is as good as the others in achieving reduction in HC emissions.

4.5.2.5 Controlled Vehicles Carbon Monoxide Emission - The analysis of covariance table for this test is:

Source	SS_x	SP	SS_y	SS'_y	d.f.	MS'_y	F Ratio
Treatments	25969.286	-5190.841	2813.505	12263.342	4	3065.835	7.648
Error	190522.091	90979.276	139653.082	96208.101	240	400.867	
Total	216491.377	85788.435	142466.587	108471.443			

The value of the F ratio (7.648) is greater than the value $F_{.90}$; 4,240 = 1.94, thus, the hypothesis of equal effectiveness of the five test regimes cannot be accepted. From the ten multiple comparison test results, five comparisons show significant differences from zero. The results are that:

Idle is better than Certificate of Compliance
Key-Mode is better than Certificate of Compliance
Diagnostic is better than Certificate of Compliance
Idle is better than AAMP
Key-Mode is better than AAMP.

Since both Key-Mode and Idle are better than Certificate of Compliance and AAMP, more comparisons were performed to determine more information about Key-Mode and Idle. The first comparison was Idle versus Certificate of Compliance, Diagnostic, and AAMP; the second one was Key-Mode versus Certificate of Compliance, Diagnostic, and AAMP. The former comparison was not significantly different from zero, while the latter comparison was. Hence, Key-Mode is better than Certificate of Compliance, Diagnostic, and AAMP. Consequently, Key-Mode is the best test regime for the reduction of carbon monoxide emission of controlled vehicles.

4.5.2.6 Controlled Vehicles Oxides of Nitrogen Emission - The analysis of covariance table for this evaluation is:

Source	SS_x	SP	SS_y	SS'_y	d.f.	MS'_y	F Ratio
Treatments	31.525	16.254	14.190	7.717	4	1.930	0.930
Error	1233.763	943.359	1219.306	497.995	240	2.075	
Total	1265.288	959.613	1233.496	505.711			

The value of the F ratio (0.930) is less than the value of $F_{.90}$; 4,240 = 1.94, therefore, the hypothesis that equal effects of the five test regimes exists is accepted.

4.5.2.7 Summary of Statistical Analysis - The results of the statistical analysis on the effectiveness of the five test regimes in reducing exhaust emissions are summarized in Table 4-42.

Table 4-42. STATISTICAL ANALYSIS SUMMARY

Vehicle Type	HC Reduction	CO Reduction	NO_x Reduction
Uncontrolled Vehicles			
a. Hypothesis: All test regimes are equally effective	Rejected	Rejected	Rejected
b. Alternate Hypothesis: All test regimes are not equally effective	Accepted	Accepted	Accepted
c. Multiple Comparisons Results	Diagnostic is better than C of C, no significant difference among other comparisons	Key-Mode is the best test regime	Key-Mode is the least desired test regime
Controlled Vehicles			
a. Hypothesis: All test regimes are equally effective	Accepted	Rejected	Accepted
b. Alternate Hypothesis: All test regimes are not equally effective	Rejected	Accepted	Rejected
c. Multiple Comparisons Results	None required	Key-Mode is the best test regime	None required

The summary table shows that for uncontrolled vehicles, there are differences between the test regimes in reducing each of the three pollutants. However, for the controlled vehicles, it was shown that there are no differences between the test regimes in reducing HC and NO_x, whereas for CO reductions Key-Mode was the best.

4.5.3 Confidence Analysis of Test Results

A vital part of any experiment is the isolation and quantification of the variables under observation. An experimental control group of inspected vehicles was included in an attempt to separate the true emission reduction attributable to maintenance services from the statistical fluctuations inherent to the measurement system and operating personnel. Without such a control group, there is no way of determining whether measured and calculated emission reductions are real or simply artifacts of the total test and measurement system which includes the personnel, equipment, and procedures.

To determine the magnitude of this system error, a random sample of 50 vehicles which passed the respective test (Idle, Key-Mode, or Diagnostic) was subjected to retesting some 4 to 30 hours later to determine the repeatability of the measurements and to determine the failure rate of initially passed vehicles during the second inspection.

The investigation, completed in May 1971, revealed that four percent of the previously passed vehicles failed to pass the second test. This may be attributed to the measured test value being comprised of the actual existing value plus some random measurement error. Experience in system tests has shown that this random error is usually distributed symmetrically about the true value (Gaussian normal distribution). Thus, if the test is implemented to fail half of the vehicles and four percent of those initially passing are subsequently rejected, then correspondingly due to symmetry a similar percentage of vehicles initially failing the test would pass the subsequent test without any service being performed on the vehicle.

The actual distribution of the measurement errors was estimated by comparing the difference in the two measurements for each vehicle. Table 4-43 presents the errors observed for each of the three pollutants. 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. 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 two percent of the mean, for the same vehicle and driver on successive tests.

Table 4-43. 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

SECTION 5

COST-EFFECTIVENESS EVALUATION

This section combines the results of the effectiveness and cost analyses to arrive at a cost-effectiveness evaluation and a comparison of the alternatives. The section begins with the definition and development of a cost-effectiveness (CE) measure. Combining the results of the effectiveness and cost analyses discussed in the previous section, program CE indices were derived for each test regime. These quantitative measures were then used to evaluate and compare the alternatives.

A vehicle owner CE analysis also was performed. Costs to the owner include the inspection fee and maintenance service costs. The value of fuel savings was calculated to determine the benefits of vehicle repair and adjustments. Owner comments relative to vehicle performance after emission service were evaluated and are discussed.

The degree of State and private industry participation in a mandatory program also was evaluated. Based on findings of the total study, a recommended arrangement is proposed.

5.1 COST-EFFECTIVENESS INDEX

Simply stated, a CE analysis attempts to identify, define, and quantify the benefits derived for the money spent. As such, it requires an understanding of the functional characteristics of the total program, the physical characteristics of the prime and supporting equipments and systems, the interrelationships and interdependencies of the machines and men, and the objectives and results of implementing such a program. The effectiveness evaluation, discussed in Section 4, relates vehicle testing and maintenance-effects data to the overall program objective of emissions reduction. The cost of resources and the funds necessary to equip, staff, operate, and manage the inspection facilities were discussed in Section 4. To conduct the CE analysis, the respective effectiveness measures and corresponding cost implications of each test regime were considered.

In the following paragraphs, the CE index is developed to evaluate and compare the alternatives. For each test regime, a CE index was calculated relative to each operating year to illustrate trends expected during the program duration. An evaluation of the individual trends and a comparison among the test regimes provides relative measures of CE. These quantitative measures are complemented with a qualitative analysis of uncertainty factors as related to future regulations and technological advancements and their effects on the test regimes being considered.

5.1.1 Development of Cost-Effectiveness Index

In previous sections of this report, program effectiveness was evaluated in terms of emission reduction achievable per year as a function of test regime. The resource acquisition costs plus operation and maintenance costs per test regime also were evaluated. Thus, although discussed and developed separately, the effectiveness and cost models are not independent. Combining the results of these two models, a CE model is achieved that is simple, computable, and representative of the alternatives. Shown below is the simplified equation to be used for determining the quantitative measures of CE.

$$\text{Cost Effectiveness (CE)} = \frac{\text{Effectiveness Measure}}{\text{Program Cost}} = \frac{\text{Tons of Pollutants}}{\text{Dollars}}$$

Recall that the effectiveness measures were calculated and plotted as a function of program calendar year, beginning in 1972 and projected to 1991. Correspondingly, the program costs were calculated on a yearly basis starting in 1972, assumed to be the initial year of implementation for this analysis. In effect, then, the above CE index, when calculated, would determine the CE of each test regime on an annual basis.

Using the CE indices thus calculated, the alternatives can be ranked in order of greatest emission reduction for money expended. The test regime achieving the greatest reduction for the least estimated total cost would generate the largest index, and would thus rank the highest. This does not necessarily mean that this particular test regime would realize the greatest reduction, nor does it imply that it would cost the least to implement. It merely identifies the one test regime that realizes the greatest potential for a specified amount of resources and money.

5.1.2 Determination of Test Regimes Indices

The CE index for each test regime is calculated for each program year. Based on the yearly effectiveness estimation and the corresponding costs incurred, a ratio of tons emission reduction per dollar spent is calculated. Equal weighting of HC, CO, and NO_x was used in the effectiveness measures. This was selected to reflect actual reduction as a function of cost. It was previously shown in Volume III, Section 5, that the different weighting factors did not alter the ranking.

5.2 PROGRAM COST EFFECTIVENESS

Facilities for the test regimes may be owned and operated by the State, private industry, or a combination of the two. Since the State owned and operated facilities were designed specifically to do only inspection, whereas the privately owned and operated would include the profit margin, taxes, and parallel administrative cost functions as related to program surveillance, the former are relatively more cost effective regardless of the test regimes, as was shown in Volume III, Section 8. Consequently, only the State owned and operated facilities are being considered in this report.

5.2.1 Yearly Cost-Effectiveness Comparison

In the alternative arrangement of State owned and operated inspection facilities, the State of California acquires the necessary sites, constructs the inspection facilities, equips the test lanes, staffs the facilities, services the equipments, and manages the total program. The CE comparisons of the five test regimes are shown on Figure 5-1 by utilizing the calculated CE indices in each year.

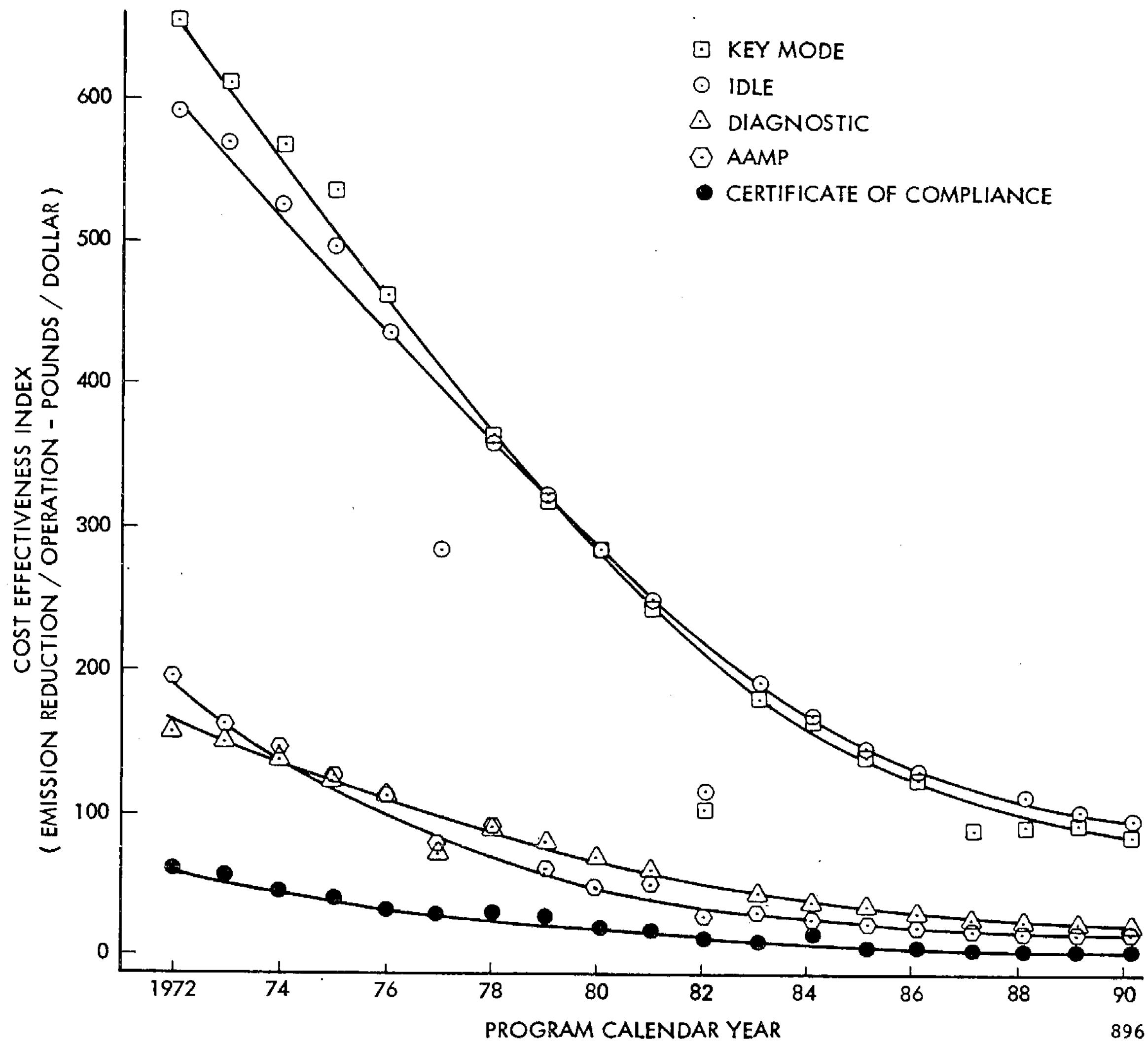

Figure 5-1. TEST REGIMES COMPARISON - STATE OWNED AND OPERATED INSPECTION FACILITIES

Key-Mode Test regime exhibits the greatest emission reduction for the cost incurred during the first 7 years. The crossover point occurs between years 1978-1979.

After that, the figure shows that the Idle Test is slightly more cost-effective than the Key-Mode Test. The occurrence of this phenomenon is caused by the greater operating cost and the higher equipment replacement cost of the Key-Mode Test compared with the Idle Test. The figure shows that, as the program progresses, the equipment replacement cost reduces the CE of the Key-Mode Test regime below that of the Idle Test.

Diagnostic Test is much lower than both Key-Mode Test and Idle Test, in spite of its fair effectiveness in achieving emission reductions. This is due to its higher annual operation cost, which is more than three times greater than either of the other two tests.

Certificate of Compliance is the least cost effective in emission reduction compared with the other test regimes. This is not surprising since it achieved relatively little emission reduction, whereas the annual operation costs were about twice that of Idle Test or Key-Mode Test.

The Annual Adjustment and Maintenance Procedure (AAMP) would cost approximately the same as the Diagnostic. However, AAMP is still significantly lower in CE than both the Key-Mode Test and Idle Test regimes.

5.2.2 Cost-Effectiveness Comparison by Air Basins

Figure 5-2 shows the CE index as a function of air basins, assuming the Key-Mode Test or Idle Test regime is implemented. The figure indicates the differences that occur based on vehicle population density per air basin. Thus, the most cost-effective air basin to implement would be the South Coast Basin (1), with the least cost effective being the Great Basin Valleys (11).

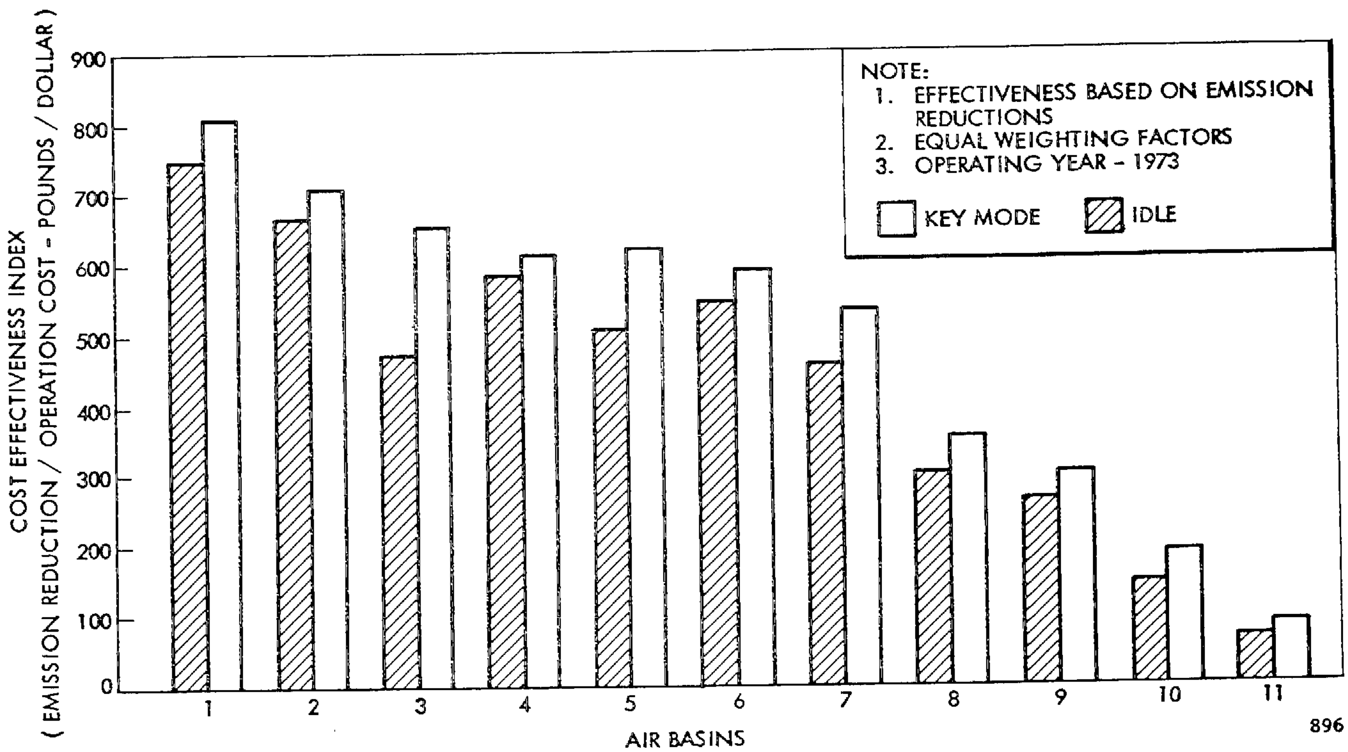

Figure 5-2. COST EFFECTIVENESS BY AIR BASINS

Revised 12/10/71

The figure considers the pollutants to be equally weighted, with both emission reductions and operating costs based on the 1973 calendar year. Subsequent calendar years would show proportionately less CE on the whole; however, the relative rankings of the air basins remain the same.

5.3 VEHICLE OWNER COST EFFECTIVENESS

The CE of an inspection program can be viewed with respect to the State or with respect to the vehicle owner. Program or State CE was previously discussed. Owner CE involves the inspection fee and service cost, fuel consumption and associated cost, and appraisal of vehicle performance after emission servicing.

5.3.1 Inspection Fee and Service Cost

The results of the in-depth cost analysis, Volume III, Section 6, and the supplemental analysis of Section 4, show that inspection fees listed in Table 5-1 may be realized for each of the test regimes.

Table 5-1. INSPECTION FEES

Test Regimes	State-Owned, Operated	Privately Owned, Operated	State-Managed, Private License
C of C	$2.31	$2.94	$ 9.00
Idle Test	0.96	1.22	6.00
Key-Mode Test	1.05	1.33	6.00
Diagnostic Test	3.07	3.90	12.00
AAMP	2.31	2.94	9.00

The cost of maintenance service and repair that would be incurred by a vehicle owner may be estimated based on the results of the study. Average costs by test regimes are shown in Table 5-2.

Table 5-2. AVERAGE REPAIR COST

Test Regime	Vehicle Emission	
	Controlled	Uncontrolled
C of C (includes inspection fee)	$ 8.65	$ 8.40
Idle Test	36.00	33.40
Key-Mode Test	26.70	32.10
Diagnostic Test	27.20	53.30
AAMP	17.10	22.00

The public opinion results indicate that the majority of those polled would oppose a mandatory vehicle emission inspection if required repair costs exceeded $10. It appears that only Certificate of Compliance would be acceptable to the general public.

The following paragraphs show that the actual annual cost to the vehicle owner for all test regimes is within or close to the public acceptability limit. Three approaches were taken:

- Identification of the benefits derived through decreased fuel consumption as a result of maintenance
- Definition of the relationships between required and normal repairs made by the average car owner
- Identification of the benefits of increased vehicle performance.

5.3.2 Fuel Economy Benefits

The benefits of fuel economy are important factors in the CE analysis. Clayton Manufacturing Company has run extensive laboratory tests, under controlled conditions with measured air and fuel into the engine, as well as exhaust analyses (Reference 15). Typical malfunctions of various types were induced to determine if an increase in exhaust HC and/or CO could be related to an increase in engine fuel demanded to maintain a constant power output. This work, which was verified on a modest number of in-service vehicles, indicated that there is a usable relationship.

A complete description of the experimental work and results appear in Volume III, Section 6. The derivation of the relationship between measured emissions and fuel consumption is repeated here.

Since the derivation is applied to each regime, any inherent inaccuracies apply to all. The intent is to indicate the relative differences.

The equation for arriving at dollar saving per year is:

$$C_s = W \cdot M \cdot K \cdot C_g$$

where

C_s = fuel savings in dollars per year
W = pounds of fuel per mile
M = miles driven per year = 10,000 miles (estimate)
K = gallons per pound fuel constant = $\frac{1}{6.26}$ at specific gravity of 0.75
C_g = cost of gasoline per gallon = \$0.37 (estimate)
1 gram = 2.205×10^{-3} pounds

$$\therefore C_s = 2.205 \times 10^{-3} \Delta E \times 10^4 \times \frac{1}{6.26} \times 0.37 = 1.3 \Delta E$$

where

ΔE = emission reduction in grams per mile.

The value of ΔE may be found by taking the HC and CO reductions observed and applying them to the following equation:

$$\Delta E = \Delta HC + 0.3\ \Delta CO$$

where ΔHC and ΔCO are in grams per mile. Fuel savings, C_s, then becomes:

$$C_s = 1.3\ \Delta HC + 0.39\ \Delta CO$$

Applying the above calculations to each of the regimes yields the results shown in Table 5-3. It should be noted that these calculations apply only to those cars serviced, using before and after emission results for each regime.

The fuel savings were calculated using the equations above, with the average mileage being 10,000 miles annually. Vehicles processed by each test regime are indicated in parentheses, with controlled vehicles listed first.

The calculations indicate that the controlled and uncontrolled vehicles inspected and serviced by the Key-Mode Test regime would realize a potential fuel savings of $16.70 and $22.40, respectively. At the other extreme, those serviced by the Certificate of Compliance method have a potential savings of $1.69 for controlled vehicles and $2.15 for uncontrolled. For each test regime, the controlled vehicles will realize less fuel savings than uncontrolled vehicles. This is to be expected since the savings are based on emission reductions.

Table 5-3. FUEL SAVINGS BASED ON EMISSION REDUCTION

Test Regime	HC (Grams/Mile)		CO (Grams/Mile)		Fuel Savings ($)	
	Controlled	Uncontrolled	Controlled	Uncontrolled	Controlled	Uncontrolled
C of C (78; 95)	0.73	0.63	1.9	3.4	1.69	2.15
Idle Test (43; 92)	1.55	4.10	29.0	27.7	13.30	16.10
Key-Mode Test (43; 111)	2.74	3.61	30.4	45.4	16.70	22.40
Diagnostic Test (31; 66)	1.49	4.70	22.8	28.4	10.80	17.10
AAMP (51; 74)	0.89	2.99	4.9	15.7	3.07	10.00

5.3.3 Owner Appraisal of Serviced Vehicle Performance

An important aspect of a mandatory vehicle inspection program requiring service and repair is the resulting vehicle operation and performance. If degradation is noted, owners would object. Ideally, an increase in performance would be desirable. An integral part of the test phase was to determine from owner comments what, if any, changes in performance were noted following vehicle servicing. Figure 5-3 is a copy of the prepaid reply postcard developed for this purpose and given to each owner whose vehicle was serviced.

Your car was tested for exhaust emissions and serviced by garages.
Please indicate below your opinion of how the car's engine is now performing.
Comments are encouraged. Return prepaid reply as soon as possible.

Thank You

☐ No Change ☐ Improved ☐ Worse

COMMENT: ______________________________

____

____

____

____

Figure 5-3. SERVICED VEHICLE PERFORMANCE QUESTIONNAIRE

The reply card provided the owner with three options: no change, improved, or worse. In addition, space for comments was provided, which allowed the owner to describe or state any descriptive information he wished to express.

Responses were tabulated as a function of these characteristics to determine whether a particular test regime or type of vehicle was sensitive to the type of repair performed. Table 5-4 summarizes the responses of vehicle owners as a function of emission control, test regime, and performance change.

Table 5-5 summarizes the information in terms of percentages of responses from owners of serviced vehicles. The data indicates that for all test regimes, except Certificate of Compliance, the majority of serviced vehicles experienced improved performance. For the uncontrolled serviced vehicles, the AAMP method registered the highest percentage in the "improved" category, followed by Idle Test and Key-Mode Test. For the controlled vehicles, the Key-Mode Test recorded the greatest percentage in the "improved" category followed by AAMP, Diagnostic Test, and Idle Test.

Over 80 percent of the owners of serviced controlled vehicles within the Idle Test regime responded to the survey, whereas less than 50 percent of owners of uncontrolled vehicles serviced by the Diagnostic Test regime responded. As a class, the dynamic testing of Key-Mode Test and Diagnostic Test received a lower response rate (less than 59 percent) than did the static testing of Certificate of Compliance, Idle Test, and AAMP (greater than 63 percent). Of the dynamic test methods, Key-Mode Test received more favorable responses than did Diagnostic Test. For the static test regimes, AAMP received more favorable responses than Idle Test or Certificate of Compliance.

Table 5-4. VEHICLE OWNER COMMENTS AFTER SERVICE

Test Regime	Performance			Responses	Vehicles Serviced
	No Change	Improved	Worse		
C of C					
Uncontrolled	23	27	9	59	95
Controlled	26	17	8	51	78
Idle Test					
Uncontrolled	13	35	3	51	92
Controlled	9	21	5	35	43
Key-Mode Test					
Uncontrolled	13	40	8	61	111
Controlled	3	24	2	29	43
Diagnostic Test					
Uncontrolled	10	18	4	32	66
Controlled	6	15	1	22	31
AAMP					
Uncontrolled	6	32	8	46	74
Controlled	7	24	3	34	51
All Vehicles	116	253	51	420	684
Uncontrolled	65	152	32	249	438
Controlled	51	101	19	171	246

5.3.4 Vehicle Owner Cost of Emission Reduction

The average motorist is more concerned with his direct costs resulting from a mandatory inspection program than with reducing exhaust emissions. Results of the public opinion survey discussed in Volume III, Section 7, show that of all those favoring such a program, 86.1 percent would still favor it if service repairs were $5, 47.3 percent would still favor it if they were $10, and only 19.5 percent of those in favor would be so inclined if the repair costs were $20. In other words, less than half the people initially in favor of an inspection program would be willing to pay $10 annually to reduce vehicle emissions. Figure 5-4 illustrates the trend regarding repair costs for those favoring an inspection program.

Another question, similar in nature, that was posed to the public was one related to the inspection fee. Of those initially in favor of an inspection program, 91.6 percent would favor the program if there were no inspection fee, and 74.7 percent would still be in favor if the fee were $1. At a fee of $3, only 40.8 percent would be in favor, and if the fee were $5, only 17.1 percent would still accept an inspection program. If the fee were $10, then just 6 percent would be in favor. Figure 5-5 shows the percent in favor of the inspection as a function of the inspection fee.

Table 5-5. SUMMARY OF VEHICLE OWNER COMMENTS

Test Regime	Performance (Percent)			Responses From Total Serviced (Percent)
	No Change	Improved	Worse	
C of C	44.5	40.0	15.5	63.6
Uncontrolled	39.0	45.7	15.3	62.1
Controlled	51.0	33.3	15.7	65.4
Idle Test	25.6	65.2	9.2	63.7
Uncontrolled	25.5	68.6	5.9	55.4
Controlled	25.7	60.0	14.3	81.4
Key-Mode Test	17.8	71.1	11.1	58.4
Uncontrolled	21.4	65.5	13.1	55.0
Controlled	10.3	82.8	6.9	67.5
Diagnostic Test	29.6	61.1	9.3	55.7
Uncontrolled	31.3	56.2	12.5	48.5
Controlled	27.2	68.3	4.5	71.0
AAMP	16.2	70.0	13.8	63.8
Uncontrolled	13.1	69.5	17.4	62.2
Controlled	20.6	70.6	8.8	67.7

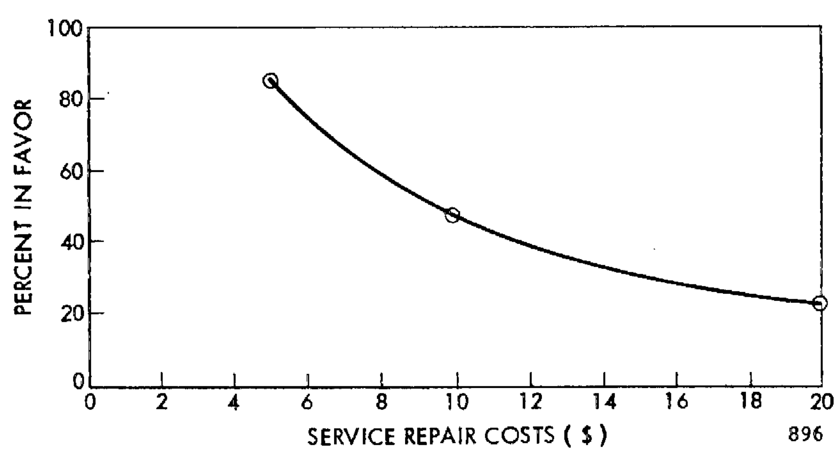

Figure 5-4. POPULATION FAVORING INSPECTION - REPAIR COSTS

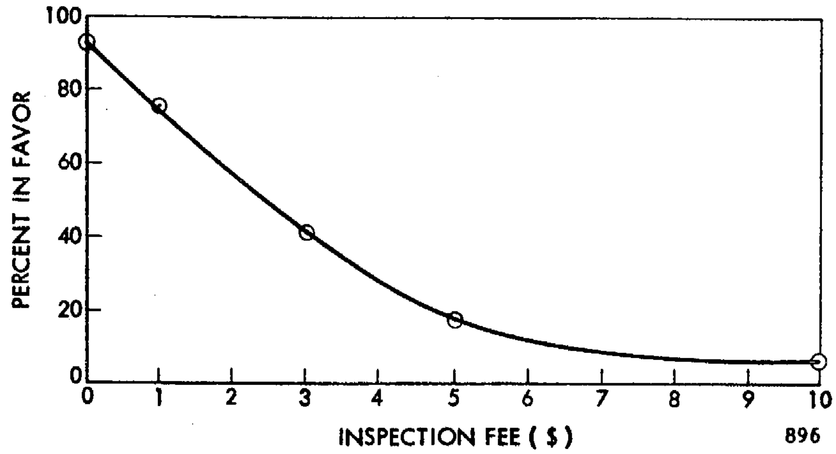

Figure 5-5. POPULATION FAVORING INSPECTION - FEE CHARGED

Considering those that were opposed to an inspection program, 53.5 percent responding would oppose even if there were no inspection fee. If the inspection fee were $1, then 68.1 percent of those opposing would remain opposed. At an inspection fee of $3, 80.3 percent of those opposed would still be opposed. Stated another way, for those not in favor of an inspection program, approximately four out of five would remain opposed if the inspection fee were only $3. With the inspection fee increased to $5, approximately 83 percent would be opposed. At a $10 inspection fee, the percent in opposition would be only slightly higher. If there were no inspection fee, over half of those opposed would still not be in favor of such a program. It appears, then, that those initially opposing an inspection program would find it unacceptable regardless of inspection fee (see Figure 5-6). Another cost that may affect their position would be repair cost.

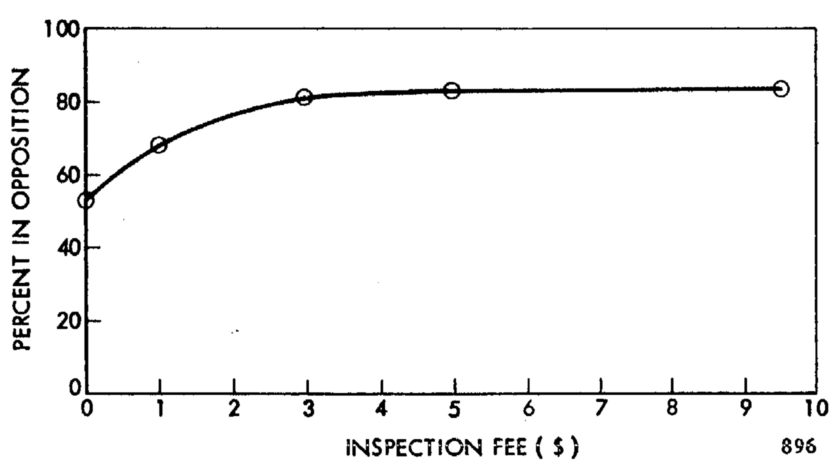

Figure 5-6. POPULATION OPPOSING INSPECTION - FEE CHARGED

Of the same group opposing the program, 59.9 percent would find the program unacceptable if average repair cost was $5. The quantity of people opposing increases to 75.5 percent if the repair cost was $10, and 83.0 percent if the repair cost was $20. Figure 5-7 shows the percent opposing the program as a function of repair cost. From this brief analysis, it is seen that three out of four respondents opposed to an inspection program would object if the inspection fee was $3 or the repair cost was $10.

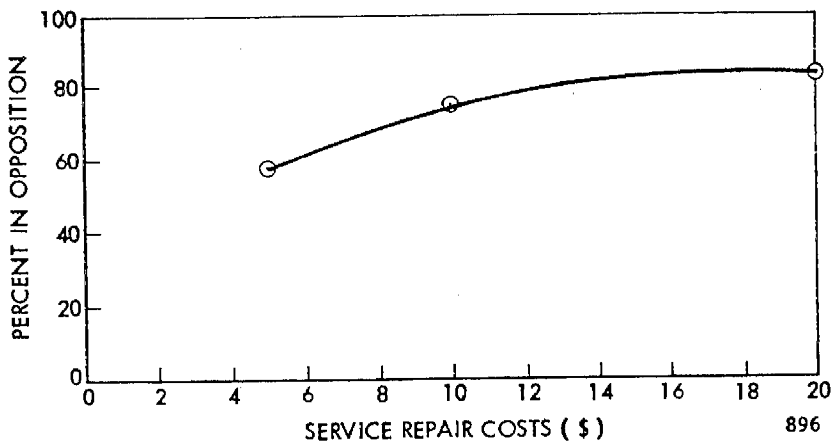

Figure 5-7. POPULATION OPPOSING INSPECTION - REPAIR COSTS

5.3.4.1 Vehicle Owner Cost-Effectiveness Index - The CE of emission inspection and maintenance may be determined in terms of the costs to vehicle owners. Previous sections have identified the average cost to owners for the expected inspection fee and typical service and repair costs. These are direct costs to vehicle owners. To obtain the net cost to the motorist, there are also the fuel savings resulting from vehicle service and repair. Additionally, there are the costs associated with the annual tuneups and maintenance now obviated by the periodic servicing.

In return for these direct and indirect costs, the motorist realizes a reduction in exhaust emissions and some improvement in vehicle performance characteristics. A CE index for the vehicle owner similar to that for the total program may be convenient for comparison purposes. This would correspond to emission reduction per dollar cost. The equation below considers these factors.

$$\text{VOEM} = \frac{\text{ER}}{\text{C}} = \frac{(\Delta\text{HC} + \Delta\text{CO} + \Delta\text{NO}_x)\ \text{M}}{(\text{SRc} + \text{IF} - \text{kFS} - \text{AT})} = \frac{\text{grams pollutant}}{\text{dollars}}$$

where:

VOEM = vehicle owner effectiveness measure
ER = average emission reduction
C = cost (total) to vehicle owner
ΔHC = hydrocarbon emission change, grams per mile
ΔCO = carbon monoxide emission change, grams per mile
ΔNO_x = oxides of nitrogen emission change, grams per mile

M = average mileage annually, 10,000 miles
SRc = service and repair costs as required
IF = inspection fees, annually
FS = fuel savings based on 10,000 miles annually
k = degradation constant based on 10,000 miles
AT = annual tuneup cost obviated by required service

Table 5-6 summarizes the emission changes as a function of test regime, and controlled and uncontrolled vehicles. The average miles driven annually has been defined as 10,000 to correspond with that used to calculate the fuel savings. A degradation factor has been inserted for fuel savings to account for degradation in engine performance as affected by component wear and adjustments. Service repair costs and inspection fees were summarized in paragraph 5.3.1. For the calculations, State owned and operated facilities were considered to determine the inspection fees.

Annual tuneup costs are those normally incurred by an average motorist within a 12- to 24-month periodic cycle. The cost of this tuneup has been estimated at $30, with $15 apportioned annually. Maintenance service data for all test regimes indicate that the Certificate of Compliance did not require tuneups. Consequently, this $15 deduction would not apply to those vehicles under the Certificate of Compliance test regime.

Table 5-6. EMISSION REDUCTION BY TEST REGIME

Test Regime	HC (Grams/Mile)	CO (Grams/Mile)	NO_x (Grams/Mile)
Controlled Vehicles			
C of C	0.73	1.9	(0.23)
Idle Test	1.55	29.0	(0.64)
Key-Mode Test	2.74	30.4	(0.56)
Diagnostic Test	1.49	22.8	(0.63)
AAMP	0.89	4.9	(0.06)
Uncontrolled Vehicles			
C of C	0.63	3.4	(0.14)
Idle Test	4.40	27.7	(0.37)
Key-Mode Test	3.61	45.4	(1.25)
Diagnostic Test	4.70	28.4	(0.63)
AAMP	2.99	15.7	0.05

The effectiveness measure does not consider improvement or degradation in performance which is more of a qualitative appraisal for the great majority of motorists. Additionally, the VOEM does not consider the beneficial effects of State management and surveillance of service and repair activities as imposed during vehicle retesting.

Table 5-7 shows the calculated VOEM as a function of test regime, and controlled and uncontrolled vehicles. The degradation constant, k, was established at 0.67, which reflects a depreciation in fuel savings of 33 percent over the year.

Table 5-7. VEHICLE OWNER EFFECTIVENESS MEASURE (VOEM)

Test Regime	Emission Reduction (x 10^4 Grams)	Cost (Dollars)	VOEM (Grams/Dollars)
C of C			
Controlled	2.40	9.83	2,440
Uncontrolled	3.89	9.28	4,190
Idle Test			
Controlled	29.9	13.10	22,800
Uncontrolled	31.7	9.29	34,200
Key-Mode Test			
Controlled	32.6	1.65	197,000
Uncontrolled	47.8	3.25	147,000
Diagnostic Test			
Controlled	23.7	8.07	29,400
Uncontrolled	32.5	29.97	10,800
AAMP			
Controlled	5.79	2.37	24,400
Uncontrolled	18.7	2.64	70,800

The data shows that Certificate of Compliance is the least cost-effective in terms of vehicle owner consideration. Key-Mode Test exhibits a dramatic superiority over the other alternatives, followed by AAMP. On a relative basis, Idle Test would be ranked below AAMP and ahead of Diagnostic Test. The relative rank order would then be as follows: Key-Mode Test, AAMP, Idle Test, Diagnostic Test, and Certificate of Compliance.

This relative ranking correlates exactly with that shown in Table 5-5, summary of vehicle owner comments. Considering the performance "improved" column, it is noted that the same order is derived by ranking in terms of highest percentage first. That is, the highest percentage of responses in the "improved" column was recorded by Key-Mode Test, followed by AAMP, and so on, ending with Certificate of Compliance. Interestingly, both the quantitative (VOEM) and the qualitative (owner comments) analyses arrived at the same relative rankings.

5.4 STATE AND PRIVATE INDUSTRY PROGRAM PARTICIPATION

It has been shown that it is technically feasible for an inspection program, coupled with directed corrective maintenance and adjustments, to result in reduced emission levels. Both the cost analysis and the CE analysis have indicated the reasonableness of having both State and private industry participate in the total program.

The questions of who should manage the total program, who should own the inspection facilities, and who should operate and maintain the facilities have been addressed or alluded to in various sections and volumes of this report. Functional requirements were discussed in Volume III, where it was essential to identify total program management functions and also inspection facility ownership and operation functions. Based on these requirements, various facilities were configured, along with possible program management structures. These different combinations were then priced and used as inputs to the cost analysis discussed in Section 4; whereas the CE of these combinations were evaluated in an earlier paragraph.

The purpose here is to collect the distributed analyses and summarize the findings to clearly identify and describe the roles of the State and private industry. This discussion begins with a brief functional description of program management, and inspection facility ownership and operation. Following this, a qualitative cost analysis of State and private industry participation is performed, based on the functional allocation. The quantitative cost analysis of the different arrangements as used in the CE discussions are evaluated. The results of the public opinion survey are considered prior to determining the degree of participation that the State and the private sector would have in a statewide inspection program.

5.4.1 Program Administration and Management

Total program management of the statewide inspection system will include the scheduling of vehicles, maintenance of records, establishing and reviewing of emission limits, evaluating current and future instrumentation requirements, and providing for future analysis and development in the areas of methodology and technology. The administration and surveillance of statewide inspection facilities will involve the establishment of qualification criteria for equipment and facilities, evaluation of candidates, and the certification and acceptance of selected units. These functions will be performed during the program lifetime.

At the outset of the program, the management agency will conduct, or will cause to be conducted, the necessary indoctrination, orientation, and training sessions for the general public and the pertinent technical personnel. To assure uniform performance of vehicle inspection for a given test regime, the management agency will issue accepted inspection test procedures to all participating facilities, review initial emission inspection results, and upgrade inspection procedures as required.

5.4.2 Inspection Facilities Ownership and Operation

Inspection facility ownership will include those functions of site acquisition, facility construction, equipment acquisition and installation, and personnel selection and training. Where suitable facilities exist, modifications to accommodate a given test regime may be required. Additionally, special equipments may be required to perform emission inspections. Depending on the test regime implemented, training may be provided by program management or on-the-job by facility management. Facility operation and maintenance will involve performing vehicle emission inspection, consulting with the vehicle owner on test results, and recording and managing inspection data and records. Equipment and facility maintenance functions will be performed by in-house personnel or contracted to service agencies. In addition, there will be the normal business administration functions of paying operating expenses such as salaries, taxes, utilities, expendable supplies, and payments on long-range loans or mortgages; handling and accounting of inspection fees, if required; and other such functions.

5.4.3 Qualitative Cost Comparison

Section 6 of Volume III and Section 4 of this volume address implementation costs to both the State and private industry. The expenditures that were quantified and calculated are the actual estimated and projected costs incurred for a particular arrangement of total program management and inspection facility ownership and operation. That is, no differentiation was made between cost to the State or private industry. Obviously, for total State involvement, including management, ownership, and operation, all costs are financed by the State (excluding the possibility of inspection fees). When the arrangement consists of private ownership and operation of inspection facilities, then direct State finances are necessary only for program surveillance personnel and related costs. The same would apply for State licensing of privately owned and operated facilities.

Table 9-1 of Volume III contains a qualitative comparison of State and private industry as a function of various cost elements. The program cost implications in terms of State finances are evaluated. It becomes readily apparent that if the concern is CE as related to State expenditures, then State surveillance of a program managed by a private enterprise and comprised of privately owned and operated facilities would be the best selection. Contrarily, should the concern be CE in terms of general economy, then total State participation would be the choice.

5.4.4 Cost-Effectiveness Comparisons

Volume III evaluated and compared the test regimes based on different arrangements of management, ownership, and operation of inspection facilities. For each test regime, three basic arrangements were considered: (1) State managed, owned, and operated; (2) private industry managed, owned, and operated; and (3) State managed with licensed, existing, privately owned facilities.

Without exception, it was shown that option (1) with total State participation was the most cost-effective for each of the four test regimes. Option (2) was next, followed by option (3). The principal reason for this outcome can be attributed to the economies of a single agency versus distributed and diverse operations. Total private enterprise participation closely approximates total State participation with a few exceptions. Private industry is profit motivated, pays more taxes than the State, and, by necessity, would have as a parallel management structure the State agency responsible for program surveillance, resulting in duplicate costs to the overall program costs.

State licensing of privately owned inspection facilities would be the most costly since the advantages of large-scale purchasing are not present, and more facilities are required to accommodate the vehicle population due to licensed facilities performing functions other than inspection. This was based on the assumption that maximum utilization of inspection facilities cannot be guaranteed to justify single-purpose licensed facilities. Thus, other services must be provided by these facilities to supplement their income.

5.4.5 The People's Choice

It was determined during the public opinion survey conducted by Opinion Research of California that 76.6 percent of 1000 interviewees believe that a mandatory vehicle emission inspection program is necessary. In addition, if a mandatory program is implemented, 82.1 percent would be in favor, 14.2 percent would be in opposition, and 3.7 percent have no opinion. Of the 1000 people contacted, 56.9 percent thought that the State of California should conduct the program, with 25 percent in favor of private garages and service stations. The remaining 18.1 percent did not know or care.

For those 569 who voted in favor of the State conducting the program, the five dominant reasons for selection were:

a. Have trust in; honest - 13.2 percent
b. Eliminate or cut down grafts, bribes - 13.2 percent
c. Do not trust private garages - 13.0 percent
d. Better enforcement - 10.9 percent
e. Private garages charge too much - 8.4 percent

Considering the 25 percent (250 to 1000) who favored private industry, the five dominant reasons for their selection were:

f. Convenience - 24 percent
g. Save taxpayers money, less cost to State - 12.4 percent
h. Support private enterprise - 11.6 percent
i. Less expensive, cheaper - 9.2 percent
j. Do a better job, generally - 8.8 percent

It is interesting to note that of the five dominant reasons for selecting the State to conduct the program, the first three involve trustworthiness of operating personnel. Those in favor of private industry cite convenience and money as their major reasons. There appears to be a paradox in the responses in that (e) indicates that people are in favor of a State-run program because private industry charges too much, while (i) shows that people are in favor of private industry because they are less expensive. Although the percentages are fairly even (8.4 to 9.2 percent), this is misleading. In actuality, the true quantity would be 8.4 percent of 569 versus 9.2 percent of 250. Thus, contrary to what the percentages indicate, the number of people who believe private industry charges too much exceeds those that believe it would be cheaper.

There were many other questions asked during the interviews. Volume III, Section 7, summarized the pertinent findings, whereas Volume IV, Appendix K, contains the detailed results. If one of the program goals is to satisfy the majority of the population, then perhaps Table 5-8 can be construed as a set of guidelines or requirements.

5.4.6 Recommended Arrangement

The results of the foregoing analysis indicate that the State of California should provide total program management, administration, and surveillance. In addition, it should have responsibility for the facility ownership and operation for the duration of the program. This was shown to be the most cost-effective combination for each of the test regimes. Furthermore, it is the opinion of the public that this would be the most acceptable arrangement, if and when a mandatory program of vehicle emission inspection is implemented.

The service and repair of vehicles that do not meet inspection requirements should be performed by the private sector.

Table 5-8. CONSIDERATIONS FOR A STATEWIDE PROGRAM BASED ON PUBLIC OPINION SURVEY

Characteristics	Majority Opinion	Source* (Table No.)
Program Management	State of California	22
Inspection Facility	State operated	23
Inspection Interval	Once a year	25
Inspection Time Duration	15 minutes or less preferred, not greater than 45 minutes	29, 30, 31
Inspection Fees	$1 or less preferred, no greater than $3	33, 34, 35
Driving Distance to Facility	Not greater than 10 miles	38
Average Repair Costs	$5 or less preferred, not greater than $10	42, 43
Repair Time Allowed	15 days acceptable, 30 days preferred	63, 64
Enforcement Penalties	If necessary, would prefer monetary fines up to $10	65, 66

*Volume IV, Appendix K, Results of Public Opinion Survey, Opinion Research of California

5.5 CONSIDERATION OF UNCERTAINTY FACTORS

The preceding analysis considered the quantitative factors of emission reduction and program cost for each of the five test regimes. Based on operational data and other available information, estimations and projections were made for the next 20 years, beginning in 1972.

There are other factors to be considered in determining which of the five alternatives would be the most suitable to implement. These factors have been classified as uncertainty factors because they consider characteristics relevant to the program and which are dependent on future circumstances. For example, the effects of future regulations and technological advancements cannot be quantified; consequently, their impact on each of the test regimes can be evaluated and compared only on a qualitative basis. In the following paragraphs, these factors are discussed and evaluated.

5.5.1 Effects of Future State and Federal Regulations

Volume III discussed the trends in both State and Federal regulations regarding vehicle emission limits. As the tighter limits are imposed, more extensive instrumentation and better measurement resolution and accuracy would be required. It is also evident that mass emissions (equivalent weight per mile) will remain as the accepted measurement standard.

These tighter emission standards will have a considerable effect on instrumentation requirements by 1975. The constant volume sampling (CVS) emission measurement technique becomes a requirement in 1972. The CVS procedure requires dynamic loading of the vehicle, normally accomplished by a dynamometer. Consequently, AAMP, Certificate of Compliance, and Idle Test would not be applicable to this type of emission inspection.

The Key-Mode and Diagnostic Test regimes both utilize dynamometers, with the former requiring a simpler and cheaper one than that required for Diagnostic or CVS testing. The basic Key-Mode Test dynamometer would require the addition of the capability to adjust loads and inertial weight. Facility requirements would not change significantly for either regime, due to CVS requirements; however, the sampling and instrumentation package, described in Volume III, Section 3, would require an additional $20,000 to $25,000.

The application and degree of end-of-assembly-line (EOAL) testing, as directed by future State or Federal regulations, would directly affect a periodic vehicle inspection program. Assuming that EOAL testing is totally effective in identifying subnormal performance, then grossly malfunctioning components would be corrected at the point of assembly or immediately thereafter. Minor adjustments also would be performed prior to resorting to remove-and-replace activities. It seems conceivable that subsequent inspections on a statewide level would detect adjustments that deviated and/or component deterioration due to wear. The requirements for this type of inspection program would be more of an enforcement of regulations, presently being considered, that would require manufacturers to guarantee a specified emission level over an initial period of the expected life of the vehicle.

5.5.2 Anticipated Future Emission Control Methods

Controlling vehicle emissions on future vehicles will be primarily by catalytic or thermal exhaust conversion plus engine modifications. The engine modifications will probably include fuel injection, atomizing carburetion, exhaust recycling, programmed spark advance, prolonged cylinder dwell time, and hybrid (internal combustion plus electric engines. Additionally, the Wankel rotary engine is currently being introduced and marketed, and shows some promise as a low emitter.

Fuel modifications also would affect pollutants emitted in future vehicles. Based on very limited foreknowledge, it seems that many of the modifications and devices would be intentionally nonoperative during part of a driving cycle. Consequently, it would be necessary to simulate a driving cycle or road conditions to achieve reasonable engine rpm or torque (horsepower) to measure actual emission characteristics.

As an example, some catalytic afterburners are nonoperative at high-temperature conditions to conserve on the catalytic media. Other devices incorporate thermostatic overrides to functionally protect either the engine or the device from failure during above-normal engine operating temperatures. These devices would necessitate engine loading capability to adequately evaluate emission control performance.

5.5.3 Estimation and Projection of Emissions Reduction

Effectiveness calculations were made for two periods of vehicles: 1957-1970 and 1971-1991. Projections for the 1971-1991 model-year vehicles were based on average reductions measured for the 1966 through 1970 vehicles. Although the method was applied equally to each test regime, it must be recognized that the sample size for each regime and for each model-year vehicle was limited.

In view of these uncertainties, the effectiveness projections in Volume III were presented in two formats. One format considered only 1957-1970 vehicles for which emission reductions were measured and calculated. The other format included the 1971-1991 vahicle emission reduction estimates with the measured reductions for the 1957-1970. Doing this, the influence of the estimated projections could be determined. The results of the effectiveness figures indicated that these projections did not alter the ranking of alternatives. Results of this section do not contradict this finding.

5.5.4 Estimation and Projection of Program Costs

All cost inputs obtained were the best figures available, and all total costs were calculated using the computerized cost model. However, some degree of uncertainty exists in the final figures computed, such that the eventual cost of implementing the various configurations of each of the regimes costed may vary to some extent due to varying cost increases with time or conditions in the marketplace.

To account for these uncertainties, a parametric analysis was performed for all variables whose values were determined to be critical in the cost analysis. Land and building costs, equipment costs, and personnel wages and salaries were varied ±20 percent to determine their net effect on total program investment and operating costs. The higher cost figure considered might be more accurate for investment and operating costs as the period of time between study completion and actual program commencement widens. Actual cost variations that may be experienced are particularly crucial in the area of land acquisition, facility construction, and personnel salaries. If these costs do, in fact, vary by as much as the allotted parametric range, the maximum quoted aggregate costs would be experienced. Aggregate land and construction costs are particularly sensitive when cost estimates are based upon a unit cost per square foot. It is for this reason that a 20 percent variability was considered. If as long as 3 years elapse prior to implementation, operating costs, as a function of time alone, may increase by 15 percent due to price escalations. Again, 20 percent was allotted as the maximum variability anticipated.

5.5.5 Private Enterprise Program Participation

In determining the program implementation costs, it was assumed that private industry would participate in varying degrees, depending on type of management, ownership, and operation considered. For the Certificate of Compliance regime, privately owned and operated service facilities are currently licensed. A larger quantity of new or existing facilities would be required to implement a vehicle emission inspection program. Each existing facility owner would be required to invest in specialized emission test equipment costing up to $2000. New facilities would require $3600 in original equipment. Based on the analysis of results obtained during this study, facilities would be under more stringent surveillance than presently imposed to assure desired performance and program effectiveness. Approximately 1366 lanes would be required.

Idle Test regime facilities owners would require investments in site, facilities, and special Idle inspection test equipment. There would be a smaller quantity of lanes required than for Certificate of Compliance due to the shorter inspection time, thus faster throughput rate. New facilities would cost about $20,000 and would require $10,000 for special equipment. Approximately 319 lanes would be required.

Key-Mode Test regime requires more extensive instrumentation than the Certificate of Compliance or Idle Test regimes. Typical new facilities for the private owner and operator would cost $40,000 and would require equipment costs of $13,000. Approximately 398 lanes would be required.

The Diagnostic Test facility would require an acquisition investment of $135,000 for the facility and $32,000 for the inspection equipment. Due to the very low throughput rate, approximately 784 lanes would be required.

The AAMP regime would require an initial investment cost slightly higher than Certificate of Compliance. This difference of approximately 10 percent would be attributable to increased instrumentation and personnel training requirements. Approximately 1366 inspection lanes would be required.

The public opinion survey indicated that vehicle owners are leery of private garages and service stations, especially in terms of corrective maintenance and repairs. Thus, if privately owned inspection facilities are incorporated, it would be almost mandatory for the State to assure that a facility performing inspection does not also perform the recommended service and repairs. This may be very difficult to enforce. Possibilities for collusion and graft exist.

Service facility profits are realized to a greater extent on products sold, rather than on labor charges. It becomes difficult to visualize, then, that many facility owners would be interested in investing thousands of dollars just to provide emission inspection services. Financial disadvantages are least severe beginning with Certificate of Compliance and AAMP, and become increasingly worse with Idle Test and Key-Mode Test, ending with the worst of all, Diagnostic Test.

It could be argued that a mandatory periodic inspection program provides a captive clientele. This may be true to a certain extent. However, there is no guarantee that all participants in a given area will patronize a designated facility. For a given implementation, it is assumed that the State would establish basic inspection fees based on anticipated workload, operating costs, and acceptable profit margin. When variations occur in vehicle throughput and/or operating costs, the profit margin is affected. This may be very oversimplified. The above discussions are a few of the considerations that would determine whether or not necessary private industry participation can be realized to fulfill program implementation requirements for privately owned and operated inspection facilities.

5.5.6 Program Objective - Immediate and Long-Range

The overall program objective is to achieve emission reduction in terms of HC, CO, and NO_x. Measures of effectiveness were calculated based on this objective. The selection between the alternatives will be facilitated by the quantitative CE indices developed as a function of calendar years. What remains is to evaluate these quantitative measures against the program goals.

To start with, is the intent of the program to achieve the greatest reduction of vehicle emissions during the first year or during the first 8 years? If it is during the first 8 years, State owned and operated Key-Mode Test facilities is the most desirable alternative. If the program intent is to achieve the greatest reduction for the least investment cost incurred during the first year of operation, then State owned and operated Idle Test facilities would be the recommended approach. If the program goal is to realize the greatest emission reduction during the next 8 years (beginning in 1972) for the least costs expended, then State owned and operated Key-Mode Test facilities would be the selection.

If the program goal is to achieve reductions in all three pollutants, then none of the test regimes are effective. This is not an indication of test regime deficiency, but more a measure of what is realizable with pre-1971 vehicles that do not have NO_x controls incorporated.

Is the program goal to achieve the most cost-effective solution during the next 20 years by incorporating a statewide inspection program? If this is the objective, then either Key-Mode Test or Idle Test facilities owned and operated by the State should be implemented.

If the intent is to achieve the greatest reduction with the least cost to the vehicle owner in terms of service and repair expense, then Key-Mode Test would be the selection. In paragraph 5.3, it was shown that Key-Mode Test realizes the greatest average emission reduction for the least vehicle owner cost.

In its entirety, this subsection has attempted to raise questions and identify areas of concern that would affect the ranking and selection of the alternatives. The intent is not to invalidate the analyses, but merely to identify areas that are dependent on future circumstances, but which affect current decisions.

5.6 RESULTS OF THE COST-EFFECTIVENESS ANALYSIS

The CE analysis of the test regimes has shown that State management, ownership, and operation of inspection facilities is the most desirable. Regardless of the test regime type considered, a State regulated program featuring private industry management, ownership, and operation of inspection facilities was ranked next in order. The least cost-effective approach was State management of existing, licensed inspection facilities owned and operated by private industry.

The relative CE ranking of the five alternative test regimes evaluated was as follows: Key-Mode Test, Idle Test, AAMP, Diagnostic Test, and Certificate of Compliance.

5.6.1 Key-Mode Test

The Key-Mode Test regime exhibited the greatest emission reduction for the resources and funds expended when compared with four other alternative test regimes. It is a highly developed and refined procedure, first introduced by the Clayton Manufacturing Company. The inspected vehicle is driven under simulated road conditions. Using three modes of operation (idle, low cruise, and high cruise), the vehicle is then monitored and exhaust gases sampled. An integral part of the inspection test procedures is a set of tables that relate excess emission levels of HC and CO to specific areas of vehicle service and repair. Reference to supplementary charts enables maintenance personnel to perform rapid and accurate service and repair.

Short inspection times (an average of 5 minutes per vehicle), coupled with explicitly defined areas of service and repair, result in lowering emissions to desired levels while keeping costs to a minimum.

The fast throughput rates per inspection facility result in efficient and economical station operation and lower total program costs. It was shown that Key-Mode Test realized the greatest emission reduction per vehicle owner cost. Considering the potential fuel savings per serviced vehicle, Key-Mode Test is the most cost effective in terms of emission reductions per vehicle owner cost and benefit. A survey of those vehicles serviced by the Key-Mode Test procedure revealed that 71.1 percent of the owners considered the post-service performance to have improved, while 17.8 percent believed no change or degradation in performance occurred.

5.6.2 Idle Test

The Idle Test regime was the second most cost-effective method. The total program effectiveness data (emission reduction achieved) showed that Idle Test was slightly less effective than Key-Mode Test. Correspondingly, the cost analysis showed that Idle Test was slightly less costly than Key-Mode Test. In terms of vehicle owner CE, Idle Test ranked below Key-Mode Test and AAMP.

The advantages of an Idle Test and inspection program are that the technicians conducting the tests are equipped with established procedures and equipment to properly service a vehicle with the intention of reducing emissions and without sacrificing vehicle performance. Technicians trained in the proper use of the Idle Test equipment can perform rapid emission measurements, interpret the results, and diagnose causes of excessive emissions. Both the equipment and the procedures are easy to use.

The Idle Test regime inspection does not require extensive testing of the vehicle to determine various operating levels of emissions, as does the Key-Mode Test. Consequently, the failure detection methods of isolating the cause of excess emission is also less extensive. These characteristics are reflected in the effectiveness measures and vehicle owner cost data which revealed that Idle Test achieved less emission reduction per vehicle owner cost than did Key-Mode Test.

5.6.3 Annual Adjustment and Maintenance Procedure (AAMP)

The AAMP regime is similar to the Idle Test regime in that it is statically performed and does not require a dynamometer. The test vehicle is brought to the proper engine operating temperature, and the HC, CO, and rpm readings are taken at idle setting. Prior to performing any adjustments to achieve lower emissions, as required, the PCV valve and other components related to emission control are inspected.

Following these steps, the idling rpm and dwell angles are noted and adjusted to manufacturer's specifications when required. Timing is checked and adjusted only if advanced beyond recommended limits. Using the HC and CO instruments, the technician then adjusts the carburetor idle mixture.

To assist the technician in troubleshooting vehicles that do not respond favorably to the idle adjustments, some guidelines are provided that delineate common cause-and-effects relationships. With the HC and CO instruments to assist in diagnosis, the technician using an oscilloscope can readily detect malfunctions and maladjustments. Additionally, idling the vehicle at 2500 rpm provides the technician with supplemental data for diagnostic purposes.

The AAMP regime is less effective than Key-Mode Test or Idle Test on a total emission reduction basis. Further, it would be more costly to initially implement and to continually operate than the previous test regimes. Consequently, on a program CE basis, AAMP would rank third. On an individual motorist basis, AAMP would rank slightly below the Key-Mode Test regime.

5.6.4 Diagnostic Test

The Diagnostic Test depends on the training, experience, and technical judgment of a skilled diagnostician to evaluate engine performance and to determine causes for excessive emission levels. To assist him, the diagnostician has various instrumentation and documentation available to identify and classify malfunction symptoms, along with service and repair actions required.

Results of efforts to reduce emissions on the test vehicles tend to indicate that relying on the technical personnel staff to identify causes for excessive emission levels was not effective. Theoretically, a Diagnostic Test should be as effective as a Key-Mode Test, because both rely on simulated road-load conditions of the tested vehicle, using a dynamometer to identify malfunctions and maladjustments.

Failure diagnosis for the Key-Mode Test is facilitated through the truth charts which were developed by skilled diagnosticians interpreting operational test data. Diagnostic Test relies on the charts accompanying the separate instrumentation equipment, and, to a large extent, on the training, education, and experience of the technical staff. It is not as regimented as Key-Mode Test diagnostics, which may or may not be an advantage. Although there are some benefits to flexibility, Diagnostic Test effectiveness results indicated that the formal methods of Key-Mode Test are more desirable.

In terms of CE, the Diagnostic Test regime was ranked lower than Key-Mode Test, Idle Test, and AAMP, due to its relatively low vehicle throughput and extensive instrumentation. More and larger facilities were required to accommodate the inspected vehicles, and expenditures were much higher for annual operating costs. Combining the relatively low effectiveness with high operating and investment costs, the Diagnostic Test regime was ranked below Key-Mode Test, Idle Test, and AAMP.

5.6.5 Certificate of Compliance

The Certificate of Compliance was relatively ineffective in achieving emission reductions. This is understandable since this test regime does not specify acceptable levels of HC, CO, and NO_x. Certification requirements, if satisfied, assured that exhaust control devices and emission control systems were operating according to manufacturer's specifications. Additionally, an implicit requirement was that the engine also was operating according to manufacturer's specifications. However, as determined from post-service seven-mode tests, engine operation did not meet these specifications in all cases.

The CE analysis indicated that Certificate of Compliance was the least desirable of the regimes evaluated, even if the service cost is considered as part of the anticipated inspection fee. It realized a relatively low effectiveness measure and a comparatively high annual operating cost on a total program basis.

SECTION 6

CONCLUSIONS

This section identifies and summarizes the conclusions derived from the various tasks performed and described in the preceding sections and volumes. Entries with (••) have been added to, or modified from, those in Volume III, previously submitted in June 1971.

6.1 INSTRUMENTATION SURVEY

Results of the instrumentation survey indicated the following:

- Equipment and technology are presently available to perform vehicle emission inspection for each of the test regimes

- A statewide network of inspection facilities will necessitate minor modifications to these equipments

- Additional effort will be required to integrate these various equipments into a workable and efficient system

- Development effort will be required in the following areas:

  a. Validation of O_2 as a reliable measurement of exhaust dilution
  b. Prototype instruments for measurement and data recording systems.

6.2 FACILITY REQUIREMENTS

Results of the requirements analysis indicated that the following facilities would be required to implement a statewide network:

- Certificate of Compliance would require 1366 lanes, each capable of processing 30 vehicles per 8-hour day

- Idle Test would require 319 lanes, each capble of processing 127 vehicles per 8-hour day

- Key-Mode Test would require 398 lanes, each capable of processing 100 vehicles per 8-hour day

- Diagnostic Test would require 784 lanes, each capable of processing 52 vehicles per 8-hour day

•• AAMP would require 1366 lanes, each capable of processing 30 vehicles per 8-hour day.

6.3 INSPECTION PERSONNEL REQUIREMENTS

Results of the personnel requirements analysis indicated the following:

- Each Certificate of Compliance test lane would require at least one technician. Training sessions would be approximately 116 hours per technician.
- Each Idle test lane would require two technicians, each with a different technical skill level. Total training required would be approximately 87 hours per technician.
- Each Key-Mode test lane would require two technicians, each with a different technical rating. Training period would be approximately 142 hours total per technician.
- Each Diagnostic test lane would require four technicians, comprised of two diagnosticians, and one each of lower technical ratings. Training requirements would amount to 174 hours per technician.
- Each AAMP test lane would require at least one technician. Training sessions would be approximately 174 hours per technician.

6.4 EFFECTIVENESS OF INSPECTION AND MAINTENANCE

Test regime effectiveness was measured in terms of emission reduction achieved as related to hydrocarbons, carbon monoxide, and oxides of nitrogen. It was shown that:

- All test regimes are effective in achieving reductions in HC and CO, but to different extents.
- All test regimes are ineffective in reducing oxides of nitrogen emissions, but to different extents.
- Fifty percent of total emission reduction achieved will be realized from the South Coast Basin, Air Basin 1.
- Eighty percent of achievable effectiveness would be realized from the three largest basins, 92 percent from the five largest basins.
- Listed in order of greatest emission reduction achieved, the test regimes are: Key-Mode, Idle, Diagnostic, AAMP, and Certificate of Compliance.
- Listed in order of greatest HC reduction achieved, the test regimes are: Key-Mode, Idle and Diagnostic essentially equal, AAMP, and Certificate of Compliance.
- Listed in order of greatest CO reduction achieved, the test regimes are: Key-Mode, Idle, Diagnostic, AAMP, and Certificate of Compliance.
- None of the test regimes was effective in achieving reductions in NO_x.
- Listed in order of least degradation to NO_x emissions, the test regimes are: AAMP, Certificate of Compliance, Diagnostic, Idle, and Key-Mode.

- Service beyond the initial repair and adjustment should not be a requirement for vehicles failing emission inspection.

- •• Emission degradation is partially dependent on mileage driven; other factors also contribute to the degradation.

- •• There is no significant difference between test regimes in emission degradation patterns as a function of mileages.

- •• The overall emission degradation for vehicles over 10,000 miles was determined to be 25 percent for HC, 44 percent for CO, and -17 percent (an improvement rather than degradation) for NO_x.

6.5 COST ANALYSIS

Results of the cost analysis for total program implementation revealed that:

- Least total cost would be a State-managed program with State ownership and operation of inspection facilities.

- Second least costly would be a State-regulated network of privately managed, owned, and operated new inspection facilities.

- Most costly would be a State-managed program comprised of licensed, existing inspection facilities privately owned and operated.

- Approximately 90 percent of total program cost is incurred by the five largest air basins.

- •• Emission inspection fees for each test regime would be as follows:

Test Regime	State-Owned, Operated	Private-Owned, Operated	State-Managed, Licensed
Certificate of Compliance	$2.31	$2.94	$ 9.00
Idle	0.96	1.22	6.00
Key-Mode	1.05	1.33	6.00
Diagnostic	3.07	3.90	12.00
AAMP	2.31	2.94	9.00

- Additional service and repair average costs exceed first or single service average cost. Average emission reduction achieved for additional service does not justify cost.

- •• Vehicle owner service and repair average costs would be as follows.

Test Regime	Controlled Vehicles	Uncontrolled Vehicles
Certificate of Compliance (including inspection fee)	$ 8.65	$ 8.40
Idle	36.00	33.40
Key-Mode	26.70	32.10
Diagnostic	27.10	53.30
AAMP	17.10	22.00

6.6 PUBLIC OPINION SURVEY

Results of the survey indicated the following:

- Three-fourths of vehicle owners believe a mandatory vehicle emission program is necessary.
- Primary advantages of inspection program as viewed by vehicle owners would be: (1) reduction in air pollution, (2) force people to repair their cars, and (3) detection of defective vehicles.
- Disadvantages of program would be expenses and inconvenience.
- More than half of those interviewed believe the program should be conducted by the State of California rather than private garages or service stations.
- Main reason for selecting the State to run the program was that people do not trust private garages or service stations.
- Main reason given for those selecting private industry was for the convenience factor.
- More than three-fourths of vehicle owners believe inspections should be required at least once a year.
- Majority of vehicle owners interviewed would continue to favor the program if the following conditions existed:

  a. Inspection took 30 minutes or less
  b. Inspection fee were $1.00 or less
  c. Driving distance to inspection facility were 10 miles or less
  d. Average repair costs were $10.00 or less.

- Acceptable length of time allowed to repair vehicle would be 15 days; majority would prefer 30 days.

6.7 COST-EFFECTIVENESS ANALYSIS

Results of the cost-effectiveness analysis indicate the following:

- State-managed, owned, and operated inspection facilities are the most cost effective, regardless of test regime implemented.

- State-regulated, privately-administered, owned, and operated newly constructed inspection facilities would rank second.

- State-managed, privately owned and licensed, existing or modified facilities would be least cost effective.

- •• Key-Mode is the most cost effective among the test regimes considered during the first 7 years of total program life.

- •• Idle Test is the next most cost-effective test regime, and is slightly more cost effective than Key-Mode after the first 7 years of operation through program duration.

- •• Diagnostic Test is less cost effective than Idle, but is more cost effective than AAMP and Certificate of Compliance.

- •• Certificate of Compliance is the least cost effective of the five test regimes evaluated.

- •• Vehicle owner effectiveness measures considering emissions, vehicle performance, direct costs, and fuel economy would rank the alternatives from top to bottom as follows: Key-Mode, AAMP, Idle, Diagnostic, and Certificate of Compliance.

6.8 STATE VERSUS PRIVATE INDUSTRY PROGRAM PARTICIPATION

The merits of State and private participation in a statewide inspection program were determined as follows:

- Cost analysis indicated that State management of inspection facilities, owned and operated by the State, would be the least costly.

- Cost-effectiveness analysis indicated that State-managed, owned, and operated inspection facilities would be the most cost effective.

- Public opinion survey established that the majority would prefer that the State manage and operate the inspection facilities.

- Least-cost program in terms of State finances would be privately owned and operated inspection facilities regulated and monitored by a State agency.

6.9 GENERAL RESULTS OF THE TECHNICAL AND ECONOMIC FEASIBILITY ANALYSES

The general results of the technical, economic and public acceptability analyses were that:

- It is technically feasible to achieve vehicle emission reductions with each of the 5 test regimes.

- The total program implementation costs favor State-managed, owned, and operated inspection facilities.

- •• The most cost-effective test regime is Key-Mode, when considered over the first 7 years of operation.
- •• The closest competitor to Key-Mode is Idle Test which is slightly more cost effective than Key-Mode after 7 years.
- • The most cost-effective arrangement would be to implement Key-Mode inspection facilities managed, owned, and operated by the State of California.
- • The expected inspection fee per vehicle owner under this arrangement would be $1.05 annually.
- •• The expected repair cost for a failed, controlled vehicle would be $26.70, and $32.10 for an uncontrolled vehicle.
- •• The typical annual fuel saving realized for a service controlled vehicle would be $11.20, and $15.00 for uncontrolled vehicles.
- • The average driving distance for a vehicle owner would be 10 miles.
- • Average inspection time is 4.8 minutes.
- •• Seventy-one percent of those vehicles serviced by Key-Mode will result in improved performance according to the owners opinions; 18 percent of the owners will note no change or degradation in performance.

SECTION 7

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APPENDIX A
CERTIFICATE OF COMPLIANCE PROCEDURES FOR PARTICIPATING GARAGES

A. PROCEDURES

1. Perform the existing "Certificate of Compliance" inspection and repair per HPH 82.1, "Handbook for Installation and Inspection Stations."

2. When vehicle is ready for certification, complete necessary certificate and/or forms and return one copy to Northrop Corporation. Name and address will be Northrop Corporation.

3. If no certification can be achieved, describe reasons why.

B. EXCEPTIONS

1. If an emission control device is physically missing from the vehicle, do not install a new one; however, perform as much of the Certificate of Compliance as possible, as indicated in Item A above.

MODIFIED CERTIFICATE OF COMPLIANCE PROCEDURE FOR PREEXHAUST CONTROLLED VEHICLES

Scope: These instructions apply to all passenger cars which do not have emission exhaust controls. This includes those with and without PCV valves.

Station License: Stations performing this work will be licensed Class A stations per CHP Handbook HPH 82.1.

Certificates: No Certificate of Compliance will be issued for cars tested to this procedure.

a. Identify the device by trademark or name, model, valve part number, etc. Check to see that it is on the list of certified devices. (Annex B or C, as appropriate, for used vehicles or for factory installation.)

b. To check control valve operation, disconnect the tube to the air cleaner.

c. With engine warm, run at idle and visually inspect for improper operation which may be indicated by the outflow of blowby gases from the tube or any engine opening. With thumb or finger, momentarily close off the inlet to the valve or orifice connected to the intake manifold; you should be able to feel suction. If you don't, the valve is clogged.

d. With the transmission in neutral and parking brake applied, open the throttle momentarily and again visually inspect for outflow of blowby gases.

e. In case the device does not pass the tests of items (c) and (d), inspect the valve or orifice for cleanliness. Clean or replace as required.

f. Follow the device manufacturer's instructions for checking and for cleaning or replacing parts. Dust, dirt, and deposits may accumulate within the device. After substantial use, parts of the device may require cleaning or replacing, including the valve, crankcase breather elements, flame arresters, carburetor air cleaner elements, air/oil separators, etc.

g. Follow the manufacturer's instructions in servicing these parts to assure their proper functioning. Make sure that the valve is not installed backwards and that the flame arrester (if used) is installed. Check to see that the proper closed or restricted breather cap is installed if specified by the manufacturer.

h. Disconnect distributor vacuum line(s) and plug at carburetor or manifold. With engine at idle speed, or speed recommended by manufacturer, observe ignition timing with timing light. Reset if variation is greater than plus or minus three degrees from manufacturer's specification.

Check the mechanical advance by watching the timing marks advance as you increase the engine speed to approximately 2,000 rpm. With the engine still running at approximately 2,000 rpm, reconnect vacuum line(s) and observe additional advance of the timing marks indicating proper operation of the vacuum advance mechanism. Operate the engine at idle speed. If the distributor has a vacuum retard diaphragm, the timing should now be retarded 6 degrees or more from the basic setting.

i. Use an exhaust analyzer to read idle air-fuel ratio. If it is richer than 12.5 or leaner than 13.5, adjust carburetor idle mixture screw(s) slowly until air-fuel ratio is between these limits. Allow time for analyzer to respond to carburetor adjustment. Don't idle for more than three minutes because high underhood temperature will enrichen the mixture and the thermostatic valve may advance the spark.

j. Check the idle speed with a tachometer. With automatic transmission, select drive range or park position as specified by manufacturer. Adjust idle speed to a speed no slower than manufacturer's recommendation.

APPENDIX B

ANNUAL ADJUSTMENT AND MAINTENANCE TEST PROCEDURE FOR PARTICIPATING GARAGES

JULY 12, 1971

The following test, adjustment, and repair procedure is recommended to bring the vehicle within prescribed emission levels. Only those adjustments or repair actions required to correct emissions are to be accomplished. Use attached data sheet to record emission measurements and return to Northrop.

A. PRE-TEST

Prepare vehicle and equipment for test.

1. Test Equipment - Service, warm up, and calibrate HC/CO test equipment per manufacturer's specifications.

2. Test Vehicle - Verify engine is at normal operating temperature (warm up as required).

3. Hookup - Insert probe in exhaust pipe (driver side if dual exhaust) and hook up tachometer per manufacturer's instructions.

B. TEST

1. Idle RPM - Operate engine at idle RPM (in drive, if automatic transmission); record RPM, HC, and CO measurements on data sheet.

C. ADJUST

Before any adjustments are made, perform the following:

1. Inspect crankcase control system to ensure proper operation. Clean or replace PCV valve, if necessary.

2. If vehicle is equipped with air-injection system, perform the following:

   With engine stopped, inspect installation of air pump and hose connections to antibackfire valve, check valves, and air distribution manifolds. All connections should be tight and air pump drive belt tension should be within manufacturer's specification.

3. If vehicle has engine-modification system, perform the following:

   With engine stopped, inspect for proper vacuum connections to thermostatic spark advance valve (if used), deceleration spark advance valve, distributor, etc.

Adjustment Procedure

1. RPM - Adjust RPM (if required) to 550 RPM or to manufacturer's specification, whichever is higher.

2. Ignition (HC) -

   a. Check dwell. If dwell is not at manufacturer's specification, adjust as required.

b. Check timing per manufacturer's procedure. If timing is advanced, adjust to manufacturer's specification, and readjust RPM, if required. If timing is retarded, make no adjustment.

3. Carburetion (CO) -

a. Adjust idle mixture to manufacturer's specification for controlled vehicles. For uncontrolled vehicles and where no specifications are available, use: 2.0 to 5.0 percent CO for uncontrolled vehicles and 1.0 to 4.0 percent CO for controlled vehicles. Readjust RPM, if required.

NOTE: When adjusting idle CO, attempt to reduce CO to lowest possible value, consistent with good idle quality. Avoid a rough idle condition, side-to-side unbalance or increase in HC (HC increase indicates a lean idle misfire).

b. Measure idle HC, CO, and RPM and record on data sheet.

D. REPAIR

Diagnose and repair engine as follows:

1. Ignition system analysis (oscilloscope).
2. Inspect one spark plug. Service or replace set, if necessary.
3. Check exhaust valve conditions by using power drop tester on diagnostic console. A 2 percent variation in speed drop indicates valve problem. If valve work is indicated, contact Northrop for instructions.
4. Measure CO at 2500 RPM, no load, and record. If CO reading is greater than idle reading, a plugged air filter or carburetor power circuit malfunction is indicated. Repair as required.
5. Check and free (if necessary) heat riser.
6. After repair, measure idle HC, CO, and RPM and record on data sheet.

Helpful Hints

High HC - Indications are caused by ignition misfires, advanced ignition timing, exhaust valve leakage, and over-lean mixtures. Ignition misfires can be idagnosed by use of oscilloscope; timing problems by use of timing light. Valve failure is indicated by cylinder balance testing with compression test verification. Lean misfire is caused by too lean idle mixture setting or manifold vacuum leaks.

High CO - Can be caused by abnormally restricted air cleaner, stuck or partially closed choke, or carburetor idle circuit failure. Rough or erratic idle can be caused by PCV valve malfunction. Idle HC/CO failure/malfunction Truth Table can be used as a guide to identify failures.

MALFUNCTION TRUTH TABLE

Malfunction	HC		CO		Rough Idle
	High	Very High	High	Very High	
PCV Valve Dirty/Restricted			X		X
Air Cleaner Dirty/Restricted			X	X	
Choke Stuck Partially Closed				X	
Carburetor Idle Circuit Malfunction	X		X		X
Intake Manifold Leak	X	X			X
Ignition Timing Advanced	X				
Leaky Exhaust Valves	X	X			X
Ignition System Misfire	X	X			X

INSPECTION AND REPAIR DATA SHEET

Car Number: ____________ License Number: ____________ Test Date: ____________

(A) TEST

RPM ____________; HC ____________ ppm; CO ____________%

(B) ADJUST

RPM ____________; HC ____________ ppm; CO ____________%

(C) REPAIR

RPM ____________; HC ____________ ppm; CO ____________% Idle RPM

CO ____________% 2500 RPM

Idle RPM: ☐ OK

☐ Adjusted

Timing: ☐ OK

☐ Adjusted

Dwell: ☐ OK

☐ Adjusted

REMARKS: ____________

APPENDIX C
IDLE TEST PROCEDURES FOR PARTICIPATING GARAGES

IDLE EMISSION TEST, ADJUSTMENT, AND REPAIR PROCEDURE

FOR

PARTICIPATING GARAGES

The following test, adjustment, and repair procedure is recommended to bring the vehicle within prescribed emission levels. Only those adjustments or repair actions required to correct Idle emissions are to be accomplished. Use attached data sheet to record emission measurements.

A. PRE-TEST

Prepare vehicle and equipment for test.

1. Test Equipment - Service, warm-up, and calibrate Sun HC/CO test equipment per manufacturer's specifications.

2. Test Vehicle - Verify engine is at normal operating temperature (warm-up as required).

3. Hook-Up - Insert probe in exhaust pipe (driver side if dual exhaust), hook-up tachometer per manufacturer's instructions.

B. TEST

Perform HC/CO and RPM measurements and compare to Idle Test Standards.

1. 2500 RPM - Operate engine in neutral at 2500 RPM, record HC/CO.

2. Idle RPM - Operate engine at Idle RPM (in drive if automatic transmission), record measurements.

3. Compare - Idle RPM emissions to test standards and record manufacturer's specified RPM; if HC or CO is high, adjust per Step C. If HC and CO are within limits return vehicle to Northrop.

C. ADJUST

Perform engine adjustments for HC/CO.

Note: When any adjustment step brings emissions within limits STOP procedure at that point and re-test per Step B.

Adjustment Procedure

1. RPM - Adjust (if required) to manufacturer's specifications; recheck HC and CO and record.

2. HC - Check timing per manufacturer's procedure and record. If timing is not at manufacturer's specification, adjust as required; re-adjust RPM, if required; re-check HC/CO and record.

3. CO

(a) Adjust Idle mixture to manufacturer's specification. Where no specifications are available use: 2.0 to 5.0% CO for uncontrolled vehicles and 1.0 to 4.0% CO for controlled vehicles. Re-adjust RPM, if required.

Note: When adjusting Idle CO, attempt to reduce CO to lowest possible value, consistent with good Idle quality. Avoid a rough Idle condition, side to side unbalance or increase in HC (HC increase indicates a lean idle misfire).

> If CO/HC emissions cannot be reduced to within limits, while maintaining acceptable Idle quality; diagnose and repair (Step D) vehicle as required. ONLY those repairs necessary to bring Idle HC/CO within limits are to be accomplished.

(b) After adjustment, enrichen mixture slightly to avoid too lean a condition. Recheck HC/CO and record.

D. REPAIR

Diagnose and repair engine; when repair is complete re-test per Step B.

1. Diagnose Engine.

2. Repair malfunction per manufacturer's specifications.

3. Retest per Step B, record measurements.

4. If emission limits cannot be achieved within the reapir constraints imposed by Northrop, contact Northrop immediately for disposition.

HELPFUL HINTS

High HC - Indications are caused by ignition misfires, advanced ignition timing, exhaust valve leakage, and over-lean mixtures. Ignition misfires can be diagnosed by use of the oscilloscope. Timing problems by use of timing light. Valve failure is indicated by cylinder balance testing with compression test verification. Lean misfire is caused by too lean Idle mixture setting or manifold vacuum leaks.

High CO - Can be caused by abnormally restricted air cleaner, stuck or partially closed choke or carburetor Idle circuit failure. Rough or erratic Idle can be caused by PCV valve malfunction. Idle HC/CO failure/malfunction Truth Table can be used as a guide to identifying failures.

MALFUNCTION TRUTH TABLE

Malfunction	HC		CO		Rough Idle
	High	Very High	High	Very High	
PCV Valve Dirty/ Restricted			X		X
Air Cleaner Dirty/ Restricted			X	X	
Choke Stuck Partially Closed				X	
Carburetor Idle Circuit Malfunction	X		X		X
Intake Manifold Leak	X	X			X
Ignition Timing Advanced	X				
Leaky Exhaust Valves	X	X			X
Ignition System Misfire	X	X			X

IDLE INSPECTION DATA SHEET

Car Number: 1297 License Number: KAE 058 Test Date: 12/22/70

TEST

1. RPM 2500; HC 1800 ppm; CO 2.5 %
2. RPM 900 ; HC 1300 ppm; CO 7.5 %
3. RPM 550 Mfg. Spec.; HC 700ppm max.; CO 5.0%max. (Uncontrolled Standard)

~~HC 250ppm max.; CO 4.0%max. (Controlled Standard)~~

ADJUST

1. (Idle Speed) RPM 550 0 to + 50; HC 1200 ppm; CO 5.7 %
2. (Timing) Mfg. Spec. 8 °TDC; Engine Timing 12 °TDC

   RPM 550 ; HC 975 ppm; CO 7.5 %
3. (CO) RPM 2500 ; HC 900 ppm; CO 6 %

REPAIR

3. RPM: 550 ; HC 650 ppm; CO 4.5 %

REMARKS: This car is suffering from very poor maintenance. After major tune-up, car went into specs, however after prolonged idle period hydrocarbon and CO increases. Suggest customer drive car period of time and recheck later to see if carbon that is holding rings to pistons dissipates

Cone Chevrolet

APPENDIX D
KEY-MODE REPORT CARDS AND REPAIR PROCEDURES

1. An emission test report card will accompany each vehicle which requires adjustment and/or repair. A sample report card is attached.

2. This report card will be used in conjunction with the Key-Mode Truth Charts instruction book published by Clayton.

3. The corresponding truth chart (found in the instruction book) will be used to assist in diagnosing the problem. Only those repairs suggested should be performed.

4. After repair, the suggested adjustments (timing, speed, and carburetor) will be made before returning vehicle to Northrop. Record results on attached data sheet.

KEY MODE REPORT CARD

CAR NUMBER____________ YEAR_________ CONTROLLED ☐

	IDLE	LOW CRUISE	HIGH CRUISE
- CO - CARBON MONOXIDE	3.0%	2.5%	2.0%
- HC - UNBURNED HYDROCARBON	290ppm	240ppm	220ppm

✓ = REJECT

After final repair or adjustment, insure that the following adjustments are within manufacturer's specification.

Idle Speed_________ RPM; Timing_________ ° TDC; Carburetion_________ A/RF

Remarks:____

KEY MODE REPORT CARD

CAR NUMBER__________ YEAR__________ UNCONTROLLED ☐

	IDLE	LOW CRUISE	HIGH CRUISE
- CO - CARBON MONOXIDE	5.5%	3.5%	3.0%
- HC - UNBURNED HYDROCARBON	700ppm	450ppm	450ppm

✓ = REJECT

After final repair or adjustment, insure that the following adjustments are within manufacturer's specification.

Idle Speed________ RPM; Timing__________ ° TDC; Carburetion__________ A/FR

REMARKS:______________________________

Clayton

MANUFACTURING COMPANY

EL MONTE, CALIF.

KEY MODE TRUTH CHARTS

THE CLAYTON MFG. CO.
EL MONTE, CALIFORNIA, U. S. A.

PRINTED IN U.S.A.

TRUTH CHARTS

(For Use In Conjunction With The Inspection Report Card Of The Key Mode Emission Evaluation And Repair System)

IMPORTANT: Read the Introduction and Chart Usage before attempting to use the Truth Charts.

INTRODUCTION

The Key Mode System operates the engine in carefully selected modes that have been found to most reliably cause emission related engine malfunctions to occur. Abnormal gas content indicates the presence of a malfunction. The mode or modes in which they occur are indications of the type of malfunctions or maladjustments.

The Truth Charts are designed as an aid to mechanics in determining the type of malfunction that is causing unnecessarily high exhaust emission. They will direct the mechanic's attention to the mode of engine operation in which the fault exists, and indicate the malfunctioning system that needs repair or adjustment.

The mechanic must understand the fundamental causes of unnecessarily high Carbon Monoxide (CO) and Hydrocarbons (HC) if he is to be effective in repairing engines to reduce exhaust emissions. Engine exhaust emission is a new parameter to practically all mechanics.

The fundamental difference between causes of high CO and high HC is as follows:

CARBON MONOXIDE (CO)

CO is a result of incomplete combustion. That is, the gas must be subjected to combustion in order to form CO. If the mixture is too rich, there is insufficient Oxygen (O_2) to complete the combustion, thus large amounts of CO result instead of the optimum condition of Carbon Dioxide (CO_2) formation. There will always be at least a small amount of CO in the exhaust because perfect combustion is not to be expected. Abnormally high CO can <u>only</u> be due to excessively rich Air/Fuel mixture.

INTRODUCTION (Cont'd)

HYDROCARBON (Gasoline is essentially 100% Hydrocarbon)

A modest amount of HC will always be present in the exhaust gas. This is a result of both incomplete combustion and fuel at the flame boundries that has not been fully subjected to combustion. When CO is normal and grossly high HC is present, an abnormal amount of raw fuel is escaping from the combustion chamber without being subjected to combustion. This is generally due to ignition misfire or leaking exhaust valves. Moderate rise in HC can result from early ignition timing, preignition causing abnormal flame propagation, or Air/Fuel mixture being too lean to consistently support combustion.

High HC and CO may exist in any one mode of engine operation, any combination of two modes or in all modes. A basic knowledge of these patterns and their meaning is important.

TRUTH CHART USAGE

The master Truth Charts, pages 8 to 14, show reject patterns resulting from various types of malfunction or maladjustment. When a test report is received on a vehicle, its reject boxes (✓) act as a repair guideline for the servicing agency by comparing it to a similar master Truth Chart. The mechanic will quickly learn to diagnose without the example cards if he remembers the fundamental difference between causes of high CO and HC, and understands the engine operating conditions represented by the Idle, Low Cruise, and High Cruise boxes of the Report Card.

The Idle Mode, as its name implies, is with normally closed throttle, thus the engine is operating at or near the conditions where basic engine adjustments are made. The high intake manifold vacuum at idle or at higher free-running engine speeds result in a relatively low compression pressure in which the spark plug fires.

The High Cruise Mode tests the engine at a point where the intake manifold vacuum is down, thus compression pressure is up. The air flow through the carburetor has increased so that the main jet system of the carburetor is in full operation. Speed and vacuum signals have changed the ignition advance. In other words, it provides dynamic test data to expose malfunctioning engine systems that are not responding properly to the signals from increase in speed and air flow.

The Low Cruise Mode is in the transition range of speed and power between Idle and High Cruise. As a general statement, the carburetor is blending the idle and main jet fuel supply. Also, with only a modest ignition advance due to speed, the vacuum advance is at or approaching maximum. Compression pressures have increased moderately from idle conditions. Engines that "stumble" or otherwise malfunction as they come off idle, are most likely to be exposed at this "mid-power, mid-speed" point.

> NOTE: The Key Mode Truth Chart can be used with all internal combustion gasoline engines. For simplicity, the numbers have been left out of the Truth Charts. Make repair based on those boxes which have been checked (✓).

EXAMPLE REPORT CARDS

(Pages 5 and 6)

The two following example Report Cards are similar to the Report Card that will be received from the inspecting agency.

The upper numbers in each box of the Report Card indicate the "Sensible Maximum" values for that type of vehicle when it is in good repair and adjustment. These values are intended as guidelines for the repairing agency.

The lower numbers are the actual values derived from dynamic test of the vehicle.

The actual values used for reject of the vehicle are not printed on the Report Card, but are usually considerably higher than the "Sensible Maximum." Repair must be made based only on the rejects (✓).

Example Report Card - Page 5

Note the "Sensible Maximum" in the upper half of each box, and the larger actual values at the bottom.

For repair of this vehicle, the mechanic would find that the second example on Truth Chart #2 matches his Report Card, and would repair accordingly.

Example Report Card - Page 6

Note the "Sensible Maximum" in the upper half of each box. These values are lower than in the previous Report Card because this is an emission control vehicle and is capable of lower emissions when in proper operating order.

Also, note that the Idle CO is higher than the "Sensible Maximum," but is not rejected. This is because it was not high enough to be rejected by the actual reject values of the inspecting agency.

For repair of this vehicle, the mechanic would find that the second example on Truth Chart #6 matches his Report Card, and would repair accordingly.

TYPICAL REPORT CARD

NON-EXHAUST EMISSION CONTROLLED

NAME: ____________ VEHICLE: ____________

VEHICLE & OWNER STATISTICS

	IDLE	LOW CRUISE	HIGH CRUISE
-CO- CARBON MONOXIDE	MAX 5.5% 2.5	MAX 3.5% 3.4	MAX 3% 7.6 ✓
-HC- UNBURNED HYDROCARBON	MAX 700 PPM 492	MAX 450 PPM 368	MAX 450 PPM 465

✓ = REJECT

TYPICAL REPORT CARD

EXHAUST EMISSION CONTROLLED

NAME: ____________________ VEHICLE: ____________________

VEHICLE & OWNER STATISTICS

	IDLE	LOW CRUISE	HIGH CRUISE
-CO- CARBON MONOXIDE	MAX 3% 3.8	MAX 2.5% .6	MAX 2% .4
-HC- UNBURNED HYDROCARBON	MAX 290 PPM 1482 ✓	MAX 240 PPM 1350 ✓	MAX 220 PPM 1252 ✓

✓ = REJECT

CARBON MONOXIDE

Basic problems involved ONLY with carburetor misadjustments or malfunctions.

Refer to these Charts for assistance in diagnosing problems where one or more of the top three boxes has been checked with a reject (✓).

CHART #1

	IDLE	LOW CRUISE	HIGH CRUISE
CO	✓		
HC			

ABNORMALLY HIGH IDLE CO

	IDLE	LOW CRUISE	HIGH CRUISE
CO	✓	✓	
HC			

ABNORMALLY HIGH IDLE CO CARRYING OVER TO LOW CRUISE

USUAL CAUSE

1. Gross error in carburetor idle air fuel mixture adjustment.
2. Rarely high idle CO carries over into Low Cruise, as shown in the second example.

SERVICE STEPS

1. Inspect the PCV system to insure it is clean and operating correctly. A PCV system malfunction can cause erratic idle operation.

2. Make basic engine idle adjustments of ignition dwell and timing, idle speed and air fuel ratio.

   CAUTION: After making the basic idle adjustment, accelerate the engine at least three times and let it return to idle. Observe the stability and repeatability of idle condition.

3. In rare cases that idle adjustments cannot be made correctly, due to excessive amounts of varnish or foreign deposits in the carburetor idle passages, it may be necessary to replace or repair the carburetor.

CHART #2

	IDLE	LOW CRUISE	HIGH CRUISE
CO		✓	
HC			

ABNORMALLY HIGH CO AT LOW CRUISE

	IDLE	LOW CRUISE	HIGH CRUISE
CO			✓
HC			

ABNORMALLY HIGH CO AT HIGH CRUISE

	IDLE	LOW CRUISE	HIGH CRUISE
CO		✓	✓
HC			

ABNORMALLY HIGH CO AT LOW AND HIGH CRUISE

USUAL CAUSE

The most common cause is a main system carburetor malfunction. This problem cannot be corrected by an Idle adjustment only.

SERVICE STEPS

1. Check carburetor air cleaner for abnormal restriction.
2. Check to see that choke is not stuck partially closed.
3. If the air cleaner and choke are satisfactory, remove the carburetor and replace or repair according to factory specifications.

   NOTE: If carburetor rebuild is undertaken, refer to the carburetor check sheet, page 17 of this manual.

ALWAYS MAKE THE BASIC IDLE ADJUSTMENTS OF IGNITION DWELL AND TIMING, IDLE SPEED AND AIR FUEL RATIO, TO COMPLETE THE REPAIR.

1147

CHART #3

	IDLE	LOW CRUISE	HIGH CRUISE
CO	✓		✓
HC			

ABNORMALLY HIGH CO AT IDLE AND HIGH CRUISE

	IDLE	LOW CRUISE	HIGH CRUISE
CO	✓	✓	✓
HC			

ABNORMALLY HIGH CO IN ALL MODES OF OPERATION

USUAL CAUSE

A combination of a malfunctioning carburetor main system and a maladjusted idle air fuel ratio.

SERVICE STEPS

1. Check carburetor air cleaner for abnormal restriction.

2. Check to see that choke is not stuck partially closed.

3. If the air cleaner and choke are satisfactory, remove the carburetor and replace or repair according to factory specifications.

   NOTE: If carburetor rebuild is undertaken, refer to the carburetor check sheet, page 17 of this manual.

4. Idle CO will be corrected when basic adjustments are made.

ALWAYS MAKE THE BASIC IDLE ADJUSTMENTS OF IGNITION DWELL AND TIMING, IDLE SPEED AND AIR FUEL RATIO, TO COMPLETE THE REPAIR.

UNBURNED HYDROCARBON

Basic problems involved ONLY with ignition misfires, vacuum leaks, valve leaks, ignition timing, or any condition which will permit raw fuel to escape into the exhaust pipe without being subjected to combustion.

Refer to these charts for assistance in diagnosing problems where one or more of the bottom three boxes has been checked with a reject (✓).

CHART #4

1149

	IDLE	LOW CRUISE	HIGH CRUISE
CO			
HC	✓		

ABNORMALLY HIGH HC AT IDLE

	IDLE	LOW CRUISE	HIGH CRUISE
CO			
HC	✓	✓	

ABNORMALLY HIGH HC AT IDLE CARRYING OVER TO LOW CRUISE

USUAL CAUSES

1. Vacuum leaks into the intake manifold causing a lean mixture and subsequent misfire in some cylinders.
2. Idle circuits on 2 and 4 barrel carburetors highly imbalanced or adjusted too lean.
3. Intermittent ignition misfire is possible but not probable.
4. Grossly advanced basic ignition timing.
5. Modest compression leak through one or more exhaust valves.
6. Excessively high CO at idle can cause moderately high HC at idle (adjust idle CO first, then determine whether further repair is necessary).

SERVICE STEPS

1. Note idle CO on Report Card and determine that idle is not adjusted too lean (less than 1.0% CO).
2. Ignition misfire at idle and not in the power modes is uncommon; however, simplicity of oscilloscope check-out suggests this be observed next.
3. Determine that basic ignition timing is not grossly advanced.
4. Check for balanced idle adjustments if 2 or 4 barrel carburetor.
5. Check for vacuum leaks into the intake manifold.
6. If above steps do not locate the source of trouble, make a cylinder compression check. Burned exhaust valves can cause up to four times normal HC at idle, with little increase in the Cruise modes.

ALWAYS MAKE THE BASIC IDLE ADJUSTMENTS OF IGNITION DWELL AND TIMING, IDLE SPEED AND AIR FUEL RATIO, TO COMPLETE THE REPAIR.

CHART #5

	IDLE	LOW CRUISE	HIGH CRUISE
CO			
HC		✓	

ABNORMALLY HIGH HC AT LOW CRUISE

	IDLE	LOW CRUISE	HIGH CRUISE
CO			
HC			✓

ABNORMALLY HIGH HC AT HIGH CRUISE

	IDLE	LOW CRUISE	HIGH CRUISE
CO			
HC		✓	✓

ABNORMALLY HIGH HC AT LOW AND HIGH CRUISE

USUAL CAUSES

Ignition misfire under higher compression pressures of power operation, due to a failure of an ignition system component.

SERVICES STEPS

1. Probably the most common problem is a faulty spark plug; however, this should not be a conclusion without proper examination.
2. Check out the ignition system with a scope and associated instruments. If the scope does not clearly show a faulty spark plug, observe for the following:
    a. Faulty ignition cables.
    b. Point arcing.
    c. Cross fire, due to cracked or carbon tracked cap or rotor.
    d. If above steps do not locate the source of trouble, refer to "Ignition Check Sheet," page 18, for added assistance.

ALWAYS MAKE THE BASIC ADJUSTMENTS OF IGNITION DWELL AND TIMING, IDLE SPEED AND AIR FUEL RATIO, TO COMPLETE THE REPAIR.

CHART #6

	IDLE	LOW CRUISE	HIGH CRUISE
CO			
HC	✓		✓

ABNORMALLY HIGH HC AT IDLE AND HIGH CRUISE

	IDLE	LOW CRUISE	HIGH CRUISE
CO			
HC	✓	✓	✓

ABNORMALLY HIGH HC IN ALL MODES OF OPERATION

USUAL CAUSES

The most probable cause is ignition misfire, as described on Chart #5.

SERVICE STEPS

1. Probably the most common problem is a faulty spark plug; however this should not be a conclusion without proper examination.
2. Check out the ignition system with a scope and associated instruments. If the scope does not clearly show a faulty spark plug, observe for the following:
   a. Faulty ignition cables.
   b. Point arcing.
   c. Cross fire, due to cracked or carbon tracked cap or rotor.
   d. If above steps do not locate the source of trouble, refer to "Ignition Check Sheet," page 18, for added assistance.
3. In RARE cases, it may be necessary to refer to Chart #4 when repair, as prescribed by Chart #5, does not bring Idle Hydrocarbons within a reasonable limit.

ALWAYS MAKE THE BASIC IDLE ADJUSTMENTS OF IGNITION DWELL AND TIMING, IDLE SPEED AND AIR FUEL RATIO, TO COMPLETE THE REPAIR.

CARBON MONOXIDE AND HYDROCARBON

Combinations of CO and HC Problems

Rejects in upper and lower boxes are simply combinations of problems causing abnormally high CO and those causing abnormally high HC. They are to be treated as separate and independent problems.

Repairs will be based on a combination of a CO chart which matches the checks in the upper row of boxes, and a HC chart which matches the checks in the lower row of boxes.

> NOTE: As a quick reference, a master wall chart has been included on the following page. This will be an aid in quickly finding the proper Truth Chart(s) and page number(s) for given reject situations.

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QUICK REFERENCES

MASTER WALL CHART

CARBON MONOXIDE

CHART NO. 1 (PAGE 8)

	IDLE	LOW CRUISE	HIGH CRUISE
CO	✓		
HC			

	IDLE	LOW CRUISE	HIGH CRUISE
CO	✓	✓	
HC			

CHART NO. 2 (PAGE 9)

	IDLE	LOW CRUISE	HIGH CRUISE
CO		✓	
HC			

	IDLE	LOW CRUISE	HIGH CRUISE
CO			✓
HC			

	IDLE	LOW CRUISE	HIGH CRUISE
CO		✓	✓
HC			

CHART NO. 3 (PAGE 10)

	IDLE	LOW CRUISE	HIGH CRUISE
CO	✓		✓
HC			

	IDLE	LOW CRUISE	HIGH CRUISE
CO	✓	✓	✓
HC			

UNBURNED HYDROCARBON

CHART NO. 4 (PAGE 12)

	IDLE	LOW CRUISE	HIGH CRUISE
CO			
HC	✓		

	IDLE	LOW CRUISE	HIGH CRUISE
CO			
HC	✓	✓	

CHART NO. 5 (PAGE 13)

	IDLE	LOW CRUISE	HIGH CRUISE
CO			
HC		✓	

	IDLE	LOW CRUISE	HIGH CRUISE
CO			
HC			✓

	IDLE	LOW CRUISE	HIGH CRUISE
CO			
HC		✓	✓

CHART NO. 6 (PAGE 14)

	IDLE	LOW CRUISE	HIGH CRUISE
CO			
HC	✓		✓

	IDLE	LOW CRUISE	HIGH CRUISE
CO			
HC	✓	✓	✓

CARBURETOR CHECK SHEET

NOTE: In rebuilding a carburetor, the following defects must be looked for. If one or more of these defects is not observed or cannot be corrected, it is suggested that the carburetor be discarded and replaced according to manufacturers recommendations.

1. Check for faulty power enrichening valve.
2. Check to be sure that all vacuum passages controlling the power enrichening valve are open and unobstructed.
3. Observe for loose main jet(s) and/or power enrichening valve.
4. Check for pitted or cracked main jet seat of seat gasket.
5. Check for worn jets and/or metering rods. A slight amount of wear can cause a grossly higher CO reading.
6. Examine the float for abnormal damage or leaks.
7. Check for a damaged or loose float valve.
8. Check the venturi cluster and cluster gasket for damage or cracks.
9. Thoroughly inspect the entire body of the carburetor for cracks and to see that all lead plugs are securely in place.

IGNITION CHECK SHEET

NOTE: Below are guidelines as to problems to look for that can cause ignition misfires and high hydrocarbons. In most cases, the problem can be traced to one of these areas and should be done so by proper diagnosis, not by repairing and replacing until the problem has been corrected.

This list is prepared in order with the most commonly occurring problems listed at the top, and the least common toward the bottom.

1. Spark plugs.
2. Spark plug cables and coil cable resistance.
3. Excessive point resistance or arcing.
4. Distributor cap and rotor cracks and carbon tracks.
5. Moisture inside the distributor cap or on the cables.
6. Extremely incorrect dwell angle or point gap.
7. Low coil output voltage.
8. Low primary voltage supplied to the coil.
9. Loose wire connections such as distributor plate ground or coil to point wire connections.

APPENDIX E
DIAGNOSTIC TEST AND PROCEDURES

1. A diagnostic analysis report will accompany each vehicle which requires adjustment and/or repair. A sample diagnostic analysis report is attached.

2. Only those adjustments and repairs indicated under REPAIR INSTRUCTIONS are to be performed.

3. The diagnostic analysis report is included for information purposes only with checks for satisfactory and unsatisfactory on those functions performed.

4. If repairs other than those requested are apparent, please indicate your recommendations under REMARKS. Keep in mind that only those repairs will be performed that are needed to bring exhaust emissions within an acceptable range.

5. If failure occurs on retest, the cars will be given additional diagnosis and returned for further repair work.

DIAGNOSTIC ANALYSIS REPORT

S	U	Function
		Air Cleaner
		Heat Riser
		Carb. Choke Action
		Rhythm Test
		PCV Valve Action
		Air Injection Pump
		Air Injection Check Valves
		Gulp Valve
		Emission System Hose Cond.
		Polarity
		Cap
		Rotor
		Condenser
		Coil
		Idle Speed Spec ______ Actual ______
		Dwell Spec ______ Actual ______
		Timing (Vac Hose Off) Spec ______ Actual ______
		Mechanical Advance (Vac Hose Off) Spec ______ Actual ______
		Total Advance (Vac Hose On) Spec ______ Actual ______
		Vacuum Advance (Total-Mech Advance) Spec ______ Actual ______
		Firing Order __ __ __ __ __ __ __ __ Power Drop Test (5 Sec per Cycle) __ __ __ __ __ __ __ __
		Plug Condition-Idle
		Carb - Idle AFR ______ CO ______
		Plug Condition - Loaded
		Carb - Power AFR ______ CO ______
		Plug Wires
		Points
		Detonation
		Carb - Cruise AFR ______ CO ______
		Carb Surges
		Blow - By
		Valve Action
		Knocks
		Head Gasket (On decel - use Bloc Chek)

NOTE: Remove & replace radiator cap above 2000 RPM

Car Number __________
License Number __________
Date __________
Test Start Time __________

S	U	Visual Check
		Battery Appearance
		Cables
		Belts
		Hoses
		Radiator
		Oil Leaks
		Fuel Leaks

REPAIR INSTRUCTIONS - Use normal operating procedure, itemize repair actions on invoice, return all parts that are replaced.

Test Completion Time __________

REMARKS -