EPA-AA-IMS-81-23

Evaluation of I/M Effectiveness Using Emission Factors Data: Phoenix vs. Other Low-Altitude, Non-California Sites

October, 1981

James Rutherford

Inspection and Maintenance Staff
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Office of Air, Noise, and Radiation
U.S. Environmental Protection Agency
Ann Arbor, Michigan

1.0 INTRODUCTION

1.1 Purpose

The Emission Factors (EF) Testing Program is a continuing project in which the Environmental Protection Agency (EPA) contracts with several independent laboratories to perform emission testing of samples of in-use vehicles in several cities in the United States. Phoenix, Arizona has been a site for EF testing for several years both before and after the advent of its Inspection/Maintenance (I/M) program. Federal Test Procedure (FTP) data recorded from EF testing in Phoenix and several non-I/M cities provide an opportunity to evaluate the effectiveness of the I/M program in reducing emissions from in-use light duty vehicles.*

This report presents an analysis of EF data directed toward estimating the effects of the Phoenix I/M program.

1.2 Summary

Preliminary evaluations of the means of the raw data indicate a definite reduction in emissions due to I/M. More sophisticated analyses of the data using analyses of covariance allow for statistical testing and quantification of the differences due to I/M in Phoenix. As a result of the analyses of covariance, the mean emissions of FTP HC and CO are found to be statistically significantly lower after I/M in Phoenix than in the other non-I/M, low-altitude, non-California EF testing sites while there was no significant difference before I/M began. Within about two years of the start of the Phoenix I/M program, reductions due to I/M are about twenty percent for both HC and CO. Analyses of test results from vehicles tested in more than one EF program provide qualitative corroboration of the reductions due to I/M.

---

* EPA has taken advantage of several other opportunities previously; reports documenting this previous work are listed in the bibliography at the end of this report.

2.0 ANALYSIS

2.1 Data Inclusion

Emission Factors testing included Phoenix, Arizona in the Fiscal Year (FY) 1974, 1975, 1977 and 1979 programs.* Other low-altitude, non-California sites in these programs were Chicago, Houston, St. Louis, and Washington, D.C. These four sites do not have I/M programs. For this analysis, all as-received FTP tests from the four non-I/M, low-altitude, non-California sites on model year 1972-1978 light duty passenger cars were used. For Phoenix, all as-received tests for these model years were used from the FY 1974 and 1975 programs. For the FY 1977 and 1979 programs, the tests for cars of these model years in Phoenix were used if there was indication that the vehicle had participated in the I/M program. Some vehicles were too young when tested to have participated yet; others may have immigrated to Phoenix too recently to have since participated.

The model years included in the analysis provide two distinct emission control technologies. The 1972 through 1974 model years are pre-catalyst vehicles subject to the same new car emission standards for HC and CO. The 1975 through 1978 vehicles are first generation catalyst vehicles all subject to a more stringent set of new car standards for HC and CO. In this report, these two groups of vehicles are referred to as Technology I and Technology II vehicles respectively. Although the EF programs included vehicles of model years before and after the above mentioned groups, they are not included in this analysis since they are sufficiently different in emission control technology and they are not included in enough of the FY programs to provide before and after I/M comparisons. Model years before 1972 were subject to less stringent new car tailpipe emission standards defined on an obsolete test procedure. Although 1979 model year vehicles were subject to the same new car HC and CO standards as the 1975-1978 model year vehicles, the majority of the sample for this model year was General Motors vehicles utilizing sealed idle mixtures. They have emission characteristics sufficiently different from the rest of the sample to cause variability problems in the analysis if included with the 1975 through 1978 model years.

2.2 Analysis of Covariance

The individual FY programs of the EF testing provide convenient discrete test points for comparison of test results between Phoenix and the non-I/M cites. One FY program was carried out at approximately the same point in time at all the sites. There was a lapse of time between FY programs. The FY74 testing was performed before the advent of the Phoenix I/M program. Based on the January 1, 1977 start-up date for mandatory Phoenix I/M and test dates from the FY75 EF testing in Phoenix, it is estimated that roughly one-fourth of those tests were on vehicles which had participated in the I/M program. For

* See bibliography at the end of this report for EF testing documentation.

the FY77 and FY79 programs, information was available indicating whether the vehicles had experienced I/M and only data from vehicles in Phoenix which had experienced I/M were included in the analysis.

A preliminary indication of I/M effects can be gleaned from examination of simple mean emissions and mileage at the test points. As will be seen, this examination was performed. However, variations in accumulated mileage need to be accounted for in making precise comparisons. This was achieved through analysis of covariance. The effects of I/M are evaluated by comparing the non-I/M cities with Phoenix at each test point after accounting for mileage as a covariate. The initial analyses of covariance using raw data were found to be invalid due to non-normality of residuals as determined by the Lilliefors adaptation of the Kolmogorov-Smirnov test. A log transformation of the emissions data was performed. The analyses of covariance performed on the transformed data were found to be valid. The resultant analyses performed at each test point within each technology with groupings for Phoenix and non-I/M cites and mileage as a covariate provided valid statistical tests of the effects of I/M. The adjusted means for Phoenix and non-I/M cites also provide good estimators of mean emissions at the mean mileage for total samples (i.e., mean mileage for Phoenix and non-I/M cites combined).

It should be noted that the validity of log-transformed data in the analyses of covariance and the invalidity of raw data for these analyses does not necessarily imply non-linearity of emissions deterioration with mileage. The usual linear estimation of emissions deterioration on mileage is based on the useful life of vehicles. This is a much larger span of mileage than was used in each of these analyses. While it may be more appropriate to assume exponential deterioration of emissions over the relatively short mileage spans used in the individual analyses of covariance presented in this report, it could yet be more appropriate to assume linear deterioration over the life of a vehicle as is commonly done.

3.0 RESULTS

3.1 Fiscal Year Results

As explained above, the individual FY programs provide convenient discreet points for estimating the relative deterioration in emissions that occurred over time in the EF data. For the FY74 program, none of the data come from vehicles exposed to I/M. Approximately one-fourth of the Phoenix vehicles had experienced I/M before the FY75 testing. From the FY77 and FY79 programs in Phoenix, data was only used from vehicles for which there was indication that the vehicle had experienced I/M.

3.1.1 Raw Data Results

A preliminary examination of the I/M effects is presented in Table 1 and Figures 1 through 4. The general conclusion from means of the raw data is that the Phoenix mean emissions are approximately equal to mean emissions from the other cites before I/M (FY74 means). After I/M, in the later EF programs (FY75, FY77, and FY79), the mean emissions for Phoenix are lower than mean emissions for the other cites.

3.1.2 Adjusted Mean Results

As discussed above, the next step in this investigation was a series of analyses of covariance performed at each test point (i.e., for each FY program), for each technology, for each pollutant, stratified by presence or absence of I/M (Phoenix or other sites) with mileage as a covariate. These analyses allow valid statistical testing of I/M effects after accounting for mileage effects and the estimation of mean emissions at the same mileage.

Table 2 and Figures 5 through 8 present the results of these analyses. As seen in Table 2, there are no significant differences between Phoenix and the other sites in the FY74 program (before Phoenix I/M). Progressing through the EF programs, a significant difference develops in both HC and CO for both technologies between Phoenix and the other sites.

The reader may notice a counterintuitive result in Table 2 and Figure 6. The adjusted mean CO emissions for Technology II vehicles drop between the FY74 and the FY75 programs for both Phoenix and the other sites. An investigation of this phenomenon indicated that Technology II vehicles in the FY74 program were primarily model year 1975 vehicles while in FY75 they were primarily 1976 vehicles. The 1976 model year vehicles in addition to having a higher percentage of catalysts and air pumps may also have been more reliable than the 1975 model year vehicles due to one year of experience with the new emission control technology. Thus, the drop in emissions is understandable. It does not affect the comparison between Phoenix and other sites.

The I/M program in Phoenix became mandatory January 1, 1977. All testing for the FY74 EF program was completed before that date. FY75 EF testing in Phoenix was performed in the first part of calendar year 1977. The Phoenix testing for the FY77 program was carried out in the last three months of

calendar year 1977. The Phoenix testing for the FY79 program occurred in the first part of calendar year 1979. From Table 2, it appears that within the first two years of the implementation of I/M in Phoenix, there is roughly a twenty percent reduction in emissions of HC and CO relative to what the emissions would be without I/M.

3.2 Repeated Testing Results

Many vehicles in the EF programs experienced repeated tests, that is, they were tested in more than one FY program. Although restricting analyses to only the vehicles with repeated tests reduces sample sizes greatly and provides less than adequate representation of the vehicle fleet, it does provide a qualitative corroboration of the conclusions reached in the above analyses.

Analyses analogous to those used in the results described above were carried out on the repeated testing samples. For example, for all vehicles included in both the FY74 and FY75 programs, an analysis of covariance was performed for each of the FY programs, for each pollutant, and each technology. The adjusted means are then compared for these repeated testing samples between Phoenix and the other sites for both FY programs.

The results of these analyses are presented in Table 3 and Figures 9 through 12. The general conclusion reached from these analyses is that with I/M the vehicles tested in Phoenix show less deterioration from one FY program to the next than the vehicles from the other sites. Thus, the conclusion reached in the previous section are supported by the analyses of the repeated testing samples.

BIBLIOGRAPHY

EPA I/M Evaluations

Becker, J., "Portland Study: First Preliminary Analysis", EPA-CAB-2/POR-1, May, 1978.

Rutherford, J., "Portland Study Interim Analysis: Observations on Six Months of Vehicle Operation", EPA-IMS, January, 1979.

Rutherford, J., "Portland Study Interim Analysis: Update With Nine Months of Vehicle Operation", EPA-IMS-004/PS-2, May, 1979.

Becker, J., and Rutherford, J., "Analysis of Oregon's Inspection and Maintenance Program", presented at 72nd Annual APCA Meeting and Exhibition, No. 79-7.3, June, 1979.

Rutherford, J., and Waring, R., "Update on EPA's Study of the Oregon Inspection/Maintenance Program", presented at 73rd Annual APCA Meeting and Exhibition, No. 80-1.2, June, 1980.

Michael, B., "Evaluation of California Change-of-Ownership I/M Program", EPA-IMS Memo, January, 1981.

Tiao, G.C., Leaolter, J., and Hudak, G., "Statistical Analysis of the Effect of Inspection and Maintenance on Carbon Monoxide Air Quality in Portland, Oregon", EPA-460/3-81-016, May, 1981.

Michael, B., "Emission Reductions from Inspection and Maintenance: Vancouver Versus Portland Snapshot", EPA-AA-IMS-81-18, August, 1981.

Emission Factors Testing Documentation

Bereus, A., and Hill, M., "Automobile Exhaust Emission Surveillance - Analysis of the FY 1974 Program", EPA-460/3-76-019, September, 1976.

Rutherford, J., "Automobile Exhaust Emission Surveillance - Analysis of the FY 1975 Program", EPA-460/3-77-022, December, 1977.

"A Study of Emissions from Passenger Cars in Six Cities", EPA-460/3-78-011-a-b, January, 1979.

"FY79 Study of Emissions from Passenger Cars in Six Cities", EPA-460/3-80-020A-B, October, 1980.

Table 1

Mean FTP Emissions and Mileages for Phoenix and Other Sites
by EF Program and Technologies

EF Program	Other Sites N	Other Sites Mileage	Other Sites HC	Other Sites CO	Phoenix N	Phoenix Mileage	Phoenix HC	Phoenix CO
Technology II (1975-78 Model Years)								
FY74	470	8454	1.33	22.73	117	10249	1.30	23.65
FY75	518	14058	1.49	22.16	200	15983	1.34	17.56
FY77	889	26141	1.97	25.94	179	20349	1.56	18.68
FY79	600	31947	2.15	28.21	135	28805	1.51	19.63
Technology I (1972-74 Model Years)								
FY74	415	29646	3.79	46.33	82	32821	3.53	45.71
FY75	398	39875	3.86	50.32	145	44579	3.67	51.52
FY77	432	56701	4.88	55.64	112	53023	3.48	43.02

Table 2

Adjusted Mean FTP Emissions and Mileages for Phoenix and Other Sites by EF Program and Technologies

EF Program	Mileage	HC Other Sites	HC Phoenix	HC % Difference	HC Sig.[1]	CO Other Sites	CO Phoenix	CO % Difference	CO Sig.
Technology II (1975-78 Model Years)									
FY74	8812	1.07	1.05	2	ns	15.24	16.02	5	ns
FY75	14595	1.19	1.06	11	*	13.47	11.08	18	*
FY77	25170	1.53	1.23	20	**	17.26	13.82	20	**
FY79	31370	1.62	1.32	19	**	19.03	15.95	16	*
Technology I (1972-74 Model Years)									
FY74	30170	3.31	3.15	5	ns	37.16	37.98	2	ns
FY75	41131	3.37	3.21	5	ns	41.75	43.32	4	ns
FY77	55944	3.80	3.05	20	**	45.93	35.39	23	**

[1] Sig. = Statistical Significance of the difference in adjusted mean emissions between Phoenix and other sites.
**: Significant at .01 level;
* : Significant at .05 level;
ns: Not significant at .05 level.

Table 3

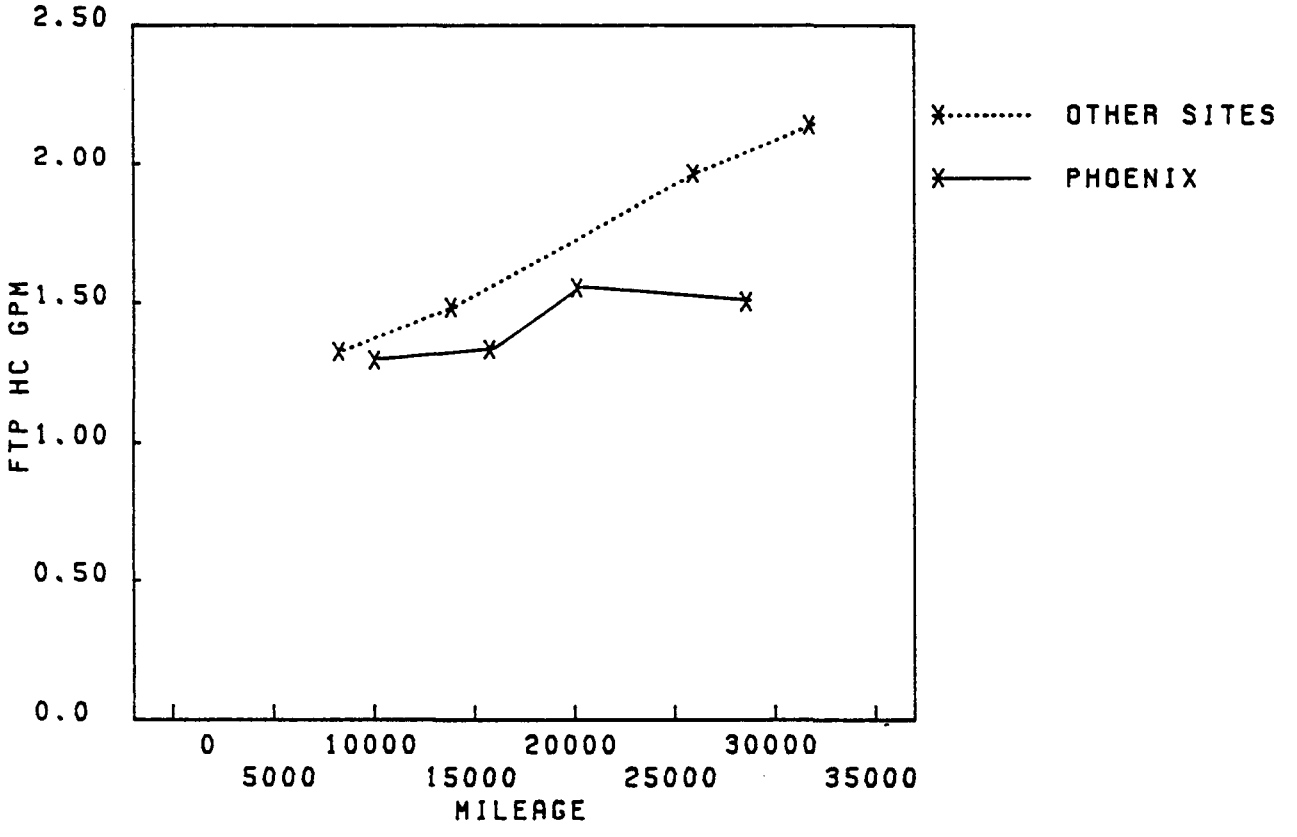
Adjusted Mean FTP Emissions and Mileages for Phoenix and Other Sites from Repeated Testing Samples by EF Program and Technology

	Sample Size			HC		CO	
Sample*	Other Sites	Phoenix	Mileage	Other Sites	Phoenix	Other Sites	Phoenix
			Technology II (1975-78 Model Years)				
74/75	86	29	7743	1.09	1.16	16.43	15.83
			21416	1.28	1.41	16.87	16.39
75/77	106	90	13386	1.16	1.10	13.47	11.16
			28461	1.59	1.32	17.80	13.90
77/79	69	36	19735	1.25	.98	13.84	12.05
			35264	1.74	1.27	19.93	15.21
			Technology I (1972-74 Model Years)				
74/75	127	42	26854	3.32	3.12	36.97	42.10
			37443	3.29	3.12	36.84	41.85
75/77	87	84	38868	3.50	3.17	40.79	43.84
			50577	3.63	3.22	45.49	40.17

* The samples are restricted to vehicles tested in both FY programs, e.g., the 74/75 sample includes only vehicles tested in both the FY74 and FY75 EF programs.

Figure 1

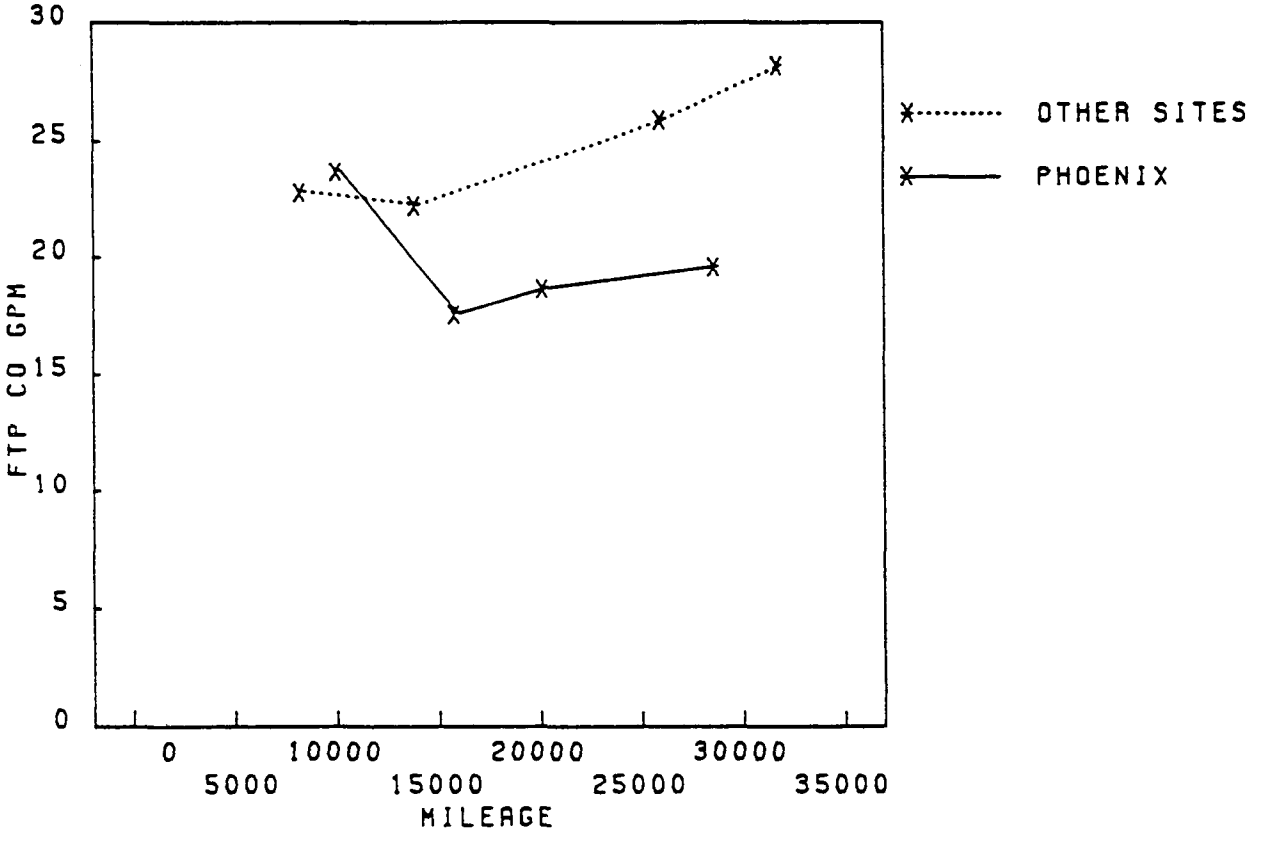
Mean HC Emissions and Mileages for Phoenix and Other Sites
by EF Program: Technology II Vehicles*



* X's indicate FY74, FY75, FY77, and FY79 means, respectively, from left to right on each line. "Other Sites" includes no I/M vehicles. "Phoenix" includes no I/M for FY74, about one-fourth I/M for FY75, and all I/M for FY77 and FY79.

Figure 2

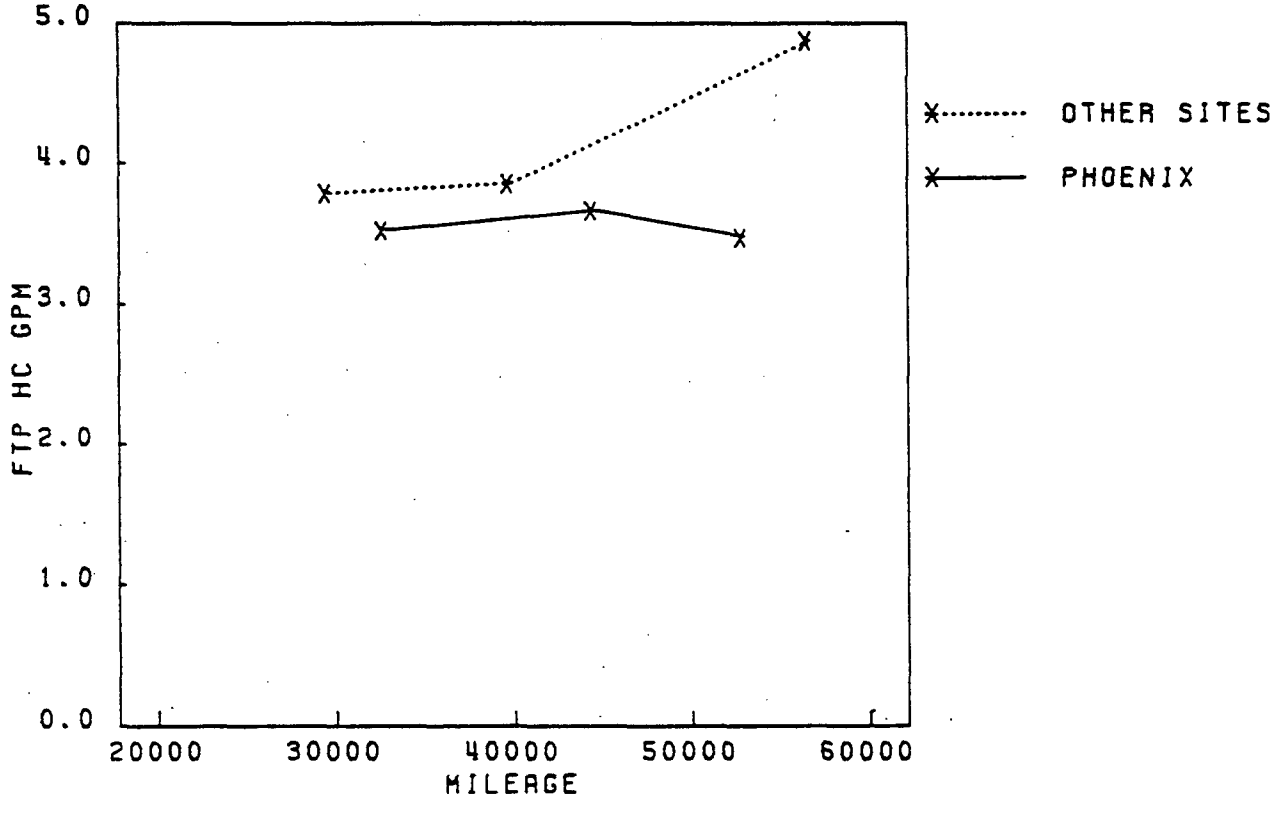
Mean CO Emissions and Mileages for Phoenix and Other Sites
by EF Program: Technology II Vehicles*



* X's indicate FY74, FY75, FY77, and FY79 means, respectively, from left to right on each line. "Other Sites" includes no I/M vehicles. "Phoenix" includes no I/M for FY74, about one-fourth I/M for FY75, and all I/M for FY77 and FY79.

Figure 3

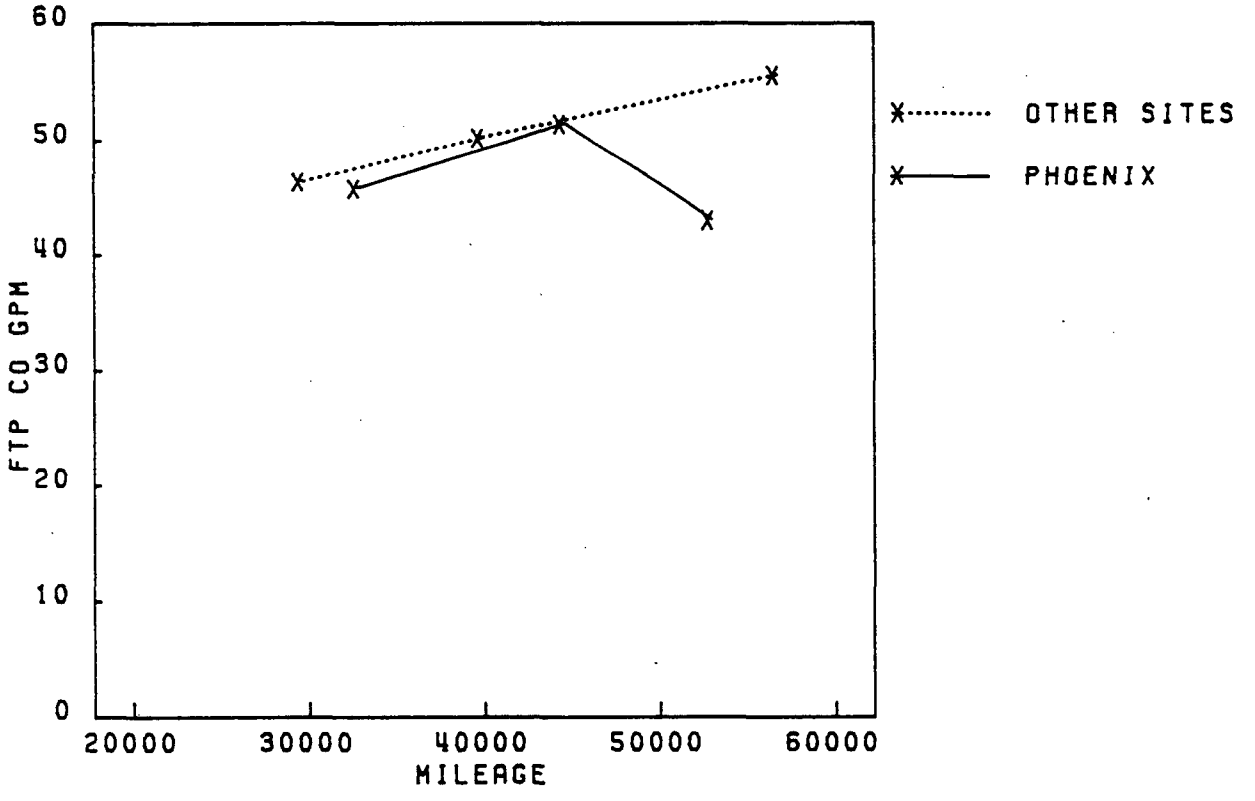
Mean HC Emissions and Mileages for Phoenix and Other Sites
by EF Program: Technology I Vehicles*



* X's indicate FY74, FY75, and FY77 means, respectively, from left to right on each line. "Other Sites" includes no I/M vehicles. "Phoenix" includes no I/M for FY74, about one-fourth I/M for FY75, and all I/M for FY77.

Figure 4

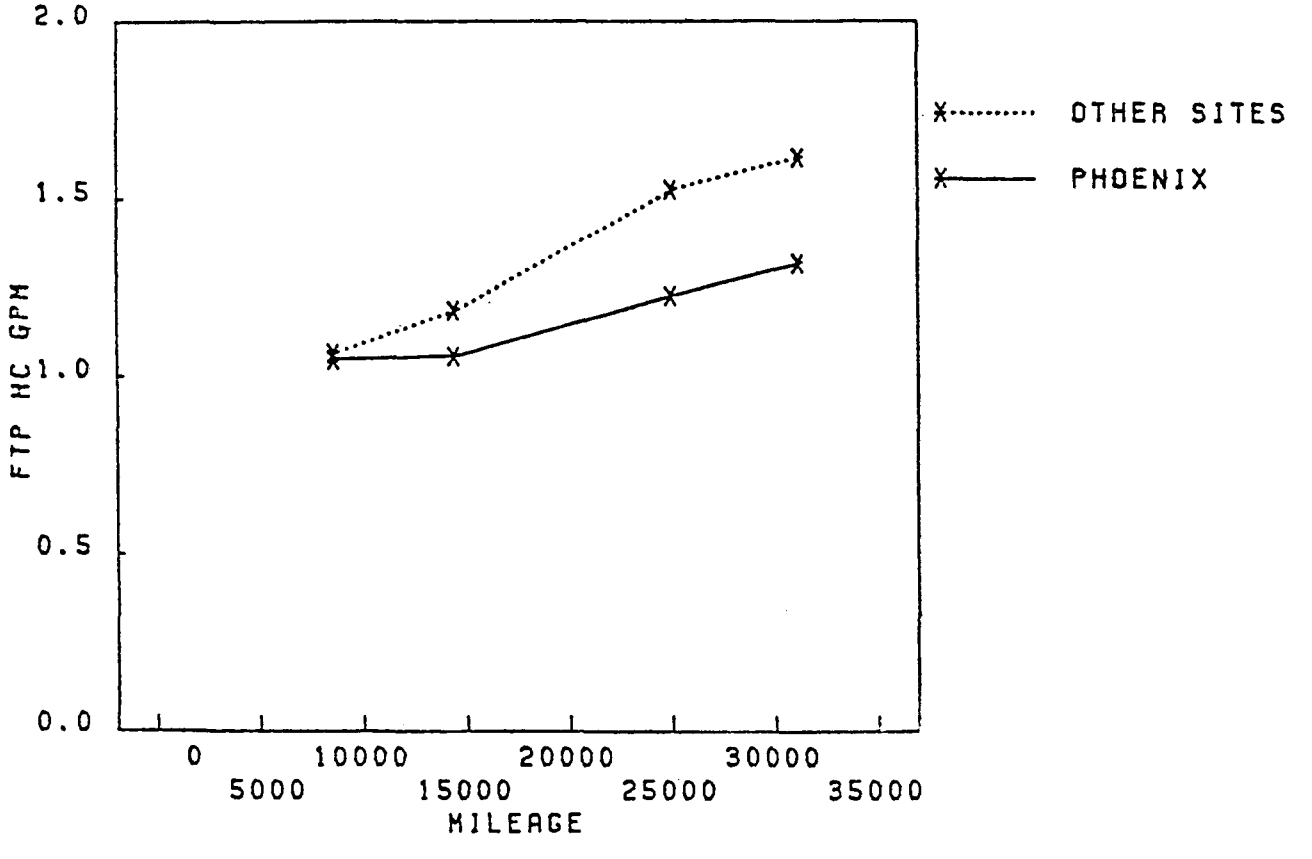
Mean CO Emissions and Mileages for Phoenix and Other Sites
by EF Program: Technology I Vehicles *



* X's indicate FY74, FY75, and FY77 means, respectively, from left to right on each line. "Other Sites" includes no I/M vehicles. "Phoenix" includes no I/M for FY74, about one-fourth I/M for FY75, and all I/M for FY77.

Figure 5

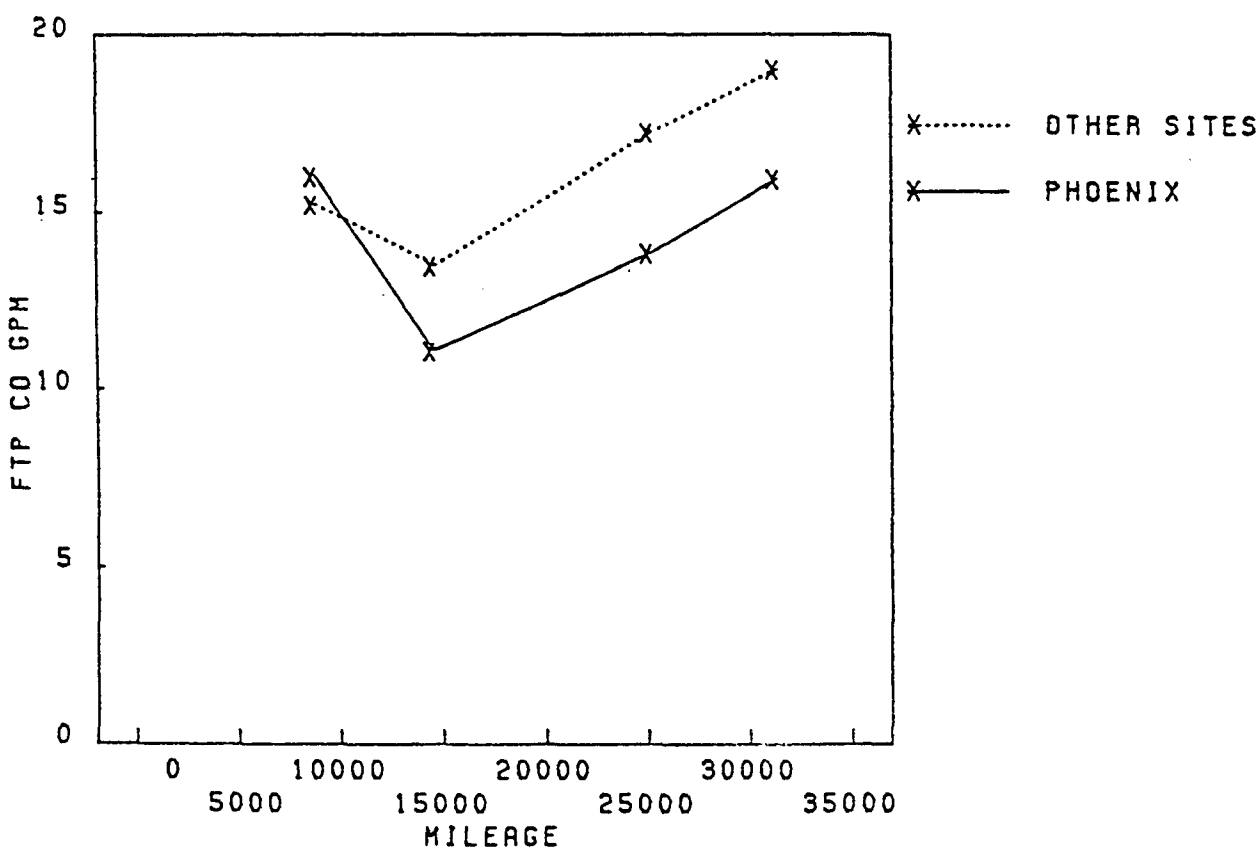
Adjusted Mean HC Emissions and Mileages for Phoenix and Other Sites
by EF Program: Technology II Vehicles*



* X's indicate FY74, FY75, FY77, and FY79 means, respectively, from left to right on each line. "Other Sites" includes no I/M vehicles. "Phoenix" includes no I/M for FY74, about one-fourth I/M for FY75, and all I/M for FY77 and FY79. The means have been adjusted relative to Figure 1 to provide estimates at identical mean mileages. (See page 5 of text.)

Figure 6

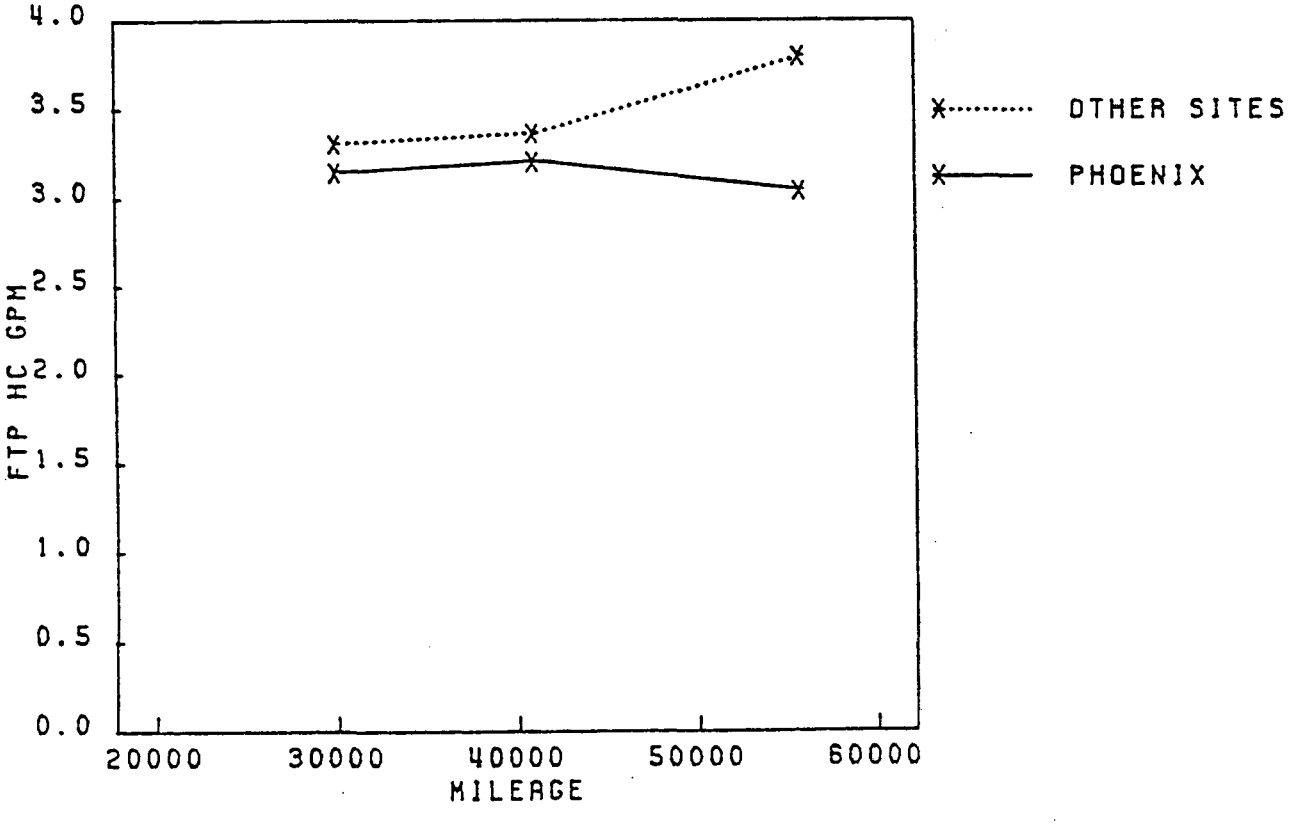
Adjusted Mean CO Emissions and Mileages for Phoenix and Other Sites
by EF Program: Technology II Vehicles *



* X's indicate FY74, FY75, FY77, and FY79 means, respectively, from left to right on each line. "Other Sites" includes no I/M vehicles. "Phoenix" includes no I/M for FY74, about one-fourth I/M for FY75, and all I/M for FY77 and FY79. The means have been adjusted relative to Figure 2 to provide estimates at identical mean mileages. The drop in mean emissions from FY74 to FY75 appear to be due to increase in proportion of model year 1976 vehicles. (See page 5 of text.)

Figure 7

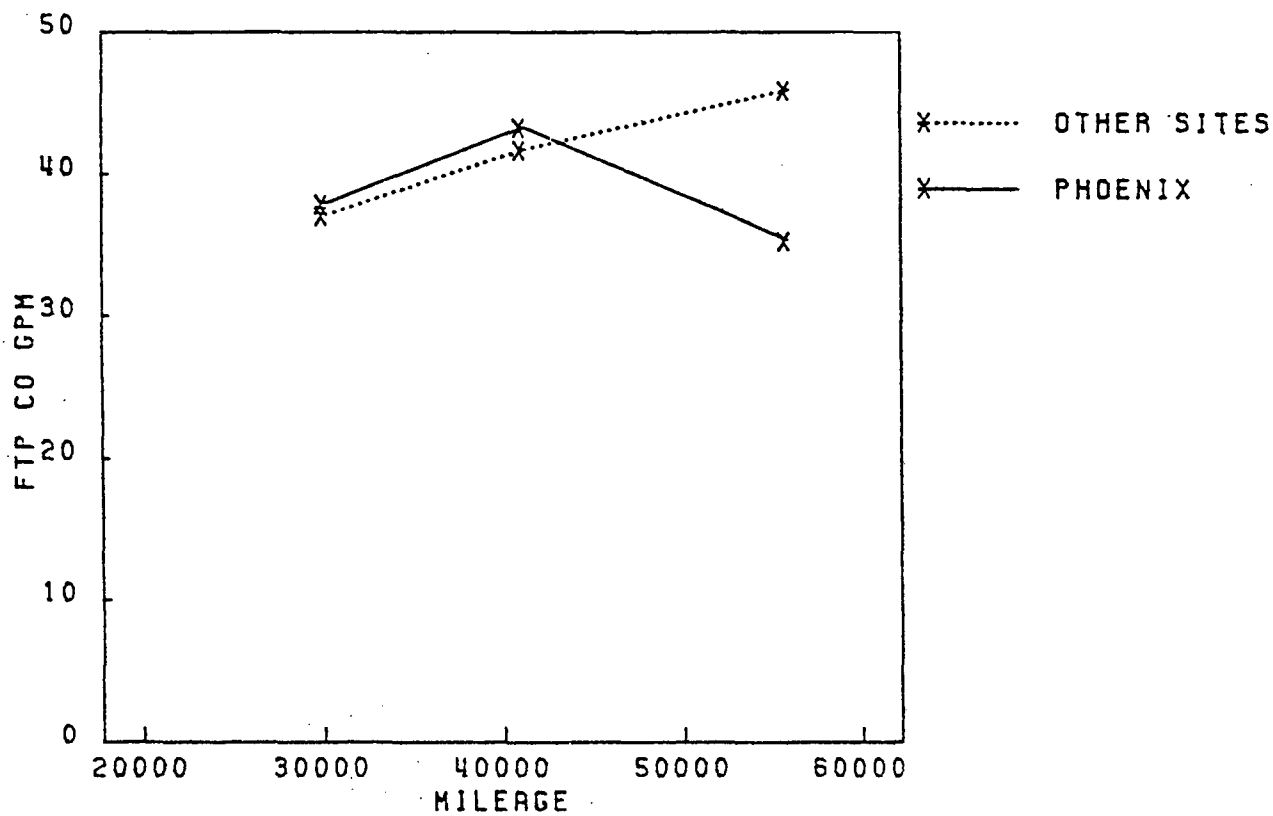
Adjusted Mean HC Emissions and Mileages for Phoenix and Other Sites by EF Program: Technology I Vehicles *



* X's indicate FY74, FY75, FY77 means, respectively, from left to right on each line. "Other Sites" includes no I/M vehicles. "Phoenix" includes no I/M for FY74, about one-fourth I/M for FY75, and all I/M for FY77. The means have been adjusted relative to Figure 3 to provide estimates at identical mean mileages. (See page 5 of text.)

Figure 8

Adjusted Mean CO Emissions and Mileages for Phoenix and Other Sites
by EF Program: Technology I Vehicles *



* X's indicate FY74, FY75, FY77 means, respectively, from left to right on each line. "Other Sites" includes no I/M vehicles. "Phoenix" includes no I/M for FY74, about one-fourth I/M for FY75, and all I/M for FY77. The means have been adjusted relative to Figure 4 to provide estimates at identical mean mileages. (See page 5 of text.)

Figure 9

Adjusted Mean HC Emissions and Mileages for Phoenix and Other Sites from Repeated Testing Samples by EF Program: Technology II Vehicles

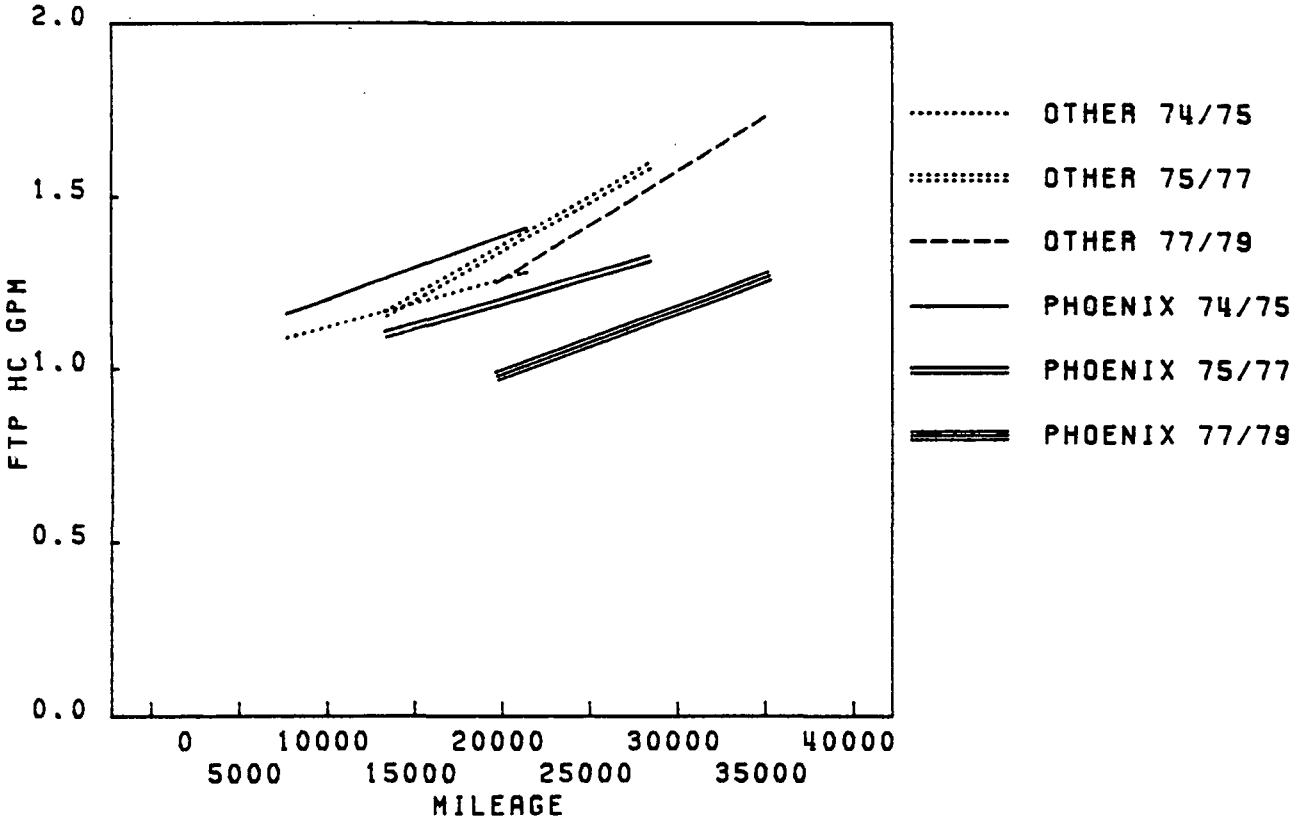


Figure 10

Adjusted Mean CO Emissions and Mileages for Phoenix and Other Sites from Repeated Testing Samples by EF Program: Technology II Vehicles

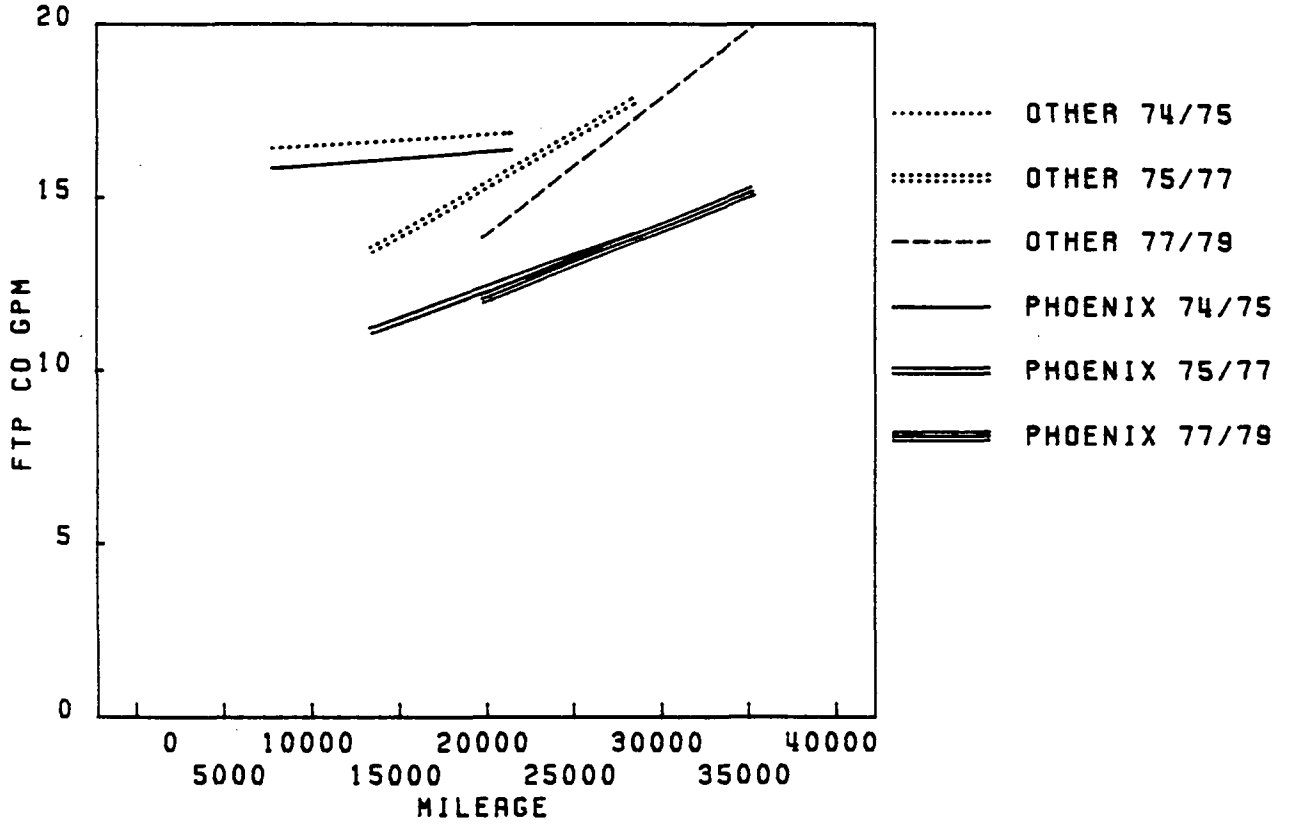


Figure 11

Adjusted Mean HC Emissions and Mileages for Phoenix and Other Sites from Repeated Testing Samples by EF Program: Technology I Vehicles

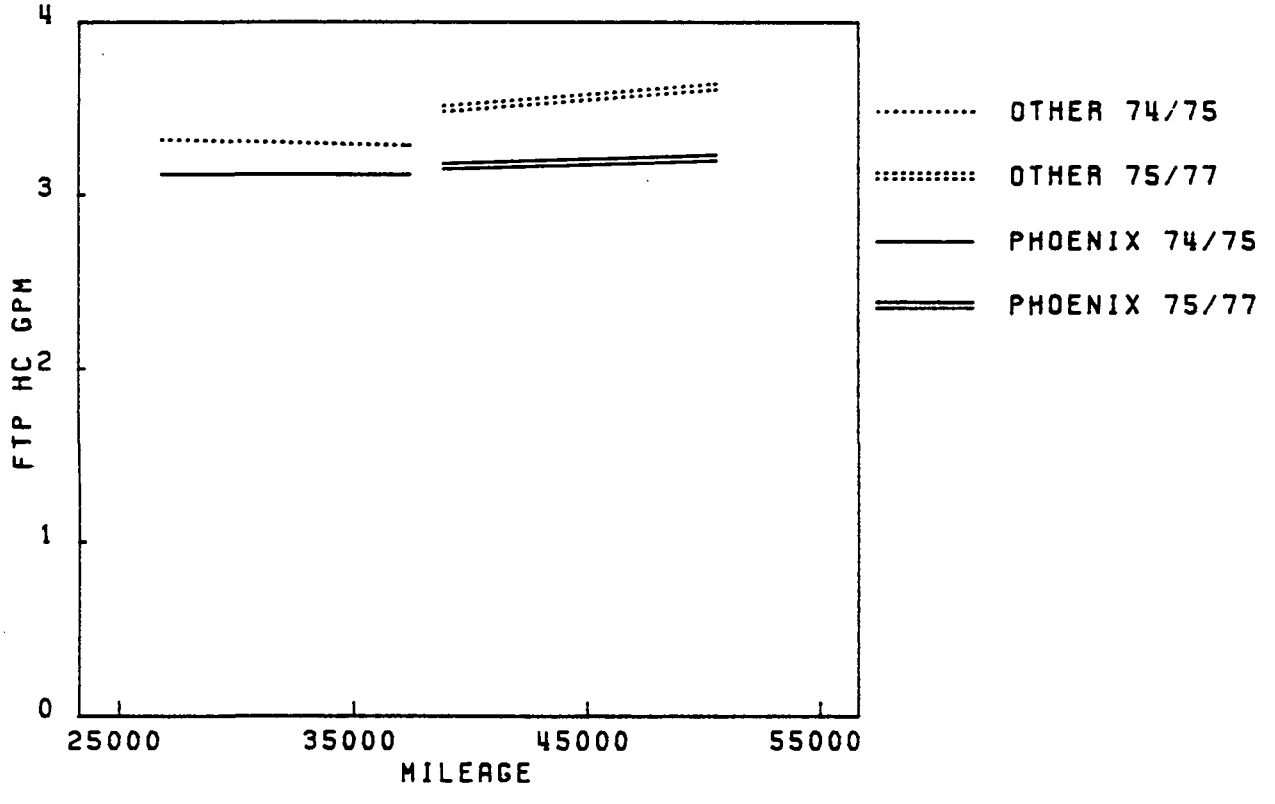
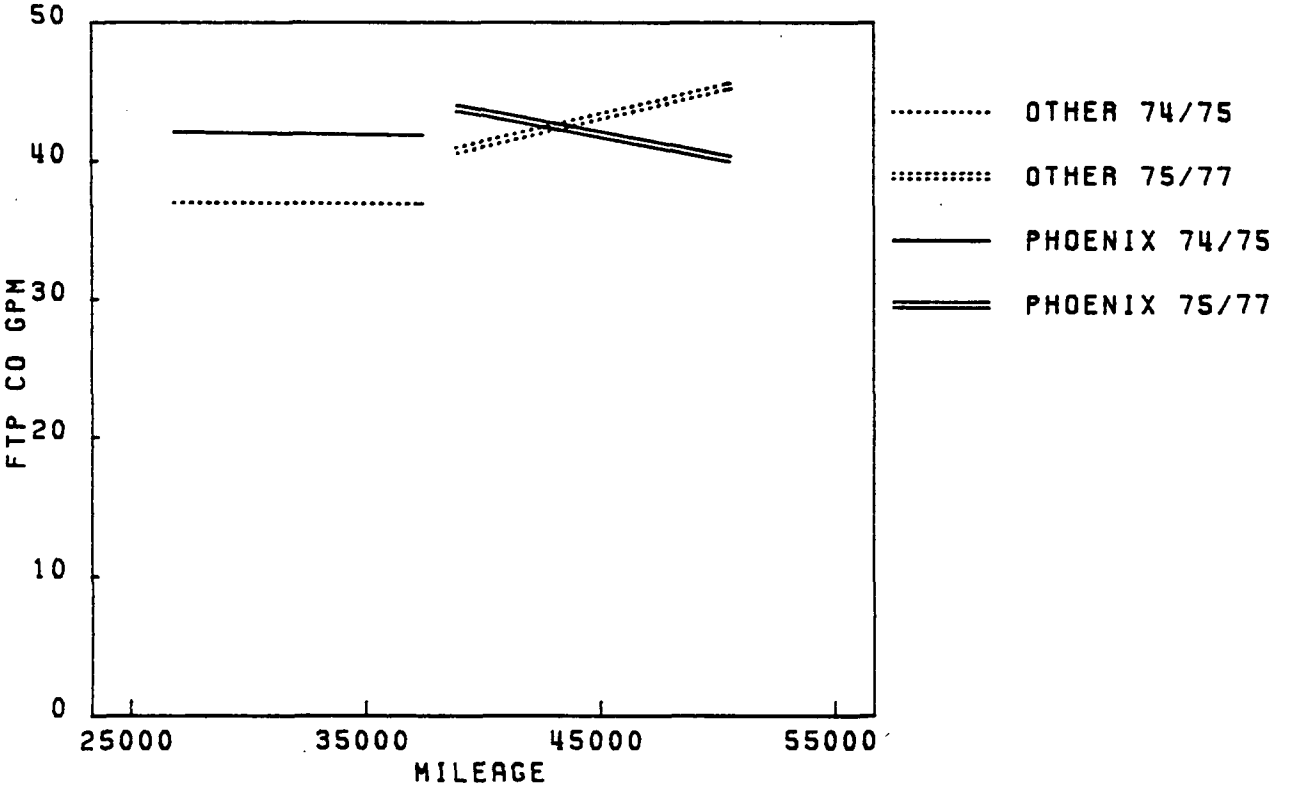


Figure 12

Adjusted Mean CO Emissions and Mileages for Phoenix and Other Sites from Repeated Testing Samples by EF Program: Technology I Vehicles



****

ORIGINAL

DO NOT TAKE

****