TEMPERATURE CORRECTION FACTORS FOR CALIFORNIA'S MOTOR VEHICLE EMISSIONS MODEL

prepared for:

California Air Resources Board

prepared under:

Tasks 1C and 2D,
ARB Contract Number A2-065-32

June, 1985

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Temperature Correction Factors
For California's
Motor Vehicle Emissions Model

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I. SUMMARY

The California Air Resources Board uses a computer model known as EMFAC to develop estimates of emissions from on-road model vehicles. The model includes correction factors to deal with a variety of local conditions; among them are factors to reflect emissions changes as a function of changes of ambient temperature.

The current ARB model uses correction factors which were developed from data collected prior to the wide-spread introduction of oxidation catalyst and 3-way catalyst vehicles. In order to improve the estimates for those vehicle categories, as well as for older model years, fifteen reference works were reviewed to identify the available emissions data needed to develop temperature correction factors.

After organizing the data from these references into a consistent computer format, and subjecting the data to a variety of control checks, new temperature correction factors were developed for passenger cars, light-duty trucks, and medium-duty vehicles.

In contrast with the current factors, which were only applied to the first 3.6 miles of driving, the new factors were developed for each of the three "Bags" which comprise the standard 7.5 mile Federal Test Procedure.

In addition, since most temperature testing has been conducted at discrete temperature intervals, correction factors were developed for five discrete temperature ranges: less than 30°F, 30-49°F, 50-67°F, 68-86°F, and greater than 86°F.

The results of the analysis indicate that the current temperature correction factors seriously underestimate cold temperature hydrocarbon and carbon monoxide emissions for most vehicle categories. In addition, the factors do not reflect the increase in hydrocarbon emissions which occurs at high temperatures after a hot start on pre-1980 model vehicles. The new factors also indicate that NOx emissions at cold temperatures have been seriously underestimated for pre-1980 model vehicles.

Finally, the data show that for 1980 and newer model cars hydrocarbon and CO emissions performance at low temperatures is a function of the type of fuel system used. Vehicles with carburetors, either open or closed loop, are far more sensitive to temperature changes than are vehicles which use multipoint fuel injection systems. Vehicles equipped with throttle body fuel injection systems appear to have performance somewhere in between those two extremes.

Somewhat surprisingly, the data indicate that there is fairly little sensitivity of NOx emission levels to changes in ambient temperature for 1980 and newer vehicles, regardless of the fuel type system used.

II. INTRODUCTION

A. Background

The California Air Resources Board, as well as several local air pollution control districts, rely on a computer model known as EMFAC to develop estimates of current and future emissions from on-road motor vehicles.[1*] The model can be run in two different modes: alone, to generate fleet average emissions per mile of vehicle travel; or in conjunction with detailed registration and travel data, to produce estimates of the total tons per day which result from motor vehicle operations.

Model users can tailor these estimates to reflect a variety of local conditions. Correction factors are included to adjust the basic emission factors for various vehicle speeds, ambient temperatures, number of daily trips per vehicle, length per average trip, and local vehicle registration mix, among other factors.

*Superscripts refer to references contained in Section V.

This report was prepared as part of a larger effort to improve California's estimates of motor vehicle emissions. In particular, this report describes the development of more accurate temperature correction factors.

Before discussing these factors, it would be useful to review light-duty vehicle emissions testing procedures.

The federal Urban Dynamometer Driving Schedule is the standard driving cycle used for measuring exhaust emissions from light and medium-duty vehicles. The schedule is designed to simulate a typical 7.5 mile trip. The typical trip is weighted to represent 43% of the actual trips starting with a cold engine (such as during a morning rush-hour commute), and 57% of the trips beginning with a warmed engine (such as after a brief stop for shopping).

In order to reduce testing costs, and to avoid the need to drive two complete 7.5 mile cycles (one cold, one warm), the standard 7.5 mile cycle is divided into two parts: the transient mode, which covers the first 505 seconds and 3.59 miles of driving; and the stabilized mode, which covers the remaining 867 seconds and 3.91 miles. The transient mode is intended to include the period when the engine is approaching its normal operating temperature, while the stabilized mode includes the period after the engine has reached operating temperature. Thus, the composite 7.5 mile trip can be represented by a total of three modes: a transient mode beginning with a cold start; a stabilized mode, equally applicable to a cold or hot start; and a transient mode beginning with a hot start.

By mathematically combining the results from the three modes, the emissions from a "standard" 7.5 mile trip can be calculated:

$$FTP = \frac{(0.43)(CT) + HS + (0.57)(HT)}{7.5}$$

where:

FTP = emissions during the federal test procedure, in grams per mile

CT = emissions during the cold transient mode, in grams

HS = emissions during the stabilized mode, in grams

HT = emissions during the hot transient mode, in grams

Emissions samples are collected and analyzed separately for each of the three modes. During the test, the samples are stored in specially treated bags until they are analyzed. Thus, the cold transient sample is called "Bag 1", the stabilized sample "Bag 2", and the hot transient sample "Bag 3".

Throughout the remainder of this report, we will refer to the three portions of the standard driving cycle by bag number.

B. Previous California Factors

The most recent version of California's motor vehicle emissions model is EMFAC6D. The temperature correction factors used in this version of the model are based on the factors used by the U.S. Environmental Protection Agency in its MOBILE1 emissions model. The latter model, released by EPA in 1978, relied on the results of extensive tests of in-use pre-catalyst (1974 and older) model cars and light trucks conducted at a variety of temperature conditions. However, for oxidation catalyst vehicles, only a limited amount of data on production vehicles was available. There were no data available at that time on production vehicles equipped with three-way catalysts or other systems which have become widely used since 1980.

The temperature correction factors in EMFAC6D are of the form:

$$E_t = E_{6886} * TCF$$

$$TCF = C_1 * e^{a-bt} + C_2$$

where:

E_t = emissions at temperature t

E_{6886} = emissions in the 68-86°F range used for "standard" emissions testing

TCF = temperature correction factor (dimensionless)

t = temperature to which the factors are to be corrected a, b = constants

C_1, C_2 = constants simplified from more complex expressions, and based in part on the age of of the vehicle

The constants are stored in the model for three different model year groupings:

pre-66

1966-74

1975 and later

Table 1 shows the temperature correction factor constants currently in use, as calculated for a five year old vehicle, and based on the standard mix of driving modes. As the table shows, the temperature correction factor for NOx is 1.00 for all vehicle categories and temperatures. Thus, the model assumes that changes in ambient temperature will only affect hydrocarbon and carbon monoxide emissions. The factor is normalized to be 1.00 for these latter two pollutants at a temperature of 75°F.

Because of the manner in which the factors are applied, it is assumed that the effects of temperature change are insignificant after the first 3.59 miles of driving from a cold start.

TABLE 1

CALCULATED TEMPERATURE CORRECTION FACTORS FOR PASSENGER CARS

EMFAC6D

	Temperature					
	0°F	20°F	40°F	60°F	80°F	100°F
Hydrocarbons						
pre-1966	1.34	1.21	1.11	1.04	0.99	0.95
1966-1974	1.48	1.30	1.16	1.06	0.99	0.93
1975 and newer	1.75	1.42	1.21	1.07	0.99	0.93
Carbon Monoxide						
pre-1966	1.47	1.29	1.15	1.06	0.98	0.93
1966-1974	1.65	1.39	1.21	1.08	0.98	0.91
1975 and newer	1.54	1.32	1.17	1.06	0.98	0.93
Oxides of Nitrogen						
pre-1966	1.00	1.00	1.00	1.00	1.00	1.00
1966-1974	1.00	1.00	1.00	1.00	1.00	1.00
1975 and newer	1.00	1.00	1.00	1.00	1.00	1.00

Calculations based on a five year old vehicle using the standard cold/hot start mix. Derived from factors contained in Table C-1 of Reference 1.

Thus, the model assumes that changes in ambient temperature will have no effect on emissions in stabilized modes or after a hot start.

The current factors are shown graphically in Figures 1 and 2 for hydrocarbons and carbon monoxide, respectively. As the figures show, the correction factors are not significantly different for different model years between 40°F and 100°F, the temperature range most commonly used for modeling vehicle emissions in California.

FIGURE 1

EMFAC6D HYDROCARBON TEMPERATURE CORRECTION FACTORS FOR PASSENGER CARS

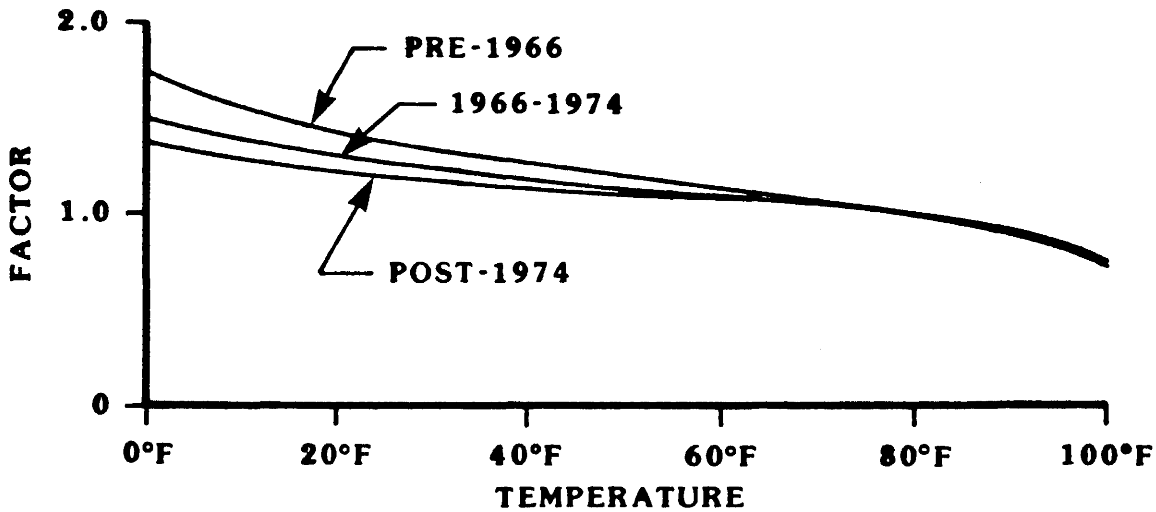
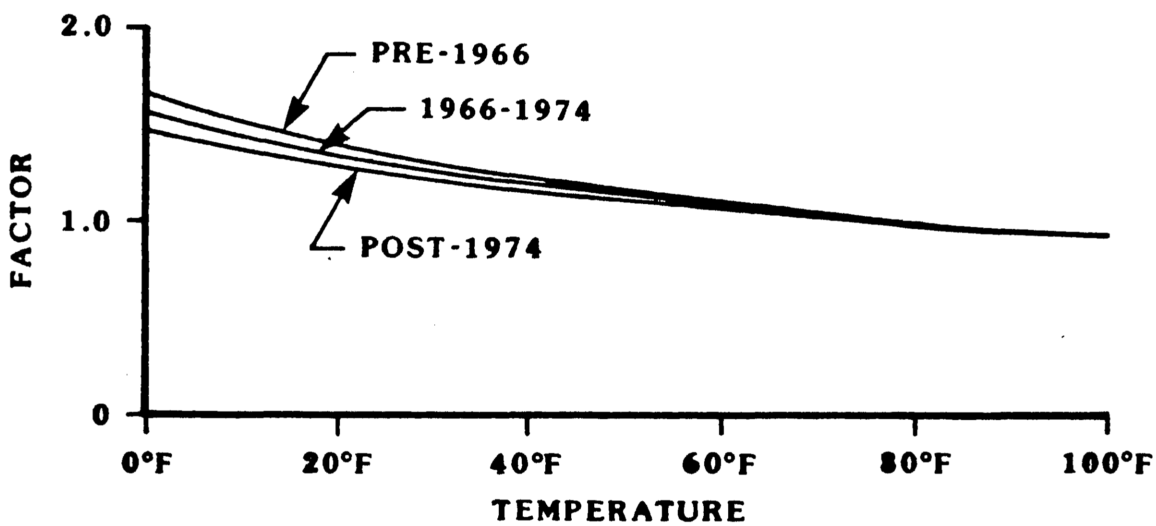


FIGURE 2

EMFAC6D CARBON MONOXIDE TEMPERATURE CORRECTION FACTORS FOR PASSENGER CARS



C. Previous EPA Factors

Since the development of the MOBILE1 emissions model, EPA has updated and improved the model several times. MOBILE1 was replaced by MOBILE2 in 1981[2], which in turn, was informally updated to MOBILE2.5 in 1982. Another version of the model, called MOBILE3, has recently been released for public review and comment.

The temperature correction factors in MOBILE2 are applied as follows:

$$E_t = E_{6886} * TCF$$
$$TCF = e^{a*dt}$$

where:

E_t = emissions at temperature t

E_{6886} = emissions in the 68-86°F range

TCF = temperature correction factor (dimensionless)

dt = the number of degrees outside the standard 68-86°F range

a = constant

The model selects the constant from a data statement in the model. There are different constants for each bag, pollutant, vehicle type, model year group, and temperature range (above or below the 68-86°F window). For temperatures between 68°F and 86°F, the temperature correction factor is set to 1.0.

Separate sets of passenger car factors are provided for the different California model year groups, depending on the pollutant.

Table 2 shows the temperature correction factors contained in MOBILE2, as calculated for a passenger car with 50,000 miles, based on the standard mix of driving modes. The data indicate that the EPA temperature correction factors for all three pollutants are generally much higher than the corresponding California factors. However, at temperatures between 40°F and 80°F, the two sets of factors are generally within 20% of each other.

One of the more significant differences between the EMFAC6D and MOBILE2 factors is that the latter predict <u>increases</u> in HC and CO emissions at temperatures above 86°F, while the EMFAC factors predict decreases.

TABLE 2

CALCULATED TEMPERATURE CORRECTION FACTORS
FOR PASSENGER CARS

MOBILE2

	Temperature					
	0°F	20°F	40°F	60°F	80°F	100°F
<u>Hydrocarbons</u>						
pre-1966	1.89	1.50	1.24	1.05	1.00	0.98
1967-1969	2.30	1.70	1.32	1.07	1.00	1.01
1970-1971	1.91	1.50	1.23	1.05	1.00	0.98
1972-1974	1.85	1.45	1.20	1.04	1.00	1.03
1975-1976	2.66	1.92	1.43	1.10	1.00	1.20
1977-1979	2.60	1.89	1.42	1.09	1.00	1.21
1980 and newer	2.31	1.72	1.34	1.08	1.00	1.06
<u>Carbon Monoxide</u>						
pre-1966	1.32	1.18	1.09	1.02	1.00	1.01
1966-1969	1.99	1.54	1.25	1.05	1.00	1.01
1970-1971	2.20	1.69	1.33	1.07	1.00	1.18
1972-1974	1.72	1.40	1.18	1.04	1.00	1.22
1975-1976	3.02	2.10	1.50	1.11	1.00	1.38
1977-1979	2.94	2.06	1.48	1.11	1.00	1.41
1980 and newer	2.55	1.91	1.44	1.10	1.00	1.07
<u>Oxides of Nitrogen</u>						
pre-1966	1.56	1.36	1.19	1.05	1.00	0.92
1966-1970	1.39	1.26	1.14	1.03	1.00	0.91
1971-1974	1.06	1.04	1.02	1.01	1.00	0.83
1975-1976	1.56	1.37	1.20	1.05	1.00	0.77
1977-1979	1.56	1.37	1.20	1.05	1.00	0.77
1980 and newer	1.02	1.01	1.01	1.00	1.00	0.66

Calculations based on a vehicle with 50,000 miles using the standard cold/hot start mix. Derived from factors contained in Reference 2.

D. Need for Revised Estimates

There are several reasons why the temperature correction factors in EMFAC6D need to be updated.

First, the factors do not reflect data from a significant number of production oxidation catalyst vehicles, or from three-way catalyst vehicles of any kind. The basic factors contained in EMFAC6D are based on the original factors contained in MOBILE1, which was developed before any significant amount of data regarding the performance of catalyst-equipped vehicles was available.

Second, the factors only reflect emissions changes during the first 3.59 miles (or Bag 1) of driving; the model assumes that there is no significant change in emissions at non-standard temperatures after this initial period. Although this may have been true, to a certain extent, for uncontrolled vehicles, the kinds of emissions control systems which have been used since 1970 include speed and temperature sensors which introduce discontinuities in the emissions performance of vehicles.

For example, many vehicles manufactured since the early 1970's have been equipped with systems to advance or retard spark timing under different speed and temperature conditions. These systems are used to reduce hydrocarbon and oxides of nitrogen emissions. Many of the temperature sensors are specifically calibrated by vehicle manufacturers so that the spark control system is activated within the first Bag of the driving cycle under standard test temperatures. However, at much lower temperatures, activation of the spark control system might not occur until some time during the second Bag of the driving cycle. A similar temperature sensor control of exhaust gas recirculation (EGR) systems is also employed on most late model cars. Thus, a temperature correction factor which only addressed Bag 1 emissions would overlook the effect that temperature has on these kinds of systems.

A third reason for reevaluating the temperature correction factors contained in EMFAC6D is that the current factors only address hydrocarbon and carbon monoxide emissions. As shown in the example above, early 1970's model vehicles, as well as later model vehicles, have NOx emission controls which are affected by changes in temperature. This is true at temperatures both above and below the standard 68-86°F range.

E. Organization of this Report

The following section of this report, Section III, includes a discussion of the sources and methods of data collection for this analysis; a description of the quality control techniques used to verify the data before analysis; and a discussion of the general techniques used to analyze the temperature correction test data.

Section IV presents the results of the analysis, and includes a discussion of the results. Separate subsections cover passenger cars; light-duty trucks and medium-duty vehicles; and Diesel powered vehicles.

III. METHODOLOGY

A. Data Collection

The data used in this analysis were collected from a total of 15 reference works. These reports were identified during a detailed search of abstracts of the Society of Automotive Engineers, EPA publications, and references cited in these publications. A list of the references used is shown in Section V; a brief description of each follows.

1. "Low Temperature Automotive Emissions"[3]

Fourteen 1976-1981 model year 49-state passenger cars and light trucks were tested at temperatures ranging from a nominal 0°F to 70°F. Several of the vehicles were repaired and retested to determine the effect of maintenance on cold temperature emissions.

2. "CO Hot Spot Preliminary Investigation"[4]

Five vehicles, two 1970 models and three 1976 models, all passenger cars, were tested on the FTP and New York City driving schedules at 10-25°F and at 77°F. All five vehicles were adjusted to manufacturers' specifications before testing.

3. "<u>The Significance of Engine Warm-up Time on Carbon Monoxide Emissions from Motor Vehicles</u>"[5]

Test results from ten 1977-1980 model vehicles were reported at 20°F and 75°F. During some tests, the cars were left idling for from 2-10 minutes after the cold start, with emissions collected in a separate bag ("Bag 0").

4. "<u>Ambient Temperature and Vehicle Emissions</u>"[6]

Twenty-three 1967-1979 model cars were tested at 20°F, 50°F, 75°F and 110°F using the standard FTP. The vehicles were adjusted to manufacturers' specifications prior to the start of the test program. Five prototype vehicles were also tested during the program, as well as a European Diesel, but were not included in this analysis.

5. "<u>Effect of Ambient Temperature on Vehicle Emissions and Performance Factors</u>"[7]

Thirteen 1972-1980 model cars were tested at 0°F, 20°F, 40°F, 60°F, 70°F, 80°F, 90°F, and 110°F using the FTP, the highway fuel economy test (HFET), the sulfate emission test (SET), and the federal short cycle. The vehicles were all adjusted to manufacturers' specifications prior to testing. One additional vehicle, a prototype three-way catalyst car, was tested but not included in this analysis.

6. "Effect of Ambient Temperature and Driving Cycle on Exhaust Emissions"[8]

Thirty-five cars (30 1970-71 models, 5 1978-79 models) were tested at 25°F, 50°F, 75°F, and 100°F using the FTP, HWFET, and New York City Driving Cycles. The vehicles were all adjusted to manufacturers' specifications prior to testing. Two additional vehicles, both production Diesel cars, were included in the program but were analyzed separately.

7. "Effects of Low Temperature on the Exhaust Emissions and Fuel Economy of 84 Automobiles in Chicago"[9]

Eighty-four 1972-1977 model year passenger cars were tested using the FTP at the standard 68-86°F temperature range, and at ambient temperatures which ranged from 16°F to 60°F. The vehicles were tested without adjustments, as received from their owners. Some of the vehicles were repaired and retested, but only at the standard temperature range.

8. "Low Ambient Temperature Emission Testing, A Preliminary Report"[10]

Five 1962-1971 model cars were tested at 40°F, 50°F, 60°F, and 68-86°F, using the FTP.

9. "An Evaluation of Automotive CO Emission Control Techniques at Low Temperatures"[11]

Ninety-eight 1976-1983 model cars and light trucks were tested at nominal 20°F and/or 75°F temperatures using the FTP. Some vehicles were repaired and retested at those temperatures, and some were equipped with retrofit devices and retested, all in order to evaluate techniques for reducing cold temperature emissions. Many vehicles were not included in this analysis because they were only tested at cold temperatures, and not at the standard FTP temperature range.

10. "Impact of Low Ambient Temperature on 3-Way Catalyst Car Emissions"[12]

Four 1979-1980 model cars equipped with closed-loop three-way catalyst systems were tested using the FTP at ambient temperatures between 50°F and 65°F, and at temperatures in the standard 68°F to 86°F range.

11. "Cold Temperature Effects on Emissions from Light-Duty Motor Vehicles"[13]

Nine 1973 model cars were tested at ambient temperatures ranging from -9°F to 80°F using the FTP. The vehicles were tuned to manufacturers specifications prior to the start of testing, and were maintained to those specifications throughout the six month test program.

12. "Evaluation of the Temperature Effects on Five 1981 Passenger Vehicles"[14]

Five 1981 model cars were tested at 20°F, 60°F, 75°F, and 100°F using the FTP and highway fuel economy test. The vehicles were all relatively new (less than 7,500 miles), and were all properly adjusted to manufacturers specifications.

13. "Emission Effects of Inspection and Maintenance at Cold Temperatures"[15]

Four 1977-1980 model cars were tested at 20°F and 50°F using the FTP. The vehicles were tested after adjustment to manufacturers' specifications, and after certain maladjustments were deliberately introduced. The data from this report were not used because none of the vehicles were tested at the standard 68-86°F range.

14. "Carbon Monoxide and Non-FTP Ambient Temperatures"[16]

Ten 1978-1981 model vehicles were tested using the FTP and highway fuel economy tests at 20°F, 60°F, 75°F and 100°F. The vehicles were all relatively low mileage, and were adjusted to manufacturers' specifications before testing. This test group includes a good cross-section of 1980 and later model technologies.

15. "Unpublished EPA Test Results"[17]

This reference contained the FTP emissions test results from 73 1980-1983 model vehicles which were tested at nominal temperatures of 20°F, 50°F and 75°F. The vehicles were tested in the condition received from their owners, and had odometer readings as high as 97,000 miles. Some of the vehicles were repaired and retested at 75°F.

B. Data Correction

As described in the preceding section, the data used to develop temperature correction factors came from a variety of sources, and had been presented in a variety of formats. All of the data from the reference works were manually entered into a computerized data base. In order to facilitate data entry and minimize the chances of error on data entry, custom computer screen displays were created which matched the form of the data display in the reference source.

Once all of the data were entered, a number of verification checks were run to minimize the chances of error. Variables which were subjected to limit checks included model year, test date, test temperature, odometer, emissions, and fuel economy. The checks for the latter two variables included both checks to ensure that emissions and fuel consumption were not outside of the ranges normally expected, and to ensure that conversions from grams to grams per mile, and from individual bag emissions to composite FTP rates, had been properly performed.

If the limit checks indicated a potential error in any record, a hard copy of the record was printed for comparison with the original reference source. Simple data entry errors were quickly identified and corrected. More difficult, however, were errors found in the original reference works. Arithmetic errors were generally not too difficult to uncover; however, typographical errors presented more of a problem. As a general rule, data errors were corrected in reference works by back-calculation from averages or composites shown in the same work; by comparing individual test results with replicate test results from the same vehicle; and by looking for transposition or slipped decimal point errors which could explain the discrepancy.

Using these techniques, all of the records which failed the quality control tests were identified and corrected.

C. Data Analysis

1. Discrete Temperature Ranges

The current temperature correction factors contained in EMFAC and MOBILE2 are continuous functions; that is, a different temperature correction factor is calculated for each temperature. For example, the models will estimate different emissions for a vehicle operating at 24°F from operations at 25°F.

However, most of the test data which is available is based on testing conducted at discrete temperature intervals. The most common test temperatures are 0, 20, 40, 60, 80 and 100°F. Some test programs were conducted with temperatures at 25, 50, 75, and 100°F; a few tested at ambient temperatures, which varied between 0 and 30°F for the Alaskan test programs, and between 20 and 60°F for the EPA Chicago test program.

Although the data from tests conducted at discrete temperature intervals could be mathematically interpolated to form a continuous function, the authors believe that such an analysis may stretch the data beyond its valid limits. In addition, if the data were forced to fit a continuous function, it would not properly reflect discontinuities associated with certain kinds of technologies (such as the spark and EGR control systems mentioned earlier).

For this reason, the test data were grouped into five temperature ranges for analysis:

$< 30^\circ F$

$30\text{-}49^\circ F$

$50\text{-}67^\circ F$

$68\text{-}86^\circ F$

$> 86^\circ F$

The temperature ranges were chosen in order to spread the data relatively evenly throughout the categories; to match the most common test conditions; and to ensure that most of the data would be towards the center of each range, rather than at each extreme. In addition, these ranges correspond to five typical weather conditions in California:

< 30°F: night and early morning winter temperatures in the Sierras and in the Lake Tahoe air basin

30-49°F: night and early morning winter temperatures in the Sacramento and San Joaquin Valley air basins, and daytime winter temperatures in the Sierras and at Lake Tahoe

50-67°F: night and early morning temperatures year-round in the San Francisco Bay, South Coast, and San Diego air basins, and winter daytime temperatures in the Central Valley

68-86°F: summer daytime temperatures in the state's coastal metropolitan areas

>86°F: summer daytime temperatures in the state's inland metropolitan areas

2. Model Year Groupings

Virtually all of the available temperature data is from 49-state vehicles. Only nineteen (of the 291 vehicles included in the sample) had been designed to meet California emission standards. Consequently, the initial model year groupings were based on the federal standards, and the analyzed data were then translated into comparable California bases.

Passenger car control technologies and emission standards generally fall into seven distinct categories:

Category	Control Technology	Federal Model Years	California Model Years
1	pre-control	pre-1968	pre-1966
2	EM/AI	1968-1969	1966-1969
3	EM/AI/spark	1970-1971	1970-1971
4	EM/AI/spark/EGR	1972-1974	1972-1974
5	early ox. cat.	1975-1979	1975-1976
6	advanced ox. cat.	1980	1977-1979
7	three-way cat.	post-1980	post-1979

EM: engine modifications; AI: air injection system; spark: spark retard systems; EGR: exhaust gas recirculation

As the groupings shown above suggest, California controls generally preceded similar federal control systems by one or two years. The relatively minor differences in emissions standards between the federal and California requirements for each technology grouping would not be expected to significantly alter the temperature effects this analysis attempted to quantify. Therefore, for the first six groups, a simple translation was used to convert the 49-state data into the appropriate model year groups to represent California data.

For 1980 and later model California vehicles (1981 and newer Federal models), the different types of emissions control technologies begin to play a more significant role. These later model cars are equipped with oxidation catalyst systems, open-loop three-way catalyst systems, and closed-loop three-way catalyst systems; some use sophisticated carburetors, some use multi-point fuel injection systems, and some use throttle body or single-point fuel injection; some have full electronic controls, while others have little or no electronics.

Unfortunately, there is insufficient data to identify separate temperature effects for each technology type. There were only 89 vehicles in the entire 1981 and newer model year category. When the category was subdivided by control technology, it was not uncommon to find only one or two vehicles which used certain technologies. In addition, for those categories where there were as many as five or six tests, there did not appear to be any significant difference between the different control technologies on the effects of temperature on emissions levels.

The only technological factor which did appear to have an effect was the vehicle fuel system. Fuel injection, and particularly intake port fuel injection, (as opposed to throttle body fuel injection) appears to reduce cold start, cold temperature emissions because it reduces the amount of fuel required to run the engine when it is cold. When fuel is injected close to the intake port, there is less opportunity for puddling of fuel on the floor of the intake manifold. Carbureted engines tend to deposit a significant amount of liquid fuel onto the walls of the intake manifold during cold temperature starts. Because this fuel does not enter the cylinder in an atomized or vaporized form, it mixes very inefficiently with the air, necessitating an overly rich air fuel ratio to achieve reliable initiation of combustion. The overly rich air fuel ratio results in higher hydrocarbon and carbon monoxide emissions.

For this reason, the 1981 and newer model category was subdivided into carbureted, throttle-body fuel injected, and multi-point fuel injected models.

3. Applicability to Other Vehicle Categories

Due to the limited amount of test data from light-duty trucks and medium-duty vehicles regarding the effects of temperature on emissions, the passenger car factors were generally applied to vehicle categories and model years where the technology groupings were similar.

The equivalences used to relate the temperature correction factors for light-duty trucks and medium-duty vehicles with the passenger car factors are shown in Tables 3 and 4, respectively.

4. Analytical Approach

As described in previous sections of the report, both the MOBILE2 and EMFAC6D temperature correction factors are multiplicative factors; that is, the increase or decrease in emissions due to the effects of temperature is assumed to be a certain percentage of the vehicle's emissions in grams per mile. Consequently, for a given temperature, model year, pollutant and bag, the current temperature correction factors assume that a poorly maintained car will exhibit a larger change in emissions due to temperature variations than a properly maintained car. However, recent work done by and for EPA and the Motor Vehicle Manufacturer's Association has suggested that, in some circumstances,

TABLE 3

LIGHT-DUTY TRUCK CATEGORIES

Control Technology	Passenger Car Model Years	Equivalent Light-Duty Truck Model Years
pre-control	pre-1966	pre-1966
EM/AI	1966-1969	1966-1969
EM/AI/spark	1970-1971	1970-1971
EM/AI/spark/EGR	1972-1974	1972-1974
early ox. cat.	1975-1976	1975-1978
advanced ox. cat.	1977-1979	1979-1982
three-way cat.	post-1979	post-1982

TABLE 4

MEDIUM-DUTY VEHICLE CATEGORIES

Control Technology	Passenger Car Model Years	Equivalent Medium-Duty Vehicle Model Years
pre-control	pre-1966	pre-1970
EM/AI	1966-1969	1970-1974
EM/AI/spark	1970-1971	1975-1976
EM/AI/spark/EGR	1972-1974	1977
early ox. cat.	1975-1976	1978-1980
advanced ox. cat.	1977-1979	1981-1982
three-way cat.	post-1979	post-1982

temperature effects are additive. That is, regardless of the state of tune of the vehicle or how long it is driven, for example, a decrease in temperature would result in a constant gram per mile increase in carbon monoxide emissions for vehicles of a given model year.

The rationale expressed for additive correction factors, particularly for cold temperature effects, has to do with the causes of increased emissions at cold temperatures. Hydrocarbon and carbon monoxide emissions tend to increase at cold temperatures due principally to the longer time the vehicle is operated with cold start mixture enrichment. Most carbureted vehicles have chokes which remain closed, richening the air/fuel ratio, until a bimetallic strip connected to the choke linkage reaches a predetermined temperature. Fuel injected vehicles usually maintain mixture enrichment until the engine temperature reaches a predetermined level. If a vehicle is started after being stored overnight at, say, 20°F, it will take significantly longer to reach these predetermined temperatures than if the vehicle was stored at 75°F. Thus, lower temperatures can be directly correlated with longer choke-on or mixture enrichment times.

In addition to the length of time the mixture is enriched, catalyst light-off time is a function of ambient temperature. Catalysts have a certain amount of thermal inertia which must be overcome by the flow rate and temperature of exhaust gas passing over the catalyst bed before it reaches its proper operating temperature. The lower the ambient temperature, the lower the intake air temperature and, consequently, the lower the exhaust gas temperature upon vehicle start-up. In addition, if a vehicle has been stored overnight at 20°F, the catalytic converter would be at that temperature as well, so that it would take additional time to reach typical operating temperatures.

The combined effect of both increased mixture enrichment time and increased catalyst light-off time is that, for a period of time after vehicle start-up, vehicle emissions are increased by fuel-rich, non-catalyst operation. The emissions level associated with that operation does not vary significantly with the vehicle's state of tune, since mixture enrichment tends to mask other vehicle malfunctions such as rich idle mixtures. In addition, emissions control system tampering would not show up under these conditions because most controls are either non-operative by design at cold temperatures or do not reach operating temperatures for some period after a cold start.

As a consequence of these effects, the increase in vehicle emissions at cold temperatures might be expected to be a function of temperature (which would determine the cold start mixture enrichment time), but not of warmed-up emissions. Thus, the temperature effect might be best represented as a constant gram per mile increase in emissions.

In order to determine whether additive or multiplicative correction factors were most appropriate, two different types of statistical analyses were conducted. The analyses were run for data subsets which consisted of vehicles grouped by temperature range, model year category, pollutant and FTP bag. For each subset, the emissions from each vehicle at the specific temperature range were compared to the emissions from the same vehicle when tested at the standard 68-86°F temperature range. The difference in emissions due to temperature for each vehicle was calculated both on an absolute grams per mile basis and on a relative (percent change) basis compared to the emissions at standard temperatures.

Within each subset, these additive and multiplicative differences were averaged, and their standard deviations and coefficients of variability were calculated. The smaller coefficient of variability was assumed to indicate that the particular statistic (additive or multiplicative factors) more appropriately and consistently reflected the effects of temperature on emissions. For example, if the additive factors had a smaller coefficient of variability than the multiplicative factors, it would suggest that despite differences in absolute emissions levels between the different vehicles in a subset, the gram per mile difference between the emissions at each temperature range for each vehicle was more constant than the percentage difference.

The second analytical technique was the performance of a linear regression of the form $y = a + bx$, where y equals the emissions at the non-standard temperature range, x equals the emissions at the standard 68-86° F temperature range, and "a" and "b" are constants. If an additive factor more appropriately reflected the relationship between emissions and temperature, one would expect the relationship to show that "b" would be close to 1.0. In this case, the equation would reduce to the form $y = a + x$, where "a" is a constant additive correction factor. If the temperature correction factor were multiplicative, one would expect the regression to show "a" as close to zero. In this case, the equation would reduce to the form $y = bx$. If there were no significant temperature effect at all, one would expect to find both "a" equal to zero and "b" equal to one, and "y" would be equal to "x".

Each of these hypotheses was tested at the 90% confidence level, and the conclusions were noted for each subgroup as a "preference" for an additive correction factor, a multiplicative factor, neither, or both. When the results of each of the two types of analyses were initially tabulated for the different subsets, no consistent trend was readily apparent. Consequently, the results of the analyses in terms of the preference for additive or multiplicative factors were consolidated into two temperature groups, below 68°F and above 86°F. After making this consolidation, several trends became apparent.

For Bag 1 hydrocarbon and carbon monoxide emissions at temperatures below 68°F, there was a moderately strong preference for additive correction factors. Although the preference was much stronger with carbon monoxide, the effect of decreasing temperatures on hydrocarbons and carbon monoxide should be similar, given the fact that cold start mixture enrichment time and catalyst light-off times are the most significant causes of the higher emissions.

In addition, for Bag 3 hydrocarbons at temperatures above 86°F, there is a slight preference for an additive correction factor. For most other bags, pollutants, and conditions, a multiplicative factor appeared more appropriate. The principal exception was in vehicle categories where catalytic controls played an important role. Since the data base used to determine the temperature correction factors is much smaller than the data available for establishing the basic emission factors, it is not surprising that the basic emission levels from the former could vary significantly from the latter. This presented particular problems when multiplicative factors were derived from a subset of the temperature data base which had emissions significantly lower than the emissions factors estimated from the larger data base.

For example, if actual average Bag 2 hydrocarbons at standard temperatures were 0.1 grams per mile, and were 0.5 grams per mile at 20°F, one would calculate a multiplicative factor of 5.0. If this factor were then applied to the standard emissions factor for this subset, which, for example, was 0.5 grams per mile, a calculated emissions factor at 20°F would be 2.5 grams per mile, significantly higher than the measured level of 0.5 grams per mile. In plotting the results of the analysis, these kinds of problems showed up as gross anomalies in otherwise consistent trends. For this reason, the temperature correction factors for Bag 2 hydrocarbons and carbon monoxide for all vehicle categories at temperature ranges below 68°F were changed from the multiplicative form suggested by the statistical analysis to an additive form. In addition, the Bag 3 factors for all three pollutants were changed to an additive form for those vehicle categories when the pollutant was generally catalytically controlled: 1975 and newer models for HC and CO, and 1980 and newer models for NOx.

IV. RESULTS

A. Passenger Cars

1. Hydrocarbons

The calculated temperature correction factors for hydrocarbon emissions from passenger cars are shown in Table 5. The results have been applied to the basic emissions factors contained in EMFAC6C for a 5 year old vehicle in Figures 3, 4, and 5 for pre-1975 models, 1975-79 models, and 1980 and newer models, respectively.

As shown in the three Figures, use of the current EMFAC temperature correction factors seriously underestimates cold temperature hydrocarbon emissions for most vehicle categories, compared to the use of the new factors developed under this study. Although hydrocarbons (and resulting oxidant levels) are not a serious concern at cold temperatures, the steepness of the increase in hydrocarbon emissions at temperatures just below the standard 68-86°F range could result in an underestimate of early morning hydrocarbon emissions which are responsible for peak oxidant levels later in the day.

TABLE 5

HYDROCARBON TEMPERATURE CORRECTION FACTORS
FOR PASSENGER CARS

BAG	MODEL YEARS	<30°F	30-49°F	50-67°F	68-86°F	>86°F
1		gm/mi	gm/mi	gm/mi	gm/mi	ratio
	pre-66	18.27	14.09*	9.90	0.00	0.72
	66-69	16.16	10.23*	4.29	0.00	0.75
	70-71	5.56	3.95*	2.33	0.00	0.83
	72-74	9.62	4.59	1.94	0.00	0.85
	75-76	8.57	6.26	1.90	0.00	0.72
	77-79	8.33	6.02*	3.71	0.00	0.94
	80+CARB	6.73	4.58*	2.43	0.00	0.74
	80+TBI	4.75	3.06*	1.37	0.00	0.74**
	80+FI	1.98	0.92	0.73	0.00	0.74**
2		gm/mi	gm/mi	gm/mi	gm/mi	ratio
	pre-66	0.98	0.56*	0.14	0.00	1.03
	66-69	0.90	0.43*	-0.04	0.00	1.11
	70-71	0.20	0.13*	0.05	0.00	1.03
	72-74	0.42	0.30	0.03	0.00	1.08
	75-76	0.44	0.95	0.14	0.00	1.36
	77-79	0.59	0.41*	0.22	0.00	1.27
	80+CARB	0.52	0.44*	0.35	0.00	0.90
	80+TBI	0.04	0.02*	0.00	0.00	0.90**
	80+FI	0.01	0.02	-0.05	0.00	0.90**
3		ratio	ratio	ratio	gm/mi	gm/mi
	pre-66	1.04	1.02*	1.00	0.00	0.56
	66-69	1.05	1.03*	1.01	0.00	0.83
	70-71	1.07	1.04*	1.00	0.00	0.30
	72-74	1.09	1.03	0.91	0.00	0.97
		gm/mi	gm/mi	gm/mi		
	75-76	0.08	0.18	0.03	0.00	0.40
	77-79	0.39	0.26*	0.12	0.00	0.41
	80+CARB	0.35	0.31*	0.26	0.00	-0.02
	80+TBI	0.48	0.38*	0.28	0.00	-0.02**
	80+FI	-0.01	0.01	-0.07	0.00	-0.02**

*No data or inadequate data available; estimated by interpolation.
**No data available; assumed to be the same as for carbureted vehicles.

FIGURE 3

HC EMISSIONS vs. TEMPERATURE PRE-1975 MODEL PASSENGER CARS EMFAC6C EMISSION RATES

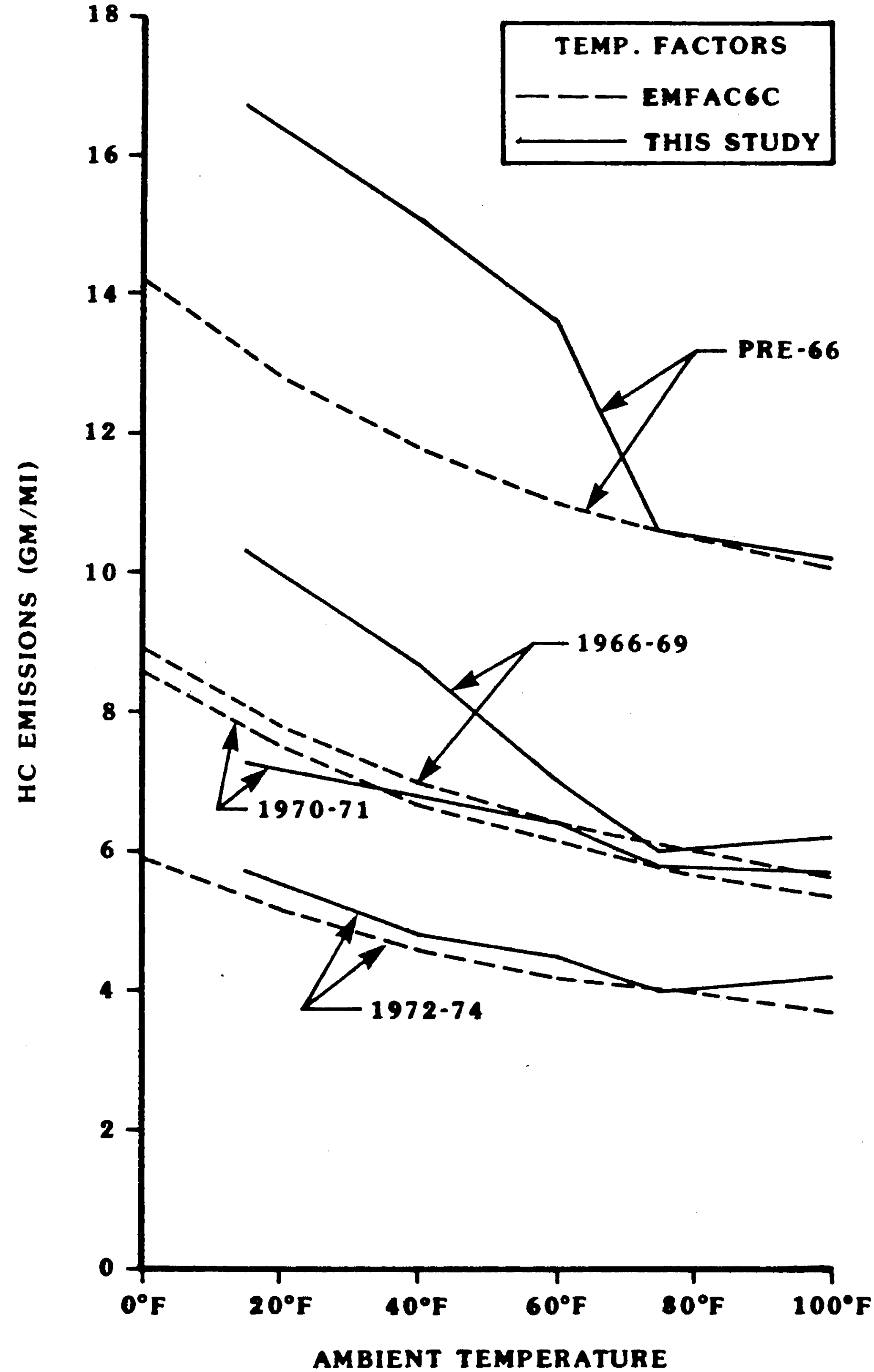


FIGURE 4

HC EMISSIONS vs. TEMPERATURE
1975-79 MODEL PASSENGER CARS
EMFAC6C EMISSION RATES

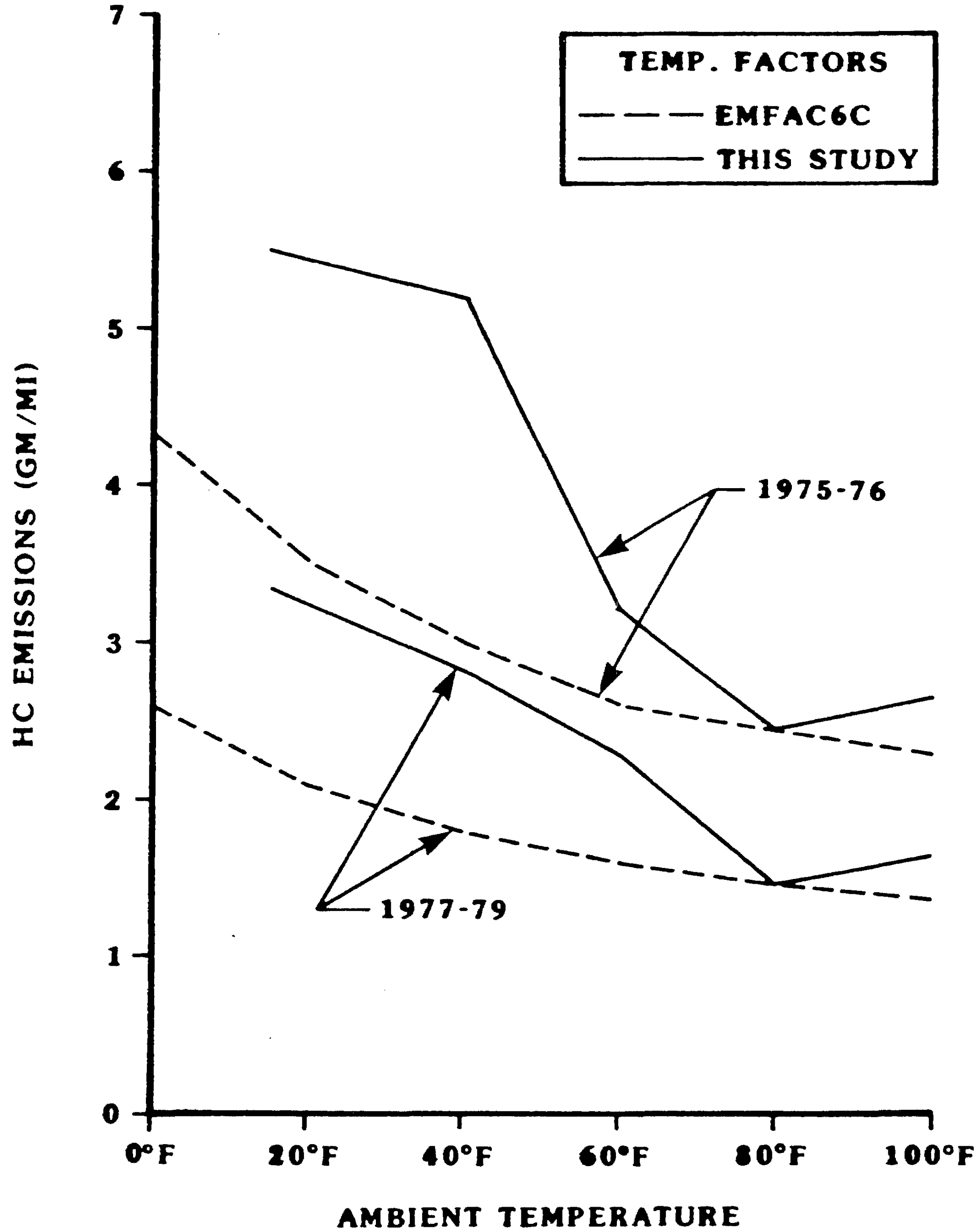
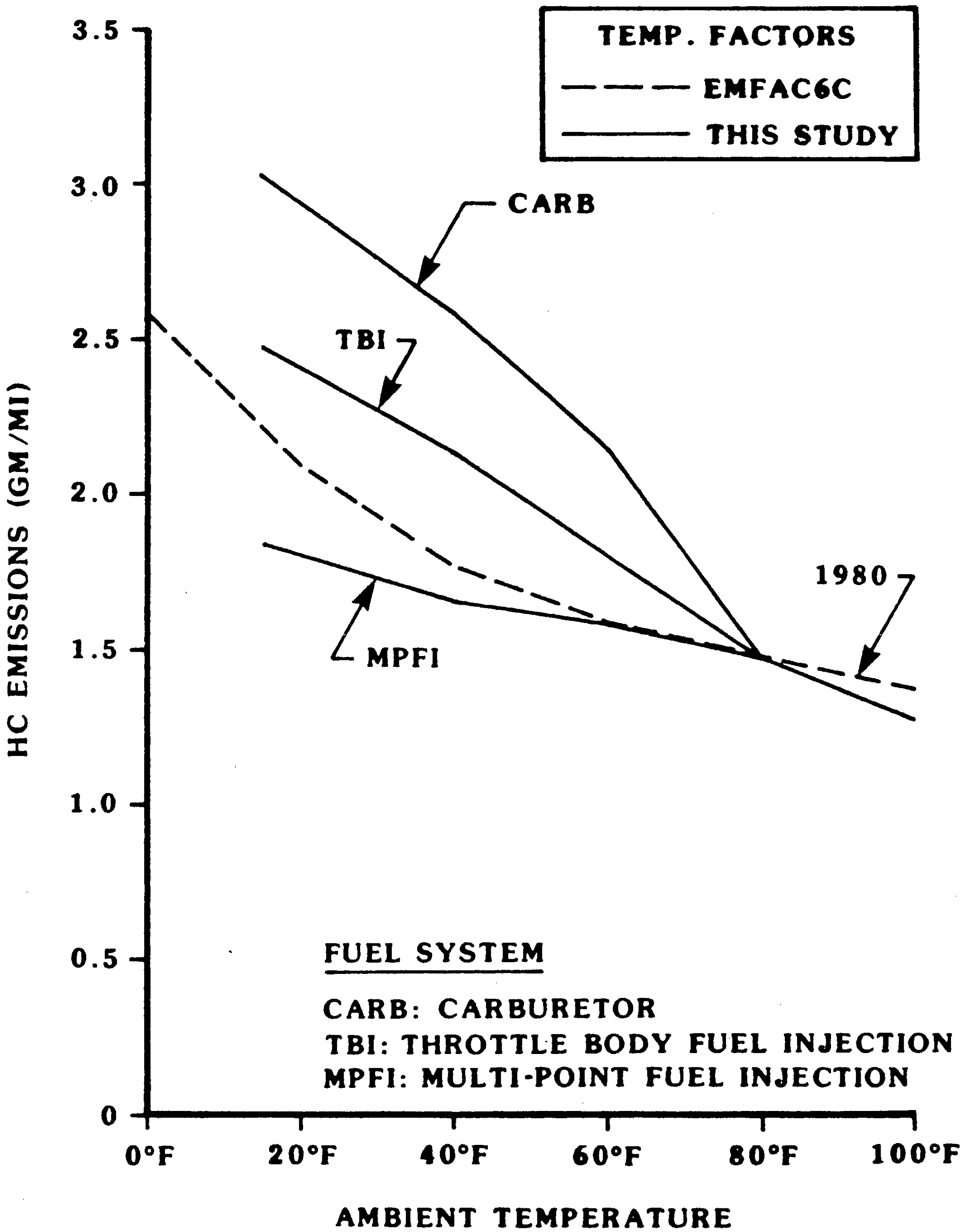


FIGURE 5

HC EMISSIONS vs. TEMPERATURE
POST-1979 MODEL PASSENGER CARS
EMFAC6C EMISSION RATES



In addition, the Figures show that the current assumption in EMFAC that ambient temperature only affects Bag 1 emissions has resulted in a slight underestimate of hydrocarbons at temperatures above 86°F. These emissions increases, principally in Bag 3 and, to a lesser extent, Bag 2, overwhelm the Bag 1 reductions which occur at warmer temperatures. It is interesting to note that this effect was relatively small for pre-1975 model cars, increased somewhat for 1975-79 models, and has been virtually eliminated with 1980 and newer models. The reasons for these changes appear to be a relatively complex interaction between underhood temperatures (which increased during the mid and late 1970's); evaporative emission standards (which were relatively ineffective during the early 1970's, and which were significantly tightened in 1980); and the sophistication of carbon canister purge controls, which became much more effective in 1980.

Finally, Figure 5 supports the hypothesis that multi-point fuel injected vehicles are relatively less sensitive to temperature variations than are carbureted vehicles. Vehicles equipped with throttle-body type fuel injection systems appear to have emissions performance in between the other two fuel system types.

2. Carbon Monoxide

The calculated temperature correction factors for carbon monoxide are shown in Table 6. The data, as applied to a 5 year old vehicle, are graphically represented in Figures 6, 7, and 8 for pre-1975, 1975-79, and 1980 and newer model vehicles.

Figure 6 shows that current CO correction factors for pre-1975 model cars appear reasonably consistent with the new factors between about 20° and 86°. However, the current factors start to overestimate CO emissions from these vehicles at very cold temperatures, and underestimate CO emissions at warmer temperatures. Figure 7 shows that the current factors seriously underestimate CO emissions at all non-standard temperatures for 1975-79 model vehicles; Figure 8 suggests the same thing for 1980 and newer models.

Figure 8 also shows again that multi-point fuel injection systems are far less sensitive to temperature variations than either carbureted or throttle-body systems. In contrast to the hydrocarbon results, however, the TBI systems do not exhibit significantly better CO performance than carbureted systems.

TABLE 6

CARBON MONOXIDE
TEMPERATURE CORRECTION FACTORS
FOR PASSENGER CARS

BAG	MODEL YEARS	<30°F	30-49°F	50-67°F	68-86°F	>86°F
1		gm/mi	gm/mi	gm/mi	gm/mi	ratio
	pre-66	126.36	97.73*	69.09	0.00	0.73
	66-69	151.76	102.64*	53.52	0.00	0.44
	70-71	84.19	63.11*	42.02	0.00	0.68
	72-74	128.35	93.44	48.84	0.00	0.83
	75-76	94.39	82.73	31.64	0.00	0.79
	77-79	75.03	36.20	29.96	0.00	0.89
	80+CARB	80.10	59.14*	38.17	0.00	0.70
	80+TBI	81.82	57.11*	32.40	0.00	0.70**
	80+FI	30.06	20.80*	24.10	0.00	0.70**
2		gm/mi	gm/mi	gm/mi	gm/mi	ratio
	pre-66	-8.83	-6.46*	-4.09	0.00	1.10
	66-69	6.85	5.05*	3.25	0.00	1.26
	70-71	4.90	3.12*	1.33	0.00	1.15
	72-74	4.43	1.49	-2.50	0.00	1.91
	75-76	9.24	7.11	3.44	0.00	2.23
	77-79	6.90	1.84	1.13	0.00	2.01
	80+CARB	9.39	7.22*	5.05	0.00	1.99
	80+TBI	0.34	0.30*	0.26	0.00	1.99**
	80+FI	0.25	0.65	-0.20	0.00	1.99**
3		ratio	ratio	ratio	gm/mi	gm/mi
	pre-66	0.95	0.97*	0.99	0.00	26.30
	66-69	0.95	1.00*	1.05	0.00	20.91
	70-71	1.09	1.07*	1.05	0.00	7.02
	72-74	1.16	0.96	1.00	0.00	25.73
		gm/mi	gm/mi	gm/mi		
	75-76	0.99	0.11	-0.99	0.00	10.22
	77-79	2.67	0.61	2.10	0.00	6.77
	80+CARB	7.25	6.57*	5.88	0.00	0.78
	80+TBI	16.70	13.97*	11.24	0.00	0.78**
	80+FI	0.38	0.45	-0.94	0.00	0.78**

*No data or inadequate data available; estimated by interpolation.
**No data available; assumed to be the same as for carbureted vehicles.

FIGURE 6

CO EMISSIONS vs. TEMPERATURE
PRE-1975 MODEL PASSENGER CARS
EMFAC6C EMISSION RATES

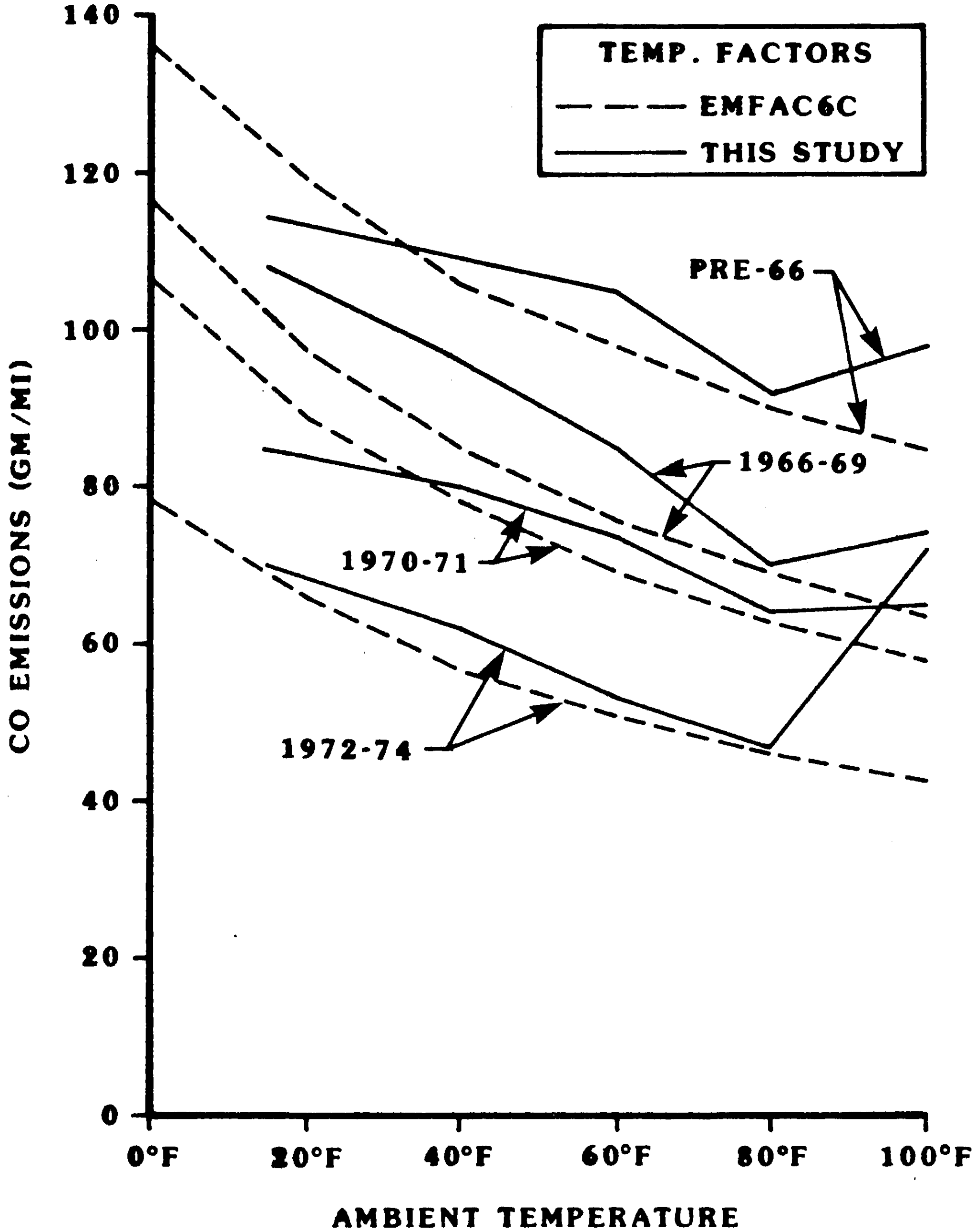


FIGURE 7

CO EMISSIONS vs. TEMPERATURE
1975-79 MODEL PASSENGER CARS
EMFAC6C EMISSION RATES

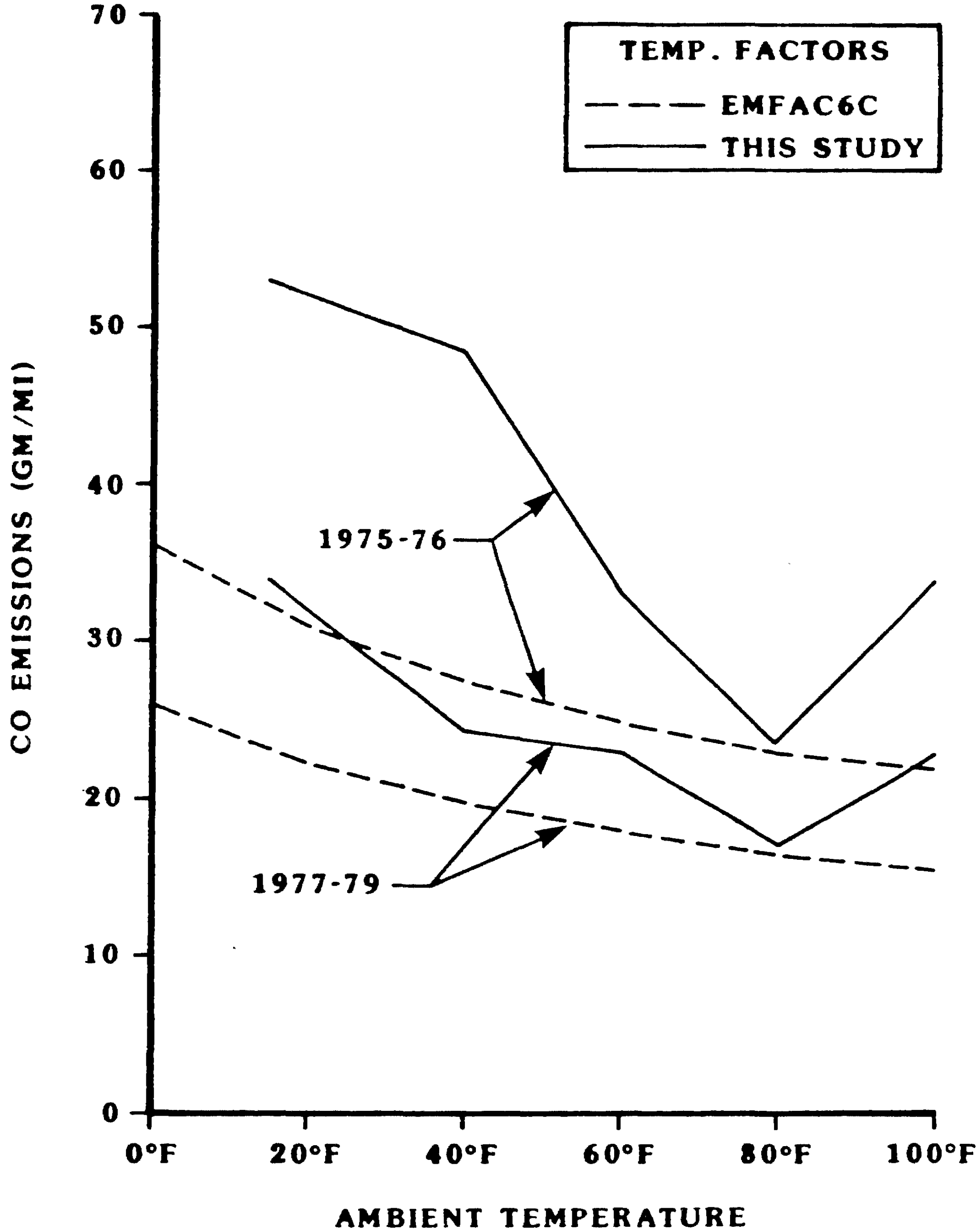
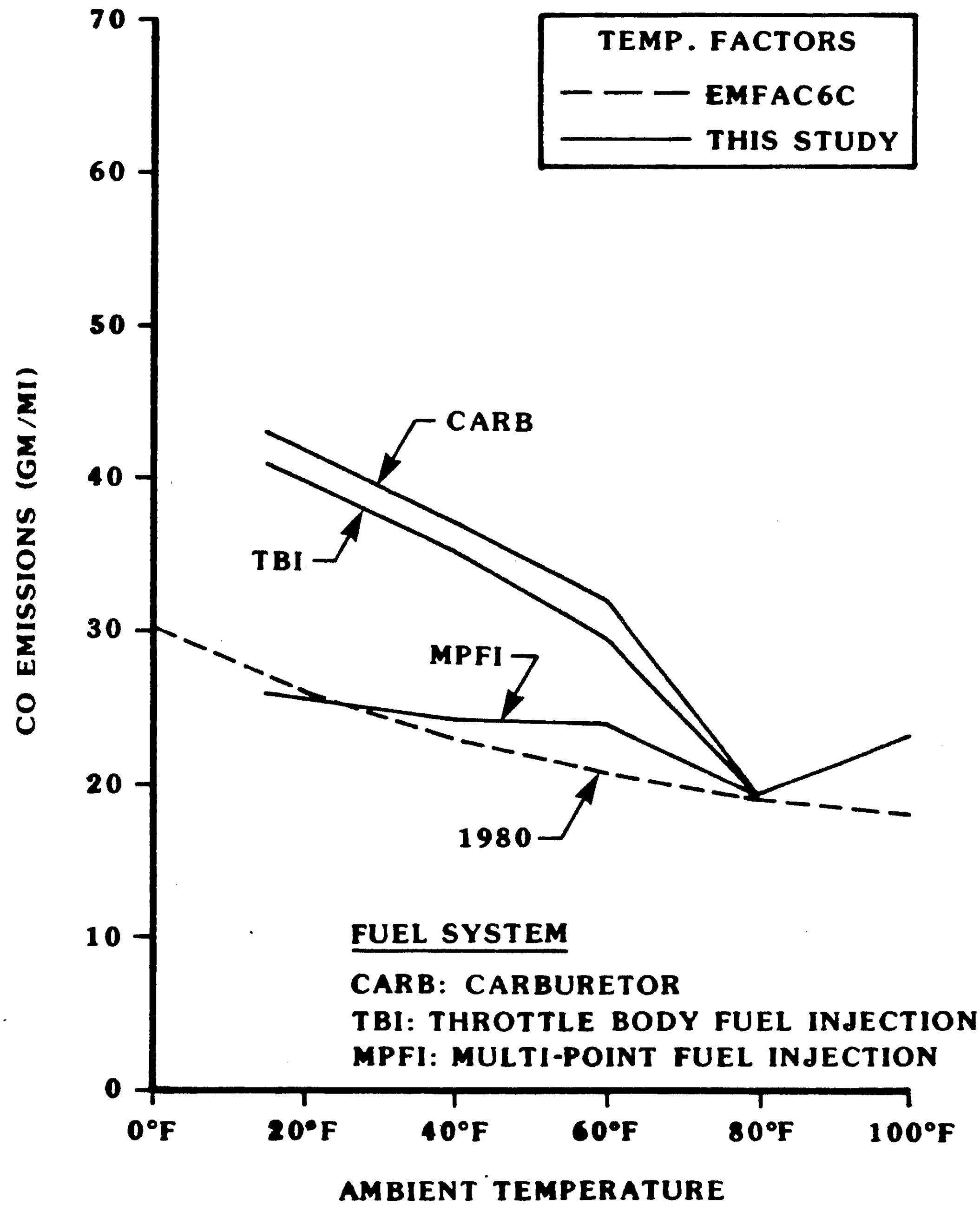


FIGURE 8

CO EMISSIONS vs. TEMPERATURE
POST-1979 MODEL PASSENGER CARS
EMFAC6C EMISSION RATES



3. Oxides of Nitrogen

The calculated oxides of nitrogen temperature correction factors are shown in Table 7, and are graphically illustrated in Figures 9, 10, and 11.

The data indicate that, in contrast with the assumption in EMFAC6 that temperature changes do not affect NOx emissions, there is a clear relationship for 1979 and older models. With a few exceptions, most pre-1980 vehicle categories showed NOx emissions increasing at colder temperatures. This is likely due to two factors: increased engine friction at colder temperatures, and coolant temperature sensors which deactivate EGR systems at cold temperatures. These two effects appear to outweigh, for most vehicle categories, the fact that warmer ambient temperatures result in slightly higher combustion temperatures, which, in turn, would tend to increase NOx emissions.

As shown in Figure 11, however, NOx emissions from 1980 and newer model vehicles appear to be insensitive to temperature changes. Since these vehicles tend to have similar EGR systems to earlier models, and, in addition, rely to some extent on catalytic NOx controls which would be affected by temperature, these results are somewhat puzzling. Since these factors are applied to bag-specific standard emissions factors in EMFAC6, which are unrepresentatively high and

TABLE 7

OXIDES OF NITROGEN
TEMPERATURE CORRECTION FACTORS
FOR PASSENGER CARS

BAG	MODEL YEARS	<30°F	30-49°F	50-67°F	68-86°F	>86°F
1		ratio	ratio	ratio	ratio	ratio
	pre-66	1.07	1.06*	1.04	1.00	1.12
	66-69	1.04	1.02*	0.99	1.00	1.23
	70-71	0.89	0.92*	0.95	1.00	1.05
	72-74	1.08	1.11	1.05	1.00	0.98
	75-76	1.12	1.30	1.21	1.00	0.91
	77-79	1.30	1.23	1.10	1.00	1.04
		gm/mi	gm/mi	gm/mi	gm/mi	gm/mi
	80+CARB	0.46	0.40*	0.34	0.00	-0.16
	80+TBI	0.12	0.14*	0.15	0.00	-0.16**
	80+FI	0.02	0.20	-0.08	0.00	-0.16**
2		ratio	ratio	ratio	ratio	ratio
	pre-66	1.58	1.39*	1.20	1.00	0.83
	66-69	1.36	1.23*	1.10	1.00	1.00
	70-71	1.03	1.03*	1.03	1.00	1.02
	72-74	1.75	1.59	1.01	1.00	0.95
	75-76	1.17	0.83	1.02	1.00	1.04
	77-79	1.55	1.28	1.21	1.00	1.02
		gm/mi	gm/mi	gm/mi	gm/mi	gm/mi
	80+CARB	0.21	0.18*	0.14	0.00	-0.03
	80+TBI	0.22	0.26*	0.30	0.00	-0.03**
	80+FI	0.16	0.14	-0.04	0.00	-0.03**
3		ratio	ratio	ratio	ratio	ratio
	pre-66	1.45	1.30*	1.15	1.00	0.78
	66-69	1.34	1.24*	1.13	1.00	0.90
	70-71	1.04	1.03*	1.02	1.00	1.02
	72-74	1.46	1.32	1.05	1.00	0.88
	75-76	1.12	0.93	1.10	1.00	1.04
	77-79	1.31	1.21	1.16	1.00	0.89
		gm/mi	gm/mi	gm/mi	gm/mi	gm/mi
	80+CARB	0.38	0.28*	0.18	0.00	-0.09
	80+TBI	0.23	0.18*	0.12	0.00	-0.09**
	80+FI	0.45	0.40	0.01	0.00	-0.09**

*No data or inadequate data available; estimated by interpolation.
**No data available; assumed to be the same as for carbureted vehicles.

FIGURE 9

NOx EMISSIONS vs. TEMPERATURE
PRE-1975 MODEL PASSENGER CARS
EMFAC6C EMISSION RATES

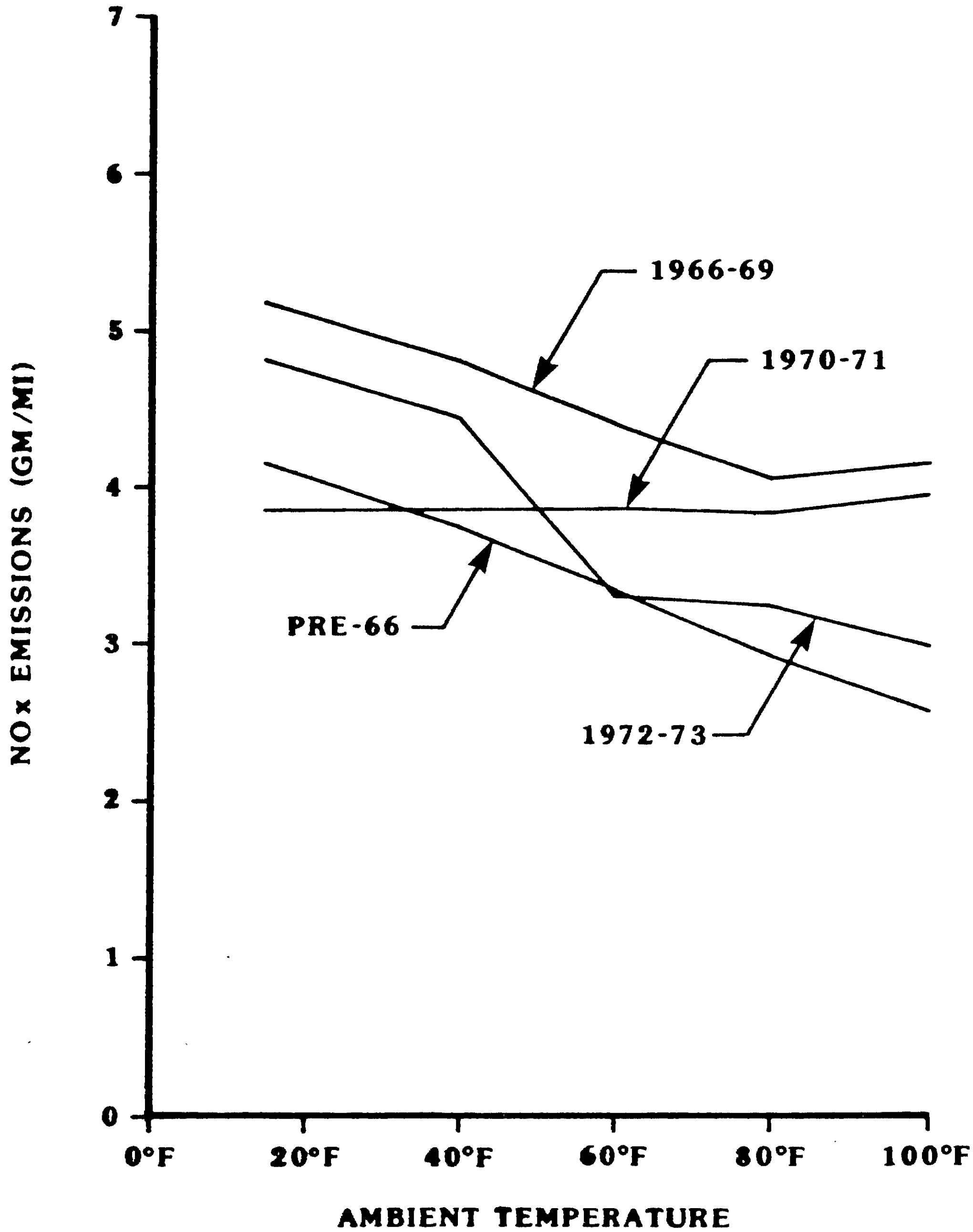


FIGURE 10

NOx EMISSIONS vs. TEMPERATURE
1975-79 MODEL PASSENGER CARS
EMFAC6C EMISSION RATES

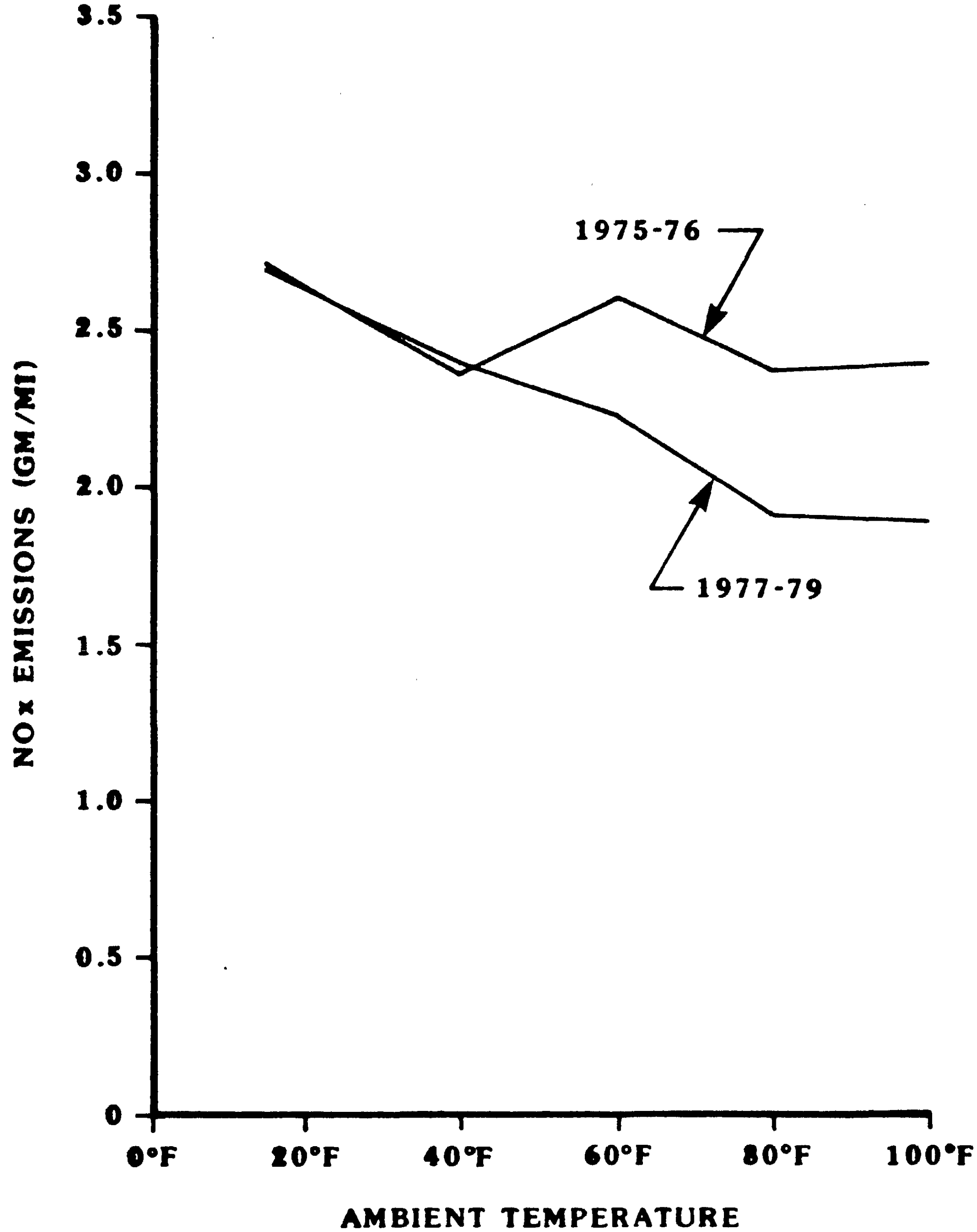
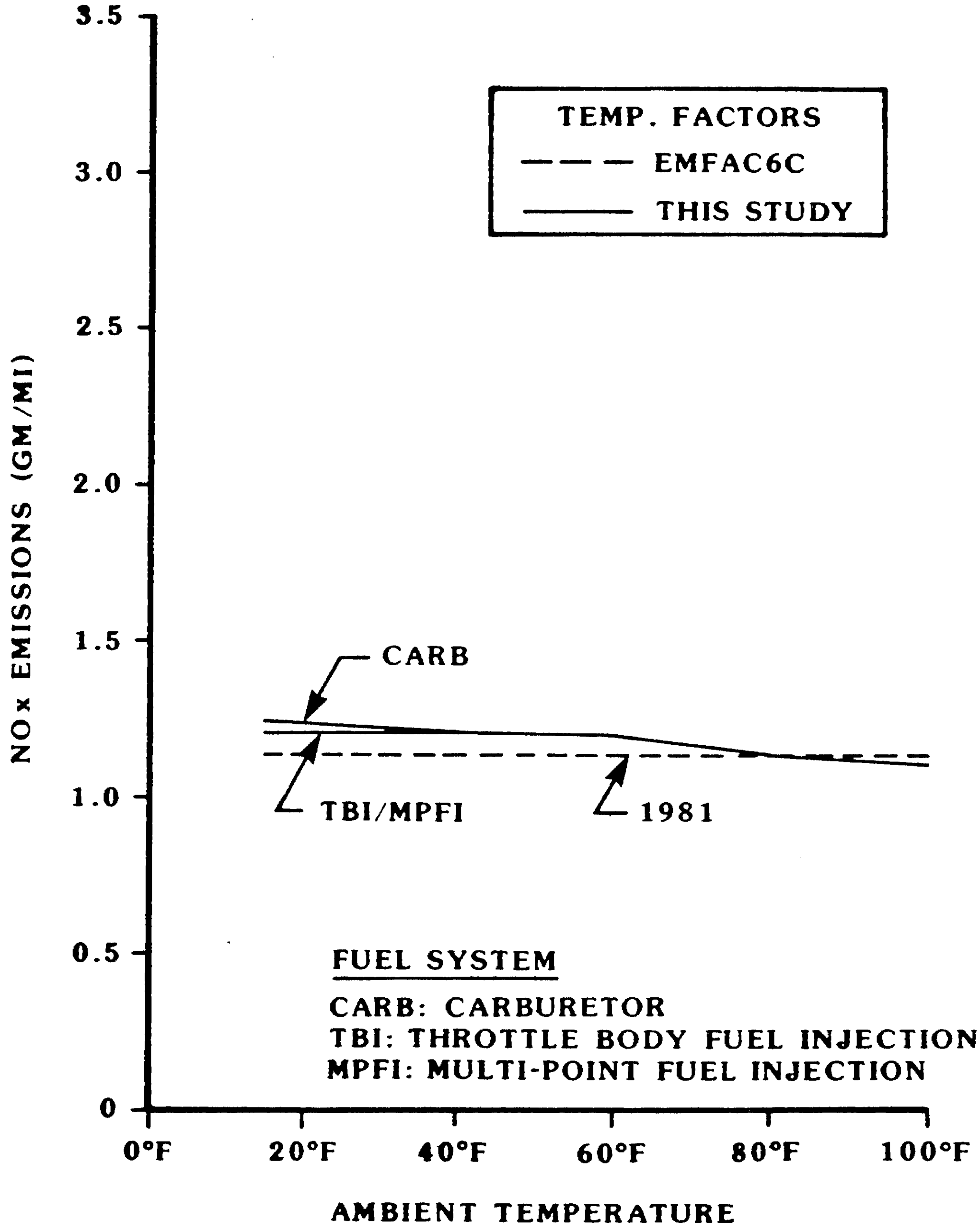


FIGURE 11
NOx EMISSIONS vs. TEMPERATURE
POST 1979 MODEL PASSENGER CARS
EMFAC6C EMISSION RATES



were established before the introduction of catalytic NOx controls, the temperature effect on NOx for these vehicles may be greater than the Figures suggest. Reconstruction of these figures using the new emissions factors developed under other tasks of this contract may present a more accurate picture of the relationship between NOx emissions and temperature for late model cars. Qualitatively, though, it appears that NOx emissions from 1980 and newer model cars are inversely related to ambient temperature.

B. Light-Duty Trucks and Medium-Duty Vehicles

As described above in Section III.C.3., the temperature correction factors for light-duty trucks and medium-duty vehicles were derived from passenger car factors for vehicles with comparable emission control technologies. The results of this analysis are shown in Tables 8, 9 and 10 for light-duty trucks, and Tables 11, 12, and 13 for medium-duty vehicles.

TABLE 8

HYDROCARBON TEMPERATURE CORRECTION FACTORS
FOR LIGHT-DUTY TRUCKS

BAG	MODEL YEARS	<30°F	30-49°F	50-67°F	68-86°F	>86°F
1		gm/mi	gm/mi	gm/mi	gm/mi	ratio
	pre-66	18.27	14.09*	9.90	0.00	0.72
	66-69	16.16	10.23*	4.29	0.00	0.75
	70-71	5.56	3.95*	2.33	0.00	0.83
	72-74	9.62	4.59	1.94	0.00	0.85
	75-78	8.57	6.26	1.90	0.00	0.72
	79-82	8.33	6.02*	3.71	0.00	0.94
	83+CARB	6.73	4.58*	2.43	0.00	0.74
	83+TBI	4.75	3.06*	1.37	0.00	0.74**
	83+FI	1.98	0.92	0.73	0.00	0.74**
2		gm/mi	gm/mi	gm/mi	gm/mi	ratio
	pre-66	0.98	0.56*	0.14	0.00	1.03
	66-69	0.90	0.43*	-0.04	0.00	1.11
	70-71	0.20	0.13*	0.05	0.00	1.03
	72-74	0.42	0.30	0.03	0.00	1.08
	75-78	0.44	0.95	0.14	0.00	1.36
	79-82	0.59	0.41*	0.22	0.00	1.27
	83+CARB	0.52	0.44*	0.35	0.00	0.90
	83+TBI	0.04	0.02*	0.00	0.00	0.90**
	83+FI	0.01	0.02	-0.05	0.00	0.90**
3		ratio	ratio	ratio	gm/mi	gm/mi
	pre-66	1.04	1.02*	1.00	0.00	0.56
	66-69	1.05	1.03*	1.01	0.00	0.83
	70-71	1.07	1.04*	1.00	0.00	0.30
	72-74	1.09	1.03	0.91	0.00	0.97
		gm/mi	gm/mi	gm/mi		
	75-78	0.08	0.18	0.03	0.00	0.40
	79-82	0.39	0.26*	0.12	0.00	0.41
	83+CARB	0.35	0.31*	0.26	0.00	-0.02
	83+TBI	0.48	0.38*	0.28	0.00	-0.02**
	83+FI	-0.01	0.01	-0.07	0.00	-0.02**

*No data or inadequate data available; estimated by interpolation.
**No data available; assumed to be the same as for carbureted vehicles.

TABLE 9

CARBON MONOXIDE
TEMPERATURE CORRECTION FACTORS
FOR LIGHT-DUTY TRUCKS

BAG	MODEL YEARS	<30°F	30-49°F	50-67°F	68-86°F	>86°F
1		gm/mi	gm/mi	gm/mi	gm/mi	ratio
	pre-66	126.36	97.73*	69.09	0.00	0.73
	66-69	151.76	102.64*	53.52	0.00	0.44
	70-71	84.19	63.11*	42.02	0.00	0.68
	72-74	128.35	93.44	48.84	0.00	0.83
	75-78	94.39	82.73	31.64	0.00	0.79
	79-82	75.03	36.20	29.96	0.00	0.89
	83+CARB	80.10	59.14*	38.17	0.00	0.70
	83+TBI	81.82	57.11*	32.40	0.00	0.70**
	83+FI	30.06	20.80*	24.10	0.00	0.70**
2		gm/mi	gm/mi	gm/mi	gm/mi	ratio
	pre-66	-8.83	-6.46*	-4.09	0.00	1.10
	66-69	6.85	5.05*	3.25	0.00	1.26
	70-71	4.90	3.12*	1.33	0.00	1.15
	72-74	4.43	1.49	-2.50	0.00	1.91
	75-78	9.24	7.11	3.44	0.00	2.23
	79-82	6.90	1.84	1.13	0.00	2.01
	83+CARB	9.39	7.22*	5.05	0.00	1.99
	83+TBI	0.34	0.30*	0.26	0.00	1.99**
	83+FI	0.25	0.65	-0.20	0.00	1.99**
3		ratio	ratio	ratio	gm/mi	gm/mi
	pre-66	0.95	0.97*	0.99	0.00	26.30
	66-69	0.95	1.00*	1.05	0.00	20.91
	70-71	1.09	1.07*	1.05	0.00	7.02
	72-74	1.16	0.96	1.00	0.00	25.73
		gm/mi	gm/mi	gm/mi		
	75-78	0.99	0.11	-0.99	0.00	10.22
	79-82	2.67	0.61	2.10	0.00	6.77
	83+CARB	7.25	6.57*	5.88	0.00	0.78
	83+TBI	16.70	13.97*	11.24	0.00	0.78**
	83+FI	0.38	0.45	-0.94	0.00	0.78**

*No data or inadequate data available; estimated by interpolation.
**No data available; assumed to be the same as for carbureted vehicles.

TABLE 10

OXIDES OF NITROGEN
TEMPERATURE CORRECTION FACTORS
FOR LIGHT-DUTY TRUCKS

BAG	MODEL YEARS	<30°F	30-49°F	50-67°F	68-86°F	>86°F
1		ratio	ratio	ratio	ratio	ratio
	pre-66	1.07	1.06*	1.04	1.00	1.12
	66-69	1.04	1.02*	0.99	1.00	1.23
	70-71	0.89	0.92*	0.95	1.00	1.05
	72-74	1.08	1.11	1.05	1.00	0.98
	75-78	1.12	1.30	1.21	1.00	0.91
	79-82	1.30	1.23	1.10	1.00	1.04
		gm/mi	gm/mi	gm/mi	gm/mi	gm/mi
	83+CARB	0.46	0.40*	0.34	0.00	-0.16
	83+TBI	0.12	0.14*	0.15	0.00	-0.16**
	83+FI	0.02	0.20	-0.08	0.00	-0.16**
2		ratio	ratio	ratio	ratio	ratio
	pre-66	1.58	1.39*	1.20	1.00	0.83
	66-69	1.36	1.23*	1.10	1.00	1.00
	70-71	1.03	1.03*	1.03	1.00	1.02
	72-74	1.75	1.59	1.01	1.00	0.95
	75-78	1.17	0.83	1.02	1.00	1.04
	79-82	1.55	1.28	1.21	1.00	1.02
		gm/mi	gm/mi	gm/mi	gm/mi	gm/mi
	83+CARB	0.21	0.18*	0.14	0.00	-0.03
	83+TBI	0.22	0.26*	0.30	0.00	-0.03**
	83+FI	0.16	0.14	-0.04	0.00	-0.03**
3		ratio	ratio	ratio	ratio	ratio
	pre-66	1.45	1.30*	1.15	1.00	0.78
	66-69	1.34	1.24*	1.13	1.00	0.90
	70-71	1.04	1.03*	1.02	1.00	1.02
	72-74	1.46	1.32	1.05	1.00	0.88
	75-78	1.12	0.93	1.10	1.00	1.04
	79-82	1.31	1.21	1.16	1.00	0.89
		gm/mi	gm/mi	gm/mi	gm/mi	gm/mi
	83+CARB	0.38	0.28*	0.18	0.00	-0.09
	83+TBI	0.23	0.18*	0.12	0.00	-0.09**
	83+FI	0.45	0.40	0.01	0.00	-0.09**

*No data or inadequate data available; estimated by interpolation.
**No data available; assumed to be the same as for carbureted vehicles.

TABLE 11

HYDROCARBON TEMPERATURE CORRECTION FACTORS FOR MEDIUM-DUTY VEHICLES

BAG	MODEL YEARS	<30°F	30-49°F	50-67°F	68-86°F	>86°F
1		gm/mi	gm/mi	gm/mi	gm/mi	ratio
	pre-70	18.27	14.09*	9.90	0.00	0.72
	70-74	16.16	10.23*	4.29	0.00	0.75
	75-76	5.56	3.95*	2.33	0.00	0.83
	77	9.62	4.59	1.94	0.00	0.85
	78-76	8.57	6.26	1.90	0.00	0.72
	77-80	8.33	6.02*	3.71	0.00	0.94
	83+CARB	6.73	4.58*	2.43	0.00	0.74
	83+TBI	4.75	3.06*	1.37	0.00	0.74**
	83+FI	1.98	0.92	0.73	0.00	0.74**
2		gm/mi	gm/mi	gm/mi	gm/mi	ratio
	pre-70	0.98	0.56*	0.14	0.00	1.03
	70-74	0.90	0.43*	-0.04	0.00	1.11
	75-76	0.20	0.13*	0.05	0.00	1.03
	77	0.42	0.30	0.03	0.00	1.08
	77-80	0.44	0.95	0.14	0.00	1.36
	81-82	0.59	0.41*	0.22	0.00	1.27
	83+CARB	0.52	0.44*	0.35	0.00	0.90
	83+TBI	0.04	0.02*	0.00	0.00	0.90**
	83+FI	0.01	0.02	-0.05	0.00	0.90**
3		ratio	ratio	ratio	gm/mi	gm/mi
	pre-70	1.04	1.02*	1.00	0.00	0.56
	71-74	1.05	1.03*	1.01	0.00	0.83
	75-76	1.07	1.04*	1.00	0.00	0.30
	77	1.09	1.03	0.91	0.00	0.97
		gm/mi	gm/mi	gm/mi		
	78-80	0.08	0.18	0.03	0.00	0.40
	81-82	0.39	0.26*	0.12	0.00	0.41
	83+CARB	0.35	0.31*	0.26	0.00	-0.02
	83+TBI	0.48	0.38*	0.28	0.00	-0.02**
	83+FI	-0.01	0.01	-0.07	0.00	-0.02**

*No data or inadequate data available; estimated by interpolation.
**No data available; assumed to be the same as for carbureted vehicles.

TABLE 12

CARBON MONOXIDE
TEMPERATURE CORRECTION FACTORS
FOR MEDIUM-DUTY VEHICLES

BAG	MODEL YEARS	<30°F	30-49°F	50-67°F	68-86°F	>86°F
1		gm/mi	gm/mi	gm/mi	gm/mi	ratio
	pre-70	126.36	97.73*	69.09	0.00	0.73
	70-74	151.76	102.64*	53.52	0.00	0.44
	75-76	84.19	63.11*	42.02	0.00	0.68
	77	128.35	93.44	48.84	0.00	0.83
	78-80	94.39	82.73	31.64	0.00	0.79
	81-82	75.03	36.20	29.96	0.00	0.89
	83+CARB	80.10	59.14*	38.17	0.00	0.70
	83+TBI	81.82	57.11*	32.40	0.00	0.70**
	83+FI	30.06	20.80*	24.10	0.00	0.70**
2		gm/mi	gm/mi	gm/mi	gm/mi	ratio
	pre-70	-8.83	-6.46*	-4.09	0.00	1.10
	70-74	6.85	5.05*	3.25	0.00	1.26
	75-76	4.90	3.12*	1.33	0.00	1.15
	77	4.43	1.49	-2.50	0.00	1.91
	78-80	9.24	7.11	3.44	0.00	2.23
	81-82	6.90	1.84	1.13	0.00	2.01
	83+CARB	9.39	7.22*	5.05	0.00	1.99
	83+TBI	0.34	0.30*	0.26	0.00	1.99**
	83+FI	0.25	0.65	-0.20	0.00	1.99**
3		ratio	ratio	ratio	gm/mi	gm/mi
	pre-70	0.95	0.97*	0.99	0.00	26.30
	70-74	0.95	1.00*	1.05	0.00	20.91
	75-76	1.09	1.07*	1.05	0.00	7.02
	77	1.16	0.96	1.00	0.00	25.73
		gm/mi	gm/mi	gm/mi		
	78-80	0.99	0.11	-0.99	0.00	10.22
	81-82	2.67	0.61	2.10	0.00	6.77
	83+CARB	7.25	6.57*	5.88	0.00	0.78
	83+TBI	16.70	13.97*	11.24	0.00	0.78**
	83+FI	0.38	0.45	-0.94	0.00	0.78**

*No data or inadequate data available; estimated by interpolation.
**No data available; assumed to be the same as for carbureted vehicles.

TABLE 13

OXIDES OF NITROGEN
TEMPERATURE CORRECTION FACTORS
FOR MEDIUM-DUTY VEHICLES

BAG	MODEL YEARS	<30°F	30-49°F	50-67°F	68-86°F	>86°F
1		ratio	ratio	ratio	ratio	ratio
	pre-70	1.07	1.06*	1.04	1.00	1.12
	70-74	1.04	1.02*	0.99	1.00	1.23
	75-76	0.89	0.92*	0.95	1.00	1.05
	77	1.08	1.11	1.05	1.00	0.98
	78-80	1.12	1.30	1.21	1.00	0.91
	81-82	1.30	1.23	1.10	1.00	1.04
		gm/mi	gm/mi	gm/mi	gm/mi	gm/mi
	83+CARB	0.46	0.40*	0.34	0.00	-0.16
	83+TBI	0.12	0.14*	0.15	0.00	-0.16**
	83+FI	0.02	0.20	-0.08	0.00	-0.16**
2		ratio	ratio	ratio	ratio	ratio
	pre-70	1.58	1.39*	1.20	1.00	0.83
	70-74	1.36	1.23*	1.10	1.00	1.00
	75-76	1.03	1.03*	1.03	1.00	1.02
	77	1.75	1.59	1.01	1.00	0.95
	78-80	1.17	0.83	1.02	1.00	1.04
	81-82	1.55	1.28	1.21	1.00	1.02
		gm/mi	gm/mi	gm/mi	gm/mi	gm/mi
	83+CARB	0.21	0.18*	0.14	0.00	-0.03
	83+TBI	0.22	0.26*	0.30	0.00	-0.03**
	83+FI	0.16	0.14	-0.04	0.00	-0.03**
3		ratio	ratio	ratio	ratio	ratio
	pre-70	1.45	1.30*	1.15	1.00	0.78
	70-74	1.34	1.24*	1.13	1.00	0.90
	75-76	1.04	1.03*	1.02	1.00	1.02
	77	1.46	1.32	1.05	1.00	0.88
	78-80	1.12	0.93	1.10	1.00	1.04
	81-82	1.31	1.21	1.16	1.00	0.89
		gm/mi	gm/mi	gm/mi	gm/mi	gm/mi
	83+CARB	0.38	0.28*	0.18	0.00	-0.09
	83+TBI	0.23	0.18*	0.12	0.00	-0.09**
	83+FI	0.45	0.40	0.01	0.00	-0.09**

*No data or inadequate data available; estimated by interpolation.
**No data available; assumed to be the same as for carbureted vehicles.

C. Diesel Vehicles

A review of the literature available on the effect of ambient temperature on vehicle emissions indicates that very little testing has been conducted in this area on Diesel powered vehicles. The data sources we reviewed included test results on only three Diesel vehicles at non-standard temperatures: a 1973 Opel Rekord; a 1978 Oldsmobile; and a 1978 Volkswagen Rabbit. The data from these three vehicles suggest that only Bag 1 hydrocarbon emissions and, to a lesser extent, Bag 1 carbon monoxide emissions, are significantly affected by ambient temperature for Diesel vehicles, and, at that, only at very cold temperatures (25°F). Because the amount of data in this area is so limited, we do not believe it possible to calculate temperature correction factors for Diesels.

The data do indicate that, of the alternatives of ignoring temperature correction for Diesels and applying gasoline factors to Diesels, the former approach is probably less in error. This is due to the fact that although the three vehicles exhibited a factor of two or three increase in Bag 1 hydrocarbon emissions at extremely cold temperatures, the HC emissions from those vehicles at standard temperatures are significantly lower than those from all but the latest model gasoline fueled vehicles. Thus, since Diesel vehicles represent a relatively small fraction of total light-duty vehicle hydrocarbon emissions, ignoring the effect of temperature on these vehicles would not be expected to have a significant impact on the inventory as a whole. On the other hand, the correction factors which have been derived for gasoline vehicles are so clearly inappropriate for Diesels (at least based on the three vehicles we found tested), particularly for CO and NOx, and for HC above 25°F, that their application could significantly misrepresent Diesel emissions. Therefore, it is our recommendation that no temperature correction factors be applied to light-duty and medium-duty Diesel emissions.

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SPEED CORRECTION FACTORS FOR CALIFORNIA'S MOTOR VEHICLE EMISSIONS MODEL

Prepared for:

CALIFORNIA AIR RESOURCES BOARD
Sacramento, California

Contract No. A2-065-32

Prepared by:

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June 1985

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SUMMARY

Data from over 200 1978-1983 model year light-duty vehicles were analyzed to develop speed correction factors for use in CARB's new emissions factor model EMFAC7. The data consisted of tests conducted by and for the U.S. Environmental Protection Agency on 49-state vehicles. The decision to use 49-state vehicles, rather than California vehicles, for this analysis was based on the fact that CARB surveillance data routinely included only one test cycle at one speed (the Federal Test Procedure, or FTP), and usually (but not always) a second test cycle (the Highway Fuel Economy Test, or HWFET). By contrast, the Federal data include results of five distinct driving schedules: the FTP and HFET, mentioned above, the New York City Cycle (NYCC), and two speed correction cycles, SCC-12 and SCC-36, specially designed for evaluating the relationship between vehicle speed and emissions levels. Since speed correction factors are developed by curve fits of emission versus vehicle speed, the larger number of speeds at which each vehicle was tested by EPA was believed to more than compensate for the shortcomings associated with the use of 49-state vehicles rather than California vehicles.

The results of the analysis performed on the 49-state vehicles were translated into corresponding model year groups for the California fleet. The results of the analysis, along with the proposed speed correction factors for California, are shown in Table S-1.

The proposed correction factors for HC and CO emissions are generally comparable to the factors employed previously in EPA and CARB vehicle emissions models. These show a very strong sensitivity at low average speeds, with emissions dropping by a factor of 2 or more from 5 mph to the FTP speed of 19.6 mph. The predicted HC and CO emissions continue to decline at speeds above the FTP, but are markedly flattened.

TABLE S-1

PROPOSED SPEED CORRECTION FACTORS FOR CALIFORNIA VEHICLES

$$CF = \exp(A + Bx + Cx^2)$$

California Model Year Group	A	B	C	Federal Model Years Analyzed
1975-1976 LDV				
HC	1.2155E+0	-7.0763E-2	4.4646E-4	1978-1979 LDV
CO	1.1618E+0	-5.9274E-2	N/A	
NO_x	0.3083E+0	-2.3036E-2	3.7283E-4	
1977-1979 LDV				
HC	1.4439E+0	-8.8086E-2	7.3568E-4	1980 LDV
CO	0.8820E+0	-4.4998E-2	N/A	
NO_x	0.2950E+0	-2.3633E-2	4.3775E-4	
1980 and Later				
HC	0.9841E+0	-5.6732E-2	-3.3282E-4	1981-1983 LDV
CO	0.8584E+0	-4.3797E-2	N/A	
NO_x	0.3860E+0	-2.6296E-2	3.3674E-4	

Note: See Tables 2-2 and 2-3 for conversion to California Light-duty Truck and Medium-duty Truck categories.

However, the proposed correction factors for NO_x are a departure from what has been used in prior modeling, which generally indicated increasing NO_x emissions with speed. The results of the present analysis demonstrate a "u-shaped" trend with speed. For oxidation catalyst vehicles using EGR for NO_x control, emission rates decline from the lowest speed tested (5 mph) to a minimum in the range of 25-30 mph, before increasing again at the higher speeds typical of highway travel. Three-way catalyst vehicles demonstrate similar behavior at low speeds but have a much weaker sensitivity at highway speeds. It is believed that the ability to capture improved NO_x correction factors and to represent the oxidation versus three-way catalyst differences justifies the use of EPA's 49-state data base.

The work presented in this report is based on work previously conducted by EEA for the U.S. Environmental Protection Agency. This work is described in the final report for that effort, "LDV Speed Correction Factors," EPA Prime Contract No. 68-01-6558, Subcontract No. 130.109, Work Assignment No. 39, Task 5 (May 1984).

1. INTRODUCTION

The California Air Resources Board is currently in the midst of an effort to udpate its motor vehicle emissions model to reflect the most recent data and predictive techniques available. The current generation of the CARB model, known as EMFAC6D, is structurally over five years old, and was based on EPA's first motor vehicle emissions model, MOBILE1. Although the data in EMFAC6D is relatively recent, its underlying structure has prevented ARB from taking advantage of more recently developed predictive techniques.

As part of this effort, Energy and Environmental Analysis, Inc. (EEA), and Sierra Research have supported ARB in developing new techniques and factors for use in the next generation ARB model, known as EMFAC7. This report summarizes the development of speed correction factors for use in EMFAC7.

2. DATA USED IN THE STUDY

2.1 DATA BASE

The data base used in this analysis consists of test results from 202 1978-1983 model year light-duty vehicles tested by and for the U.S. Environmental Protection Agency. These in-use vehicles were each tested over five different driving cycles, which were selected by EPA to represent a variety of travel conditions. Average speeds range from 7.1 miles per hour for the New York City Cycle (NYCC) to 47.9 mph for the Highway Fuel Economy Test (HFET). The Federal Test Procedure (FTP) falls in the middle with an average speed of 19.6 mph. The testing was conducted by EPA with the specific intention of developing data for speed correction factors through preplanned and statistically balanced testing.

The EPA data base consists solely of 49-state vehicles. Although it was originally anticipated that results of ARB surveilliance tests on California vehicles would be used for this analysis, a review of the data available indicated that there were only two tests routinely conducted by CARB during its programs: the FTP and the HFET. Since the model developed by CARB (as well as all other motor vehicle emissions models) requires that speed correction factors be expressed as a proportional factor which is a function of vehicle speed, the CARB data base would have provided for regressions of emissions through only two speed points: one each for the FTP and HFET.

By contrast, the EPA data base allows the regresion to use five data points, one for each test cycle used by EPA. Due to the fact that all previous work conducted both by CARB and EPA have indicated that the speed versus emissions function is non-linear, the accuracy gained by using the EPA data base was judged to far outweigh any shortcomings associated with translating this analysis to California vehicles.

The five test cycles which comprised the data set for each vehicle are described in Table 2-1. In addition to the FTP and HFET, both of which were developed by EPA and are in routine use, three other driving cycles were included. The New York City Cycle (NYCC) was developed by the New York EPA for estimating emissions from motor vehicles in congested urban areas. This low speed cycle (5 mph) is based on driving samples from vehicles in downtown Manhattan. Two new speed correction cycles, or SCC's, were developed by EPA specifically to fill the data gaps between the other three (and more common) cycles. SCC-12 and SCC-36 were developed by EPA from portions of the LA-4 and the Congested Freeway Driving cycles, respectively.

The data used in this study were limited only to those vehicles which had been tested in the "as-received" condition. All of the vehicles had been tested over each of the five driving cycles, and none were selected for testing based on high FTP emissions levels. Therefore, the data set is both balanced and may be considered to be representative of the in-use fleet.

The vehicle samples included in the testing program were as follows:

MY 1978-1979	70 vehicles
MY 1980	19 vehicles
MY 1981-1983	113 vehicles

The analytical work was conducted by aggregating the vehicle samples into these model year groups to reflect the 49-state certification standards and the associated trends in vehicle emission control technology.

Four data points were reported with missing or negative emissions values and were dropped from the analysis. The final sample sizes of vehicle speed tests are shown below:

TABLE 2-1

STATISTICS OF DRIVING CYCLES USED IN
THE EPA MISSION FACTORS PROGRAM

	NYCC	SCC-12	FTP	SCC-36	HFET
Average speed (MPH)	7.1	12.1	19.6	35.9	47.9
Duration (secs)	599	349	1372	996	766
Distance (miles)	1.2	1.2	7.5	9.9	10.2
Time at idle (%)	32	25	18	6	1
Time at accel (%)	24	26	26	19	14
Time in cruise (%)	21	28	36	62	76
Time in decel (%)	23	21	20	13	9
Stops per mile	15	5.1	2.3	.2	.1

Source: Reference No. 5.

	HC	CO	NOx
MY 1978-1979	350	349	350
MY 1980	95	95	95
MY 1981-1983	565	565	562

2.2 CONVERSION TO CALIFORNIA MODEL YEAR GROUPINGS

The results of the EPA analysis were converted to California model years based on the similarities of control technologies and emission standards. These similarities were discussed in detail in the Sierra Research report "Temperature Correction Factors for California's Motor Vehicle Emissions Model," prepared under a separate task of this contract.

Passenger car control technologies and emission standards generally fall into seven distinct categories:

Category	Control Technology	Federal MY	California MY
1	Pre-control	Pre-1968	Pre-1966
2	EM/AI	1968-1969	1966-1969
3	EM/AI/spark	1970-1971	1970-1971
4	EM/AI/spark/EGR	1972-1974	1972-1974
5	Early ox. cat	1975-1979	1975-1979
6	Advanced ox. cat	1980	1977-1979
7	Three-way cat	Post-1980	Post-1979

(EM: engine modifications; AI: air injection system; sparks: spark retard systems; EGR: exhaust gas recirculation; ox. cat: oxidation catalyst systems)

As the groupings shown above suggest, California controls generally preceded similar Federal control systems by one or two years. The relatively minor differences in emission standards between the Federal and California requirements for each technology grouping would not be expected to significantly alter the speed correction effects under study in this analysis. Therefore, the above translation scheme was used to convert the EPA data base for 1978-1983 model years into speed correction factors for 1975 and later California model years.

In both the temperature correction factor analyses and the emission factor analyses for California vehicles, the 1980 and later model year group was subdivided into control technology subgroups, based on either broad fuel system categories or more detailed fuel system/air injection system combinations. However, this level of detail was judged not practicable given that there were only a total of 113 vehicles for the post-1979 group in the speed correction factor data base. As EPA (and, perhaps CARB) increases the available speed correction data, more detailed technology-based breakdowns of this category may be possible.

Furthermore, due to the very limited amount of test data from light-duty trucks and medium-duty vehicles regarding the effects of speed changes on emissions, the passenger car factors developed in this work have been applied to light- and medium-truck categories based on control technology similarities. The translation schemes used to convert passenger car speed correction factors to light-duty truck and medium-duty vehicle factors are shown in Tables 2-2 and 2-3, respectively.

TABLE 2-2

LIGHT-DUTY TRUCK CATEGORIES

Control Technology	Passenger Car Model Years	Equivalent Light-Duty Truck Model Years
Pre-control	Pre-1966	Pre-1966
EM/AI	1966-1969	1966-1969
EM/AI/spark	1970-1971	1970-1971
EM/AI/spark/EGR	1972-1974	1972-1974
Early ox. cat.	1975-1976	1975-1978
Advanced ox. cat.	1977-1979	1979-1982
Three-way cat.	Post-1979	Post-1982

TABLE 2-3

MEDIUM-DUTY VEHICLE CATEGORIES

Control Technology	Passenger Car Model Years	Equivalent Medium-Duty Truck Model Years
Pre-control	Pre-1966	Pre-1970
EM/AI	1966-1969	1970-1974
EM/AI/spark	1970-1971	1975-1976
EM/AI/spark/EGR	1972-1974	1977
Early ox. cat.	1975-1976	1978-1980
Advanced ox. cat.	1977-1979	1981-1982
Three-way cat.	Post-1979	Post-1982

3. METHODOLOGY

Prior vehicle emissions models have used polynomial functional forms to correct exhaust emissions for changes in average speed. The EPA MOBILE2 model uses the following forms:

$$\ln HC = a + bx + cx^2 + dx^3 + ex^4 + fx^5 \qquad (3\text{-}1)$$

$$\ln CO = a + bx + cx^2 + dx^3 + ex^4 + fx^5 \qquad (3\text{-}2)$$

$$NO_x = a + bx + cx^2 + dx^3 + ex^4 \qquad (3\text{-}3)$$

where: x = average speed (mph)

As is conventional, the speed correction factor equations are normalized to a value of 1.00 at the FTP cycle average speed of 19.6 mph.

The EPA data base described in Section 2.1 was used to estimate both logarithmic and nominal (or absolute) polynomial regression equations by pollutant for three model year groups (MY 1978-1979, MY 1980, and MY 1981-1983). Since the emissions data consisted of measurements at exactly five average speeds, the regression equations were limited to a maximum fourth order polynomial.

The regression models were stratified by vehicle in order to improve the statistical power for estimating speed correction. This stratification was accomplished by absorption of an individual vehicle effect. Absorption is a statistical technique which eliminates cross-sectional differences that are not of interest -- in this problem, vehicle-to-vehicle variability in emissions. Absorption of the individual vehicle effect therefore bases the regression only on the within-vehicle variation with the independent variable.

This is somewhat comparable to a regression model which employs dummy variables for individual vehicles except that only one parameter (the speed sensitivity) is estimated. However, the absorption technique is more powerful in that it is conceptually similar to computing the speed sensitivity for each vehicle individually and then averaging the parameter estimates across the sample.

The mathematical formulation for multi-variate regression analysis involves the normalization of (X,Y) data relative to the mean values for individual vehicles as follows:

$$Y \rightarrow Y - \overline{Y} \quad \text{(dependent variable)}$$

$$X \rightarrow X - \overline{X} \quad \text{cycle speed}$$

$$X^2 \rightarrow X^2 - \overline{X^2} \quad \text{squared speed}$$

$$\vdots$$

$$X^4 \rightarrow X^4 - \overline{X}^4 \quad \text{quartic speed}$$

The general form of the regression equation is therefore:

$$Y - \overline{Y} = a(x - \overline{x}) + b(x^2 - \overline{x^2}) + \ldots d(x^4 - \overline{x^4}) \qquad (3\text{-}4)$$

To yield correction factors it is then necessary to normalize the regression equations to the value of 1.0 at the FTP cycle average speed of 19.6 mph. This was accomplished by computing the predicted emissions value at $x = 19.6$ mph and then dividing each regression coefficient in equation (3-4) by that result.

In evaluating the regression equations, two criteria were used to select appropriate speed correction factors. These were to select those regressions:

- In which all coefficients were statistically significant at the 0.05 level or better; and
- Which represented the highest order polynomial that fit the data and captured the observed trend in decreasing emissions with increasing cycle speed over the range of 5 mph to 55 mph

4. RESULTS

Analysis of the speed correction data proceeded in two phases. In the first phase, both absolute (X) and logarithmic (ln X) polynomial equations were estimated for each pollutant and model year group. The absolute polynomials proved to be divergent for HC and CO (i.e., the equations produced negative emissions values) and were therefore rejected. The absolute polynomials for NO_x proved to be less representative of the data than logarithmic polynomials. Therefore, the remainder of the analysis focused on alternative log-polynomials for each pollutant and model year group.

The initial phase of the analysis showed that first order log-polynomial correction factors produced the best "fit" for the HC and CO emissions data; third order log-polynomial regressions appeared to be the most representative of trends in NO_x data. These equation forms are consistent with prior findings on the speed-sensitivity of emissions. However, the review of these results from the viewpoint of the predicted emissions trends raised two points of concern, which led to a second round of analysis.

First, there was concern regarding the representativeness of the SCC-36 driving cycle with respect to actual in-use cycles in the 36 mph speed range, particularly in regard to NO_x emissions. As seen in the data set, average NO_x emissions declined as average speeds increased from 5 mph to 25 mph, but then rose to a "hump" at 36 mph before dropping at higher speeds. This phenomenon was quite unlike that observed for HC and CO emissions which exhibited sharp declines at low speeds of 5-15 mph followed by a more gradual decline at higher average speeds.

Following review of cycle characteristics, it was concluded that the SCC-36, with relatively hard accelerations, was stringent with respect to NOx formation. While very difficult to evaluate in terms of its representativeness of in-use driving cycles in the 30-40 mph range, it was felt that the NO_x "hump" produced by the SCC-36 cycle should not be reflected in the correction factor polynomial

A second concern related to the consistency among the 5 driving cycles from which test data were drawn. All of the cycles, except for the FTP, represented hot-stabilized driving conditions. The FTP represented the conventional weighted-average of emissions data collected during both the "hot-start" and "cold-start" phases of vehicle operation. To make the FTP consistent with the other four driving cycles, the emissions data were reweighted by distance travelled in each bag according to the following "hot-start" definition of FTP:

$$\text{HOT FTP} = (3.91/7.5)\text{Bag}_2 + (3.59/7.5)\text{Bag}_3$$

Based on this revision of the FTP data, a second series of first, second, and third order log-polynomial regression equations was calculated for each pollutant and model year category.

Using the selection criteria outlined in the methodology discussion, second order log-polynomials were found to provide the "best" fit of the data on HC emissions. These models were statistically significant at the 0.05 level and did not provide unreasonable estimates of correction factors at either high or low extremes in average speed. With respect to CO emissions, first order log-polynomials provided the "best" fit of the available data.

Both second and third order log-polynomials were acceptable models for NOx emissions from the standpoint of statistical significance. Given the issue concerning the representativeness of the 36 mph driving cycle, the second order polynomial was selected as the more appropriate functional form for NO_x, since it avoided a pronounced downturn in predicted emissions above the HFET speed. Furthermore, the second-order polynomial's upturn in emissions above 47.8 mph is a reasonable reflection of the effects of greater engine load at increasing highway speeds.

Tables 4-1 through 4-3 present summary comparisons of the selected (normalized) speed correction factors at ten cycle speeds for each pollutant and model year category. MOBILE2 speed correction factors (for 1975 and later vehicles) are included as a reference point on the changes introduced in the modeling of 49-state vehicles by the new data base.

As described in Section 2, the results for the 49-state data base have been mapped into California model year groups based on technology similarity. The following matrix gives the appropriate translation from the Federal vehicle groups tested to the corresponding California population.

Federal Group	California Model Year Groups		
Light-Duty Vehicles	Passenger Cars	Light-Duty Trucks	Medium-Duty Trucks
1978-1979	1975-1976	1975-1978	1978-1980
1980	1977-1979	1979-1982	1981-1982
1981-1983	Post-1979	Post-1982	Post-1982

TABLE 4-1

COMPARISON OF MOBILE2 AND REVISED NORMALIZED SPEED CORRECTION FACTORS FOR HC EMISSIONS AT SELECTED CYCLE SPEEDS

Speed* (mph)	MOBILE2 MY1975+	Federal Vehicle Groups MY 1978-79	MY 1980	MY 1981-83
5	3.19	2.39	2.78	2.03
9.1	1.86	1.84	2.02	1.64
12.1	1.45	1.53	1.62	1.41
19.6	1.00	1.00	1.00	1.00
25	0.80	0.76	0.74	0.80
30	0.65	0.60	0.58	0.66
35.9	0.52	0.47	0.46	0.54
40	0.47	0.41	0.41	0.47
47.9	0.42	0.32	0.34	0.38
55	0.38	0.27	0.31	0.32

*Average speeds given to 0.1 mph are for the driving cycles used in EPA testing.

TABLE 4-2

COMPARISON OF MOBILE2 AND REVISED NORMALIZED SPEED CORRECTION FACTORS FOR CO EMISSIONS AT SELECTED CYCLE SPEEDS

		Federal Vehicle Groups		
Speed* (mph)	MOBILE2 MY1975+	MY 1978-79	MY 1980	MY 1981-83
5	2.99	2.38	1.93	1.90
9.1	1.71	1.86	1.60	1.58
12.1	1.36	1.56	1.40	1.39
19.6	1.00	1.00	1.00	1.00
25	0.82	0.73	0.78	0.79
30	0.67	0.54	0.63	0.63
35.9	0.54	0.38	0.48	0.49
40	0.49	0.30	0.40	0.41
47.9	0.48	0.19	0.28	0.29
55	0.43	0.12	0.20	0.21

*Average speeds given to 0.1 mph are for the driving cycles used in EPA testing.

TABLE 4-3

COMPARISON OF MOBILE2 AND REVISED NORMALIZED SPEED CORRECT FACTORS FOR NO_x EMISSIONS AT SELECTED CYCLE SPEEDS

		Federal Vehicle Groups		
Speed* (mph)	MOBILE2 MY1975+	MY 1978-79	MY 1980	MY 1981-83
5	0.82	1.22	1.21	1.30
9.1	0.81	1.14	1.12	1.19
12.1	0.84	1.09	1.08	1.12
19.6	1.00	1.00	1.00	1.00
25	1.12	0.97	0.98	0.94
30	1.22	0.95	0.98	0.90
35.9	1.30	0.96	1.01	0.88
40	1.34	0.98	1.05	0.88
47.9	1.42	1.06	1.18	0.90
55	1.56	1.18	1.38	0.96

*Average speeds given to 0.1 mph are for the driving cycles used in EPA testing.

REFERENCES

1. Energy and Environmental Analysis, Inc., "LDV Temperature Correction Factors," Final Report, prepared for the U.S. Environmental Protection Agency, April 30, 1984.

2. Energy and Environmental Analysis, Inc., "HDDV Emission and Speed Correction Factors," prepared for the U.S. Environmental Protection Agency, December 2, 1983.

3. Energy and Environmental Analysis, Inc., "Fleet Characterization Data," Final Report, prepared for the U.S. Environmental Protection Agency, December 20, 1983.

4. M. Smith and T. Aldrich, Olson Laboratories, "Development of Revised Light-Duty Vehicle Emission-Average Speed Relationships," prepared for the U.S. Environmental Protection Agency, EPA-460/3-77-011, August 1977.

5. J.T. White and L. Platte, U.S. Environmental Protection Agency, Office of Mobile Source Air Pollution Control, Emission Control Technology Division, Test and Evaluation Branch, "New Test Sequence for Emission Factors Work," internal memorandum dated December 17, 1982.

6. Energy and Environmental Analysis, Inc., "LDV Speed Correction Factors," Final Report, prepared for the U.S. Environmental Protection Agency, May 1984.

APPENDIX A

DETAILED SUMMARIES OF LDV SPEED CORRECTION MODELS

CHART 1A

LDV SPEED CORRECTION FACTOR STUDY

QUADRATIC POLYNOMIAL IN AVERAGE CYCLE SPEED
MYGRP=1978-1979 LDV

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: L_HC LOG HC

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	71	455.96526112	6.42204593	48.14	0.0001	0.924776	104.7358
ERROR	278	37.08963454	0.13341595		STD DEV		L_HC MEAN
CORRECTED TOTAL	349	493.05489566			0.36526148		0.34874569

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
VEHNO	69	296.07126020	32.16	0.0001				
SPD1	1	158.53361268	1188.27	0.0001	1	10.42353069	78.13	0.0001
SPD2	1	1.36038824	10.20	0.0016	1	1.36038824	10.20	0.0016

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
SPD1	-0.07076338	-8.84	0.0001	0.00800581
SPD2	0.00044646	3.19	0.0016	0.00013982

CHART 1B

LDV SPEED CORRECTION FACTOR STUDY

QUADRATIC POLYNOMIAL IN AVERAGE CYCLE SPEED

SUMMARY OF REGRESSION MODEL   MODEL YEAR GROUP: MY 1978-1979 LDV

DEPENDENT VARIABLE:	L_HC	LOG HC
INDEPENDENT VARIABLE:	SPEED	POLYNOMIAL IN CYCLE SPEED
OBSERVATIONS:	350	
DEGREES OF FREEDOM:	278	
R_SQUARED:	0.9248	

PARAMETERS

	ESTIMATE	STD ERR	NORMALIZED MODEL	NORMALIZED MOBILE2
INT	-	-	1.21545E+00	2.39540E+00
SPD1	-7.07633E-02	8.00581E-03	-7.07633E-02	-3.35780E-01
SPD2	4.46460E-04	1.39820E-04	4.46460E-04	2.11610E-02
SPD3	-	-	-	-7.31550E-04
SPD4	-	-	-	1.20720E-05
SPD5	-	-	-	-7.48570E-08

EVALUATION AT SELECTED CYCLE SPEEDS

SPEED	-- MODEL -- FACTOR	GM/MI	DATA VALUES GM/MI	STD ERR	-- MOBILE2 -- FACTOR	GM/MI
5	2.394	5.92	-	-	3.194	7.90
9.1	1.838	4.55	5.93	1.00	1.857	4.60
12.1	1.529	3.78	3.43	0.41	1.454	3.60
19.6	1.000	2.47	2.47	0.28	1.000	2.47
25	0.760	1.88	-	-	0.803	1.99
30	0.603	1.49	-	-	0.653	1.62
35.9	0.473	1.17	1.27	0.15	0.524	1.30
40	0.406	1.01	-	-	0.468	1.16
47.9	0.317	0.78	0.87	0.11	0.423	1.05
55	0.266	0.66	-	-	0.375	0.93

NOTES: (1) PREDICTED GM/MI VALUES BASED ON CORRECTION FACTORS APPLIED TO MEAN EMISSIONS VALUE AT FTP CYCLE SPEED. CORRECTION FACTORS ARE NORMALIZED TO 1.00 AT MEAN FTP SPEED (19.6 MPH).
(2) AVERAGE SPEEDS GIVEN TO 0.1 MPH ARE FOR THE TEST CYCLES USED IN EPA TESTING.

CHART. 2A

LDV SPEED CORRECTION FACTOR STUDY

QUADRATIC POLYNOMIAL IN AVERAGE CYCLE SPEED
MYGRP=1980 LDV

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: L_HC LOG HC

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	20	100.54645654	5.02732283	36.93	0.0001	0.908944	61.0782
ERROR	74	10.07256986	0.13611581		STD DEV		L_HC MEAN
CORRECTED TOTAL	94	110.61902640			0.36893876		-0.60404360

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
VEHNO	18	54.62551253	22.30	0.0001				
SPD1	1	44.91832072	330.00	0.0001	1	4.38393140	32.21	0.0001
SPD2	1	1.00262329	7.37	0.0083	1	1.00262329	7.37	0.0083

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
SPD1	-0.08808567	-5.68	0.0001	0.01552128
SPD2	0.00073568	2.71	0.0083	0.00027107

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CHART 2B

LDV SPEED CORRECTION FACTOR STUDY

QUADRATIC POLYNOMIAL IN AVERAGE CYCLE SPEED

SUMMARY OF REGRESSION MODEL — MODEL YEAR GROUP: MY 1980 LDV

DEPENDENT VARIABLE:	L_HC	LOG HC
INDEPENDENT VARIABLE:	SPEED	POLYNOMIAL IN CYCLE SPEED
OBSERVATIONS:	95	
DEGREES OF FREEDOM:	74	
R_SQUARED:	0.9089	

PARAMETERS

	ESTIMATE	STD ERR	NORMALIZED MODEL	NORMALIZED MOBILE2
INT	-	-	1.44386E+00	2.39540E+00
SPD1	-8.80857E-02	1.55213E-02	-8.80857E-02	-3.35780E-01
SPD2	7.35680E-04	2.71070E-04	7.35680E-04	2.11610E-02
SPD3	-	-	-	-7.31550E-04
SPD4	-	-	-	1.20720E-05
SPD5	-	-	-	-7.48570E-08

EVALUATION AT SELECTED CYCLE SPEEDS

SPEED	MODEL FACTOR	MODEL GM/MI	DATA VALUES GM/MI	DATA VALUES STD ERR	MOBILE2 FACTOR	MOBILE2 GM/MI
5	2.778	2.40	-	-	3.194	2.76
9.1	2.020	1.74	2.46	0.68	1.857	1.60
12.1	1.625	1.40	1.29	0.36	1.454	1.25
19.6	1.000	0.86	0.86	0.18	1.000	0.86
25	0.742	0.64	-	-	0.803	0.69
30	0.585	0.50	-	-	0.653	0.56
35.9	0.463	0.40	0.40	0.08	0.524	0.45
40	0.406	0.35	-	-	0.468	0.40
47.9	0.337	0.29	0.29	0.06	0.423	0.36
55	0.309	0.27	-	-	0.375	0.32

NOTES: (1) PREDICTED GM/MI VALUES BASED ON CORRECTION FACTORS APPLIED TO MEAN EMISSIONS VALUE AT FTP CYCLE SPEED. CORRECTION FACTORS ARE NORMALIZED TO 1.00 AT MEAN FTP SPEED (19.6 MPH).
(2) AVERAGE SPEEDS GIVEN TO 0.1 MPH ARE FOR THE TEST CYCLES USED IN EPA TESTING.

CHART 3A

LDV SPEED CORRECTION FACTOR STUDY

QUADRATIC POLYNOMIAL IN AVERAGE CYCLE SPEED
MYGRP=1981-1983 LDV

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: L_HC LOG HC

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	114	775.46100278	6.80228950	41.80	0.0001	0.913713	27.4690
ERROR	450	73.23069930	0.16273489		STD DEV		L_HC MEAN
CORRECTED TOTAL	564	848.69170209			0.40340412		-1.46857974

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
VEHNO	112	596.72816771	32.74	0.0001				
SPD1	1	177.51241682	1090.81	0.0001	1	10.81517021	66.46	0.0001
SPD2	1	1.22041825	7.50	0.0064	1	1.22041825	7.50	0.0064

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
SPD1	-0.05673194	-8.15	0.0001	0.00695907
SPD2	0.00033282	2.74	0.0064	0.00012153

CHART 3B

LDV SPEED CORRECTION FACTOR STUDY

QUADRATIC POLYNOMIAL IN AVERAGE CYCLE SPEED

SUMMARY OF REGRESSION MODEL   MODEL YEAR GROUP: MY 1981-1983 LDV

DEPENDENT VARIABLE: L_HC   LOG HC

INDEPENDENT VARIABLE: SPEED   POLYNOMIAL IN CYCLE SPEED

OBSERVATIONS: 565
DEGREES OF FREEDOM: 450
R_SQUARED: 0.9137

PARAMETERS

	ESTIMATE	STD ERR	NORMALIZED MODEL	NORMALIZED MOBILE2
INT	-	-	9.84090E-01	2.39540E+00
SPD1	-5.67319E-02	6.95907E-03	-5.67319E-02	-3.35780E-01
SPD2	3.32820E-04	1.21530E-04	3.32820E-04	2.11610E-02
SPD3	-	-	-	-7.31550E-04
SPD4	-	-	-	1.20720E-05
SPD5	-	-	-	-7.48570E-08

EVALUATION AT SELECTED CYCLE SPEEDS

SPEED	-- MODEL -- FACTOR	-- MODEL -- GM/MI	DATA VALUES GM/MI	DATA VALUES STD ERR	-- MOBILE2 -- FACTOR	-- MOBILE2 -- GM/MI
5	2.031	1.17	-	-	3.194	1.84
9.1	1.641	0.94	1.26	0.27	1.857	1.07
12.1	1.414	0.81	0.85	0.22	1.454	0.84
19.6	1.000	0.58	0.58	0.13	1.000	0.58
25	0.798	0.46	-	-	0.803	0.46
30	0.658	0.38	-	-	0.653	0.38
35.9	0.536	0.31	0.32	0.07	0.524	0.30
40	0.471	0.27	-	-	0.468	0.27
47.9	0.379	0.22	0.22	0.05	0.423	0.24
55	0.323	0.19	-	-	0.375	0.22

NOTES: (1) PREDICTED GM/MI VALUES BASED ON CORRECTION FACTORS APPLIED TO MEAN EMISSIONS VALUE AT FTP CYCLE SPEED. CORRECTION FACTORS ARE NORMALIZED TO 1.00 AT MEAN FTP SPEED (19.6 MPH).
(2) AVERAGE SPEEDS GIVEN TO 0.1 MPH ARE FOR THE TEST CYCLES USED IN EPA TESTING.

CHART 4A

LDV SPEED CORRECTION FACTOR STUDY

LINEAR FUNCTION IN LOG AVERAGE CYCLE SPEED
MYGRP=1978-1979 LDV

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: L_CO LOG CO

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	70	791.33632285	11.30480461	32.43	0.0001	0.890891	23.0065
ERROR	278	96.91594927	0.34861852		STD DEV		L_CO MEAN
CORRECTED TOTAL	348	888.25227211			0.59043926		2.56640030

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
VEHNO	69	523.60197911	21.77	0.0001				
SPD1	1	267.73434374	767.99	0.0001	1	267.73434374	767.99	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
SPD1	-0.05927374	-27.71	0.0001	0.00213888

CHART 4B

LDV SPEED CORRECTION FACTOR STUDY

LINEAR FUNCTION IN LOG AVERAGE CYCLE SPEED

SUMMARY OF REGRESSION MODEL MODEL YEAR GROUP: MY 1978-1979 LDV

DEPENDENT VARIABLE:	L_CO	LOG CO
INDEPENDENT VARIABLE:	SPEED	POLYNOMIAL IN CYCLE SPEED
OBSERVATIONS:	349	
DEGREES OF FREEDOM:	278	
R_SQUARED:	0.8909	

PARAMETERS

	ESTIMATE	STD ERR	NORMALIZED MODEL	NORMALIZED MOBILE2
INT	-	-	1.16177E+00	2.48750E+00
SPD1	-5.92737E-C2	2.13888E-03	-5.92737E-02	-3.91560E-01
SPD2	-	-	-	2.70720E-02
SPD3	-	-	-	-9.76180E-04
SPD4	-	-	-	1.65270E-05
SPD5	-	-	-	-1.04320E-07

EVALUATION AT SELECTED CYCLE SPEEDS

SPEED	-- MODEL -- FACTOR	GM/MI	DATA VALUES GM/MI	STD ERR	-- MOBILE2 -- FACTOR	GM/MI
5	2.376	73.21	-	-	2.988	92.06
9.1	1.863	57.42	80.13	10.12	1.711	52.74
12.1	1.560	48.06	42.53	5.33	1.365	42.06
19.6	1.000	30.81	30.81	3.78	1.000	30.81
25	0.726	22.37	-	-	0.821	25.30
30	0.540	16.64	-	-	0.671	20.67
35.9	0.381	11.73	13.29	1.70	0.541	16.68
40	0.298	9.20	-	-	0.492	15.17
47.9	0.187	5.76	8.10	1.34	0.477	14.70
55	0.123	3.78	-	-	0.433	13.33

NOTES: (1) PREDICTED GM/MI VALUES BASED ON CORRECTION FACTORS APPLIED TO MEAN EMISSIONS VALUE AT FTP CYCLE SPEED. CORRECTION FACTORS ARE NORMALIZED TO 1.00 AT MEAN FTP SPEED (19.6 MPH).
(2) AVERAGE SPEEDS GIVEN TO 0.1 MPH ARE FOR THE TEST CYCLES USED IN EPA TESTING.

CHART 5A

LDV SPEED CORRECTION FACTOR STUDY

LINEAR FUNCTION IN LOG AVERAGE CYCLE SPEED
MYGRP=1980 LDV

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: L_CO LOG CO

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	19	273.27994457	14.38315498	14.81	0.0001	0.789599	104.7288
ERROR	75	72.81976726	0.97093023		STD DEV		L_CO MEAN
CORRECTED TOTAL	94	346.09971183			0.98535792		0.94086591

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
VEHNO	18	231.28640430	13.23	0.0001				
SPD1	1	41.99354027	43.25	0.0001	1	41.99354027	43.25	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
SPD1	-0.04499757	-6.58	0.0001	0.00684214

CHART 5B

LDV SPEED CORRECTION FACTOR STUDY

LINEAR FUNCTION IN LOG AVERAGE CYCLE SPEED

SUMMARY OF REGRESSION MODEL   MODEL YEAR GROUP: MY 1980 LDV

DEPENDENT VARIABLE:	L_CO	LOG CO
INDEPENDENT VARIABLE:	SPEED	POLYNOMIAL IN CYCLE SPEED
OBSERVATIONS:	95	
DEGREES OF FREEDOM:	75	
R_SQUARED:	0.7896	

PARAMETERS

	ESTIMATE	STD ERR	NORMALIZED MODEL	NORMALIZED MOBILE2
INT	-	-	8.81952E-01	2.48750E+00
SPD1	-4.49976E-02	6.84214E-03	-4.49976E-02	-3.91560E-01
SPD2	-	-	-	2.70720E-02
SPD3	-	-	-	-9.76180E-04
SPD4	-	-	-	1.65270E-05
SPD5	-	-	-	-1.04320E-07

EVALUATION AT SELECTED CYCLE SPEEDS

SPEED	MODEL FACTOR	MODEL GM/MI	DATA VALUES GM/MI	DATA VALUES STD ERR	MOBILE2 FACTOR	MOBILE2 GM/MI
5	1.929	15.91	-	-	2.988	24.64
9.1	1.604	13.23	23.01	6.98	1.711	14.11
12.1	1.401	11.56	10.76	3.44	1.365	11.26
19.6	1.000	8.25	8.25	2.14	1.000	8.25
25	0.784	6.47	-	-	0.821	6.77
30	0.626	5.16	-	-	0.671	5.53
35.9	0.480	3.96	3.93	1.28	0.541	4.46
40	0.399	3.29	-	-	0.492	4.06
47.9	0.280	2.31	3.10	1.43	0.477	3.93
55	0.203	1.68	-	-	0.433	3.57

NOTES: (1) PREDICTED GM/MI VALUES BASED ON CORRECTION FACTORS APPLIED TO MEAN EMISSIONS VALUE AT FTP CYCLE SPEED. CORRECTION FACTORS ARE NORMALIZED TO 1.00 AT MEAN FTP SPEED (19.6 MPH).
(2) AVERAGE SPEEDS GIVEN TO 0.1 MPH ARE FOR THE TEST CYCLES USED IN EPA TESTING.

CHART 6A

LDV SPEED CORRECTION FACTOR STUDY

LINEAR FUNCTION IN LOG AVERAGE CYCLE SPEED
MYGRP=1981-1983 LDV

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: L_CO LOG CO

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	113	1514.96932462	13.40680818	14.60	0.0001	0.785271	219.4291
ERROR	451	414.26175703	0.91854048		STD DEV		L_CO MEAN
CORRECTED TOTAL	564	1929.23108165			0.95840518		0.43677217

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
VEHNO	112	1278.36874279	12.43	0.0001				
SPD1	1	236.60058183	257.58	0.0001	1	236.60058183	257.58	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
SPD1	-0.04379690	-16.05	0.0001	0.00272888

CHART 6B

LDV SPEED CORRECTION FACTOR STUDY

LINEAR FUNCTION IN LOG AVERAGE CYCLE SPEED

SUMMARY OF REGRESSION MODEL — MODEL YEAR GROUP: MY 1981-1983 LDV

DEPENDENT VARIABLE: L_CO — LOG CO

INDEPENDENT VARIABLE: SPEED — POLYNOMIAL IN CYCLE SPEED

OBSERVATIONS: 565
DEGREES OF FREEDOM: 451
R_SQUARED: 0.7853

PARAMETERS

	ESTIMATE	STD ERR	NORMALIZED MODEL	NORMALIZED MOBILE2
INT	-	-	8.58419E-01	2.48750E+00
SPD1	-4.37969E-02	2.72888E-03	-4.37969E-02	-3.91560E-01
SPD2	-	-	-	2.70720E-02
SPD3	-	-	-	-9.76180E-04
SPD4	-	-	-	1.65270E-05
SPD5	-	-	-	-1.04320E-07

EVALUATION AT SELECTED CYCLE SPEEDS

SPEED	-- MODEL -- FACTOR	GM/MI	DATA VALUES GM/MI	STD ERR	-- MOBILE2 -- FACTOR	GM/MI
5	1.895	13.69	-	-	2.988	21.58
9.1	1.584	11.44	19.42	4.35	1.711	12.36
12.1	1.389	10.03	10.04	2.86	1.365	9.86
19.6	1.000	7.22	7.22	1.90	1.000	7.22
25	0.789	5.70	-	-	0.821	5.93
30	0.634	4.58	-	-	0.671	4.84
35.9	0.490	3.54	5.63	1.40	0.541	3.91
40	0.409	2.96	-	-	0.492	3.56
47.9	0.290	2.09	3.06	1.11	0.477	3.44
55	0.212	1.53	-	-	0.433	3.13

NOTES: (1) PREDICTED GM/MI VALUES BASED ON CORRECTION FACTORS APPLIED TO MEAN EMISSIONS VALUE AT FTP CYCLE SPEED. CORRECTION FACTORS ARE NORMALIZED TO 1.00 AT MEAN FTP SPEED (19.6 MPH).
(2) AVERAGE SPEEDS GIVEN TO 0.1 MPH ARE FOR THE TEST CYCLES USED IN EPA TESTING.

CHART 7A

LDV SPEED CORRECTION FACTOR STUDY

QUADRATIC POLYNOMIAL IN AVERAGE CYCLE SPEED
MYGRP=1978-1979 LDV

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: L_NOX LOG NOX

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	71	130.94469036	1.84429141	31.83	0.0001	0.890456	31.8165
ERROR	278	16.10878908	0.05794528		STD DEV		L_NOX MEAN
CORRECTED TOTAL	349	147.05347944			0.24071827		0.75658324

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
VEHNO	69	129.69620593	32.44	0.0001				
SPD1	1	0.29981111	5.17	0.0237	1	1.10463227	19.06	0.0001
SPD2	1	0.94867331	16.37	0.0001	1	0.94867331	16.37	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
SPD1	-0.02303616	-4.37	0.0001	0.00527607
SPD2	0.00037283	4.05	0.0001	0.00009214

CHART 7B

LDV SPEED CORRECTION FACTOR STUDY

QUADRATIC POLYNOMIAL IN AVERAGE CYCLE SPEED

SUMMARY OF REGRESSION MODEL MODEL YEAR GROUP: MY 1978-1979 LDV

DEPENDENT VARIABLE: L_NOX LOG NOX

INDEPENDENT VARIABLE: SPEED POLYNOMIAL IN CYCLE SPEED

OBSERVATIONS: 350
DEGREES OF FREEDOM: 278
R_SQUARED: 0.8905

PARAMETERS

	ESTIMATE	STD ERR	NORMALIZED MODEL	NORMALIZED MOBILE2
INT	-	-	3.08282E-01	9.42130E-01
SPD1	-2.30362E-02	5.27607E-03	-2.30362E-02	-4.23240E-02
SPD2	3.72830E-04	9.21400E-05	3.72830E-04	3.86250E-03
SPD3	-	-	-	-9.39850E-05
SPD4	-	-	-	7.53880E-07
SPD5	-	-	-	0.00000E+00

EVALUATION AT SELECTED CYCLE SPEEDS

SPEED	MODEL FACTOR	MODEL GM/MI	DATA VALUES GM/MI	DATA VALUES STD ERR	MOBILE2 FACTOR	MOBILE2 GM/MI
5	1.224	2.89	-	-	0.816	1.92
9.1	1.138	2.68	3.09	0.23	0.811	1.91
12.1	1.088	2.56	2.45	0.20	0.845	1.99
19.6	1.000	2.36	2.36	0.19	1.000	2.36
25	0.966	2.28	-	-	1.124	2.65
30	0.954	2.25	-	-	1.222	2.88
35.9	0.963	2.27	2.69	0.22	1.304	3.07
40	0.984	2.32	-	-	1.344	3.17
47.9	1.062	2.50	2.52	0.18	1.416	3.34
55	1.184	2.79	-	-	1.560	3.68

NOTES: (1) PREDICTED GM/MI VALUES BASED ON CORRECTION FACTORS APPLIED TO MEAN EMISSIONS VALUE AT FTP CYCLE SPEED. CORRECTION FACTORS ARE NORMALIZED TO 1.00 AT MEAN FTP SPEED (19.6 MPH).
(2) AVERAGE SPEEDS GIVEN TO 0.1 MPH ARE FOR THE TEST CYCLES USED IN EPA TESTING.

CHART 8A

LDV SPEED CORRECTION FACTOR STUDY

QUADRATIC POLYNOMIAL IN AVERAGE CYCLE SPEED
MYGRP=1980 LDV

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: L_NOX LOG NOX

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	20	33.17281384	1.65864069	27.89	0.0001	0.882873	41.7367
ERROR	74	4.40089259	0.05947152		STD DEV		L_NOX MEAN
CORRECTED TOTAL	94	37.57370643			0.24386784		0.58430127

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
VEHNO	18	32.79325672	30.63	0.0001				
SPD1	1	0.02457376	0.41	0.5223	1	0.31557353	5.31	0.0241
SPD2	1	0.35498336	5.97	0.0169	1	0.35498336	5.97	0.0169

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
SPD1	-0.02363326	-2.30	0.0241	0.01025954
SPD2	0.00043775	2.44	0.0169	0.00017917

CHART 8B

LDV SPEED CORRECTION FACTOR STUDY

QUADRATIC POLYNOMIAL IN AVERAGE CYCLE SPEED

SUMMARY OF REGRESSION MODEL MODEL YEAR GROUP: MY 1980 LDV

DEPENDENT VARIABLE: L_NOX LOG NOX

INDEPENDENT VARIABLE: SPEED POLYNOMIAL IN CYCLE SPEED

OBSERVATIONS: 95
DEGREES OF FREEDOM: 74
R_SQUARED: 0.8829

PARAMETERS

	ESTIMATE	STD ERR	NORMALIZED MODEL	NORMALIZED MOBILE2
INT	-	-	2.95046E-01	9.42130E-01
SPD1	-2.36333E-02	1.02595E-02	-2.36333E-02	-4.23240E-02
SPD2	4.37750E-04	1.79170E-04	4.37750E-04	3.86250E-03
SPD3	-	-	-	-9.39850E-05
SPD4	-	-	-	7.53880E-07
SPD5	-	-	-	0.00000E+00

EVALUATION AT SELECTED CYCLE SPEEDS

SPEED	MODEL FACTOR	MODEL GM/MI	DATA VALUES GM/MI	DATA VALUES STD ERR	MOBILE2 FACTOR	MOBILE2 GM/MI
5	1.207	2.21	-	-	0.816	1.49
9.1	1.123	2.06	2.62	0.38	0.811	1.49
12.1	1.076	1.97	1.88	0.27	0.845	1.55
19.6	1.000	1.83	1.83	0.23	1.000	1.83
25	0.978	1.79	-	-	1.124	2.06
30	0.980	1.79	-	-	1.222	2.24
35.9	1.011	1.85	2.17	0.28	1.304	2.39
40	1.051	1.92	-	-	1.344	2.46
47.9	1.182	2.16	2.23	0.29	1.416	2.59
55	1.376	2.52	-	-	1.560	2.86

NOTES: (1) PREDICTED GM/MI VALUES BASED ON CORRECTION FACTORS APPLIED TO MEAN EMISSIONS VALUE AT FTP CYCLE SPEED. CORRECTION FACTORS ARE NORMALIZED TO 1.00 AT MEAN FTP SPEED (19.6 MPH).
(2) AVERAGE SPEEDS GIVEN TO 0.1 MPH ARE FOR THE TEST CYCLES USED IN EPA TESTING.

CHART 9A

LDV SPEED CORRECTION FACTOR STUDY

QUADRATIC POLYNOMIAL IN AVERAGE CYCLE SPEED
MYGRP=1981-1983 LDV

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: L_NOX LOG NOX

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	114	286.32841801	2.51165279	28.81	0.0001	0.880201	79.5598
ERROR	447	38.97041373	0.08718213		STD DEV		L_NOX MEAN
CORRECTED TOTAL	561	325.29883174			0.29526621		-0.37112503

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE IV SS	F VALUE	PR > F
VEHNO	112	278.63697857	28.54	0.0001				
SPD1	1	6.44811659	73.96	0.0001	1	2.30774515	26.47	0.0001
SPD2	1	1.24332286	14.26	0.0002	1	1.24332286	14.26	0.0002

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
SPD1	-0.02629607	-5.14	0.0001	0.00511106
SPD2	0.00033674	3.78	0.0002	0.00008917

CHART 9B

LDV SPEED CORRECTION FACTOR STUDY

QUADRATIC POLYNOMIAL IN AVERAGE CYCLE SPEED

SUMMARY OF REGRESSION MODEL MODEL YEAR GROUP: MY 1981-1983 LDV

DEPENDENT VARIABLE: L_NOX LOG NOX

INDEPENDENT VARIABLE: SPEED POLYNOMIAL IN CYCLE SPEED

OBSERVATIONS: 562
DEGREES OF FREEDOM: 447
R_SQUARED: 0.8802

PARAMETERS

	ESTIMATE	STD ERR	NORMALIZED MODEL	NORMALIZED MOBILE2
INT	-	-	3.86041E-01	9.42130E-01
SPD1	-2.62961E-02	5.11106E-03	-2.62961E-02	-4.23240E-02
SPD2	3.36740E-04	8.91700E-05	3.36740E-04	3.86250E-03
SPD3	-	-	-	-9.39850E-05
SPD4	-	-	-	7.53880E-07
SPD5	-	-	-	0.00000E+00

EVALUATION AT SELECTED CYCLE SPEEDS

SPEED	MODEL FACTOR	MODEL GM/MI	DATA VALUES GM/MI	DATA VALUES STD ERR	MOBILE2 FACTOR	MOBILE2 GM/MI
5	1.301	1.04	-	-	0.816	0.65
9.1	1.191	0.96	1.16	0.08	0.811	0.65
12.1	1.124	0.90	0.88	0.07	0.845	0.68
19.6	1.000	0.80	0.80	0.06	1.000	0.80
25	0.941	0.75	-	-	1.124	0.90
30	0.905	0.73	-	-	1.222	0.98
35.9	0.883	0.71	0.84	0.07	1.304	1.05
40	0.881	0.71	-	-	1.344	1.08
47.9	0.904	0.73	0.82	0.08	1.416	1.14
55	0.959	0.77	-	-	1.560	1.25

NOTES: (1) PREDICTED GM/MI VALUES BASED ON CORRECTION FACTORS APPLIED TO MEAN EMISSIONS VALUE AT FTP CYCLE SPEED. CORRECTION FACTORS ARE NORMALIZED TO 1.00 AT MEAN FTP SPEED (19.6 MPH).
(2) AVERAGE SPEEDS GIVEN TO 0.1 MPH ARE FOR THE TEST CYCLES USED IN EPA TESTING.

CRITIQUE OF THE EPA I/M BENEFITS MODEL FOR 1980 AND OLDER MODEL CARS

prepared for:

California Air Resources Board

prepared under:

Task 1D,
ARB Contract Number A2-065-32

June, 1985

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Critique of the
EPA I/M Benefits Model
for 1980 and Older Model Cars

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Summary

The computer model used by the U. S. Environmental Protection Agency to predict emissions benefits for inspection and maintenance programs for 1980 and older model vehicles has several assumptions which should be verified or changed before the model is used by the California Air Resources Board.

Areas needing attention and which are specific to California include the fact that the model does not project NOx emissions reductions, and it uses inspection standards which deemphasize failures due to excessive hydrocarbon emissions and which are not consistent with California's cutpoints based on cost/effectiveness estimates.

Of more general concern is the lack of distinction between emission control technologies (except for catalysts), the frequent need to "normalize" the input data, the use of regression equations instead of actual test data to predict after maintenance emissions, and the use of low

deterioration rates after repairs which are based on extremely limited data and which tend to compound the benefits of I/M programs in future years.

A separate EPA computer model which estimates I/M benefits for 1981 and newer model vehicles is not addressed in this report.

In summary, we believe that the model for 1980 and older vehicles may seriously overestimate the benefits of an I/M program in California.

1. Introduction

For several years, the Environmental Protection Agency (EPA) has been using a computer simulation model, sometimes referred to as the Appendix N model, to estimate Inspection/ Maintenance (I/M) emission reduction benefits for pre-1981 model year light-duty vehicles. (A separate EPA computer model which estimates I/M program benefits for 1981 and newer vehicles is not addressed in this report.) The I/M benefits are used in EPA's MOBILE2 emission factor model to estimate fleet average emissions of hydrocarbons and carbon monoxide for different calendar years and ambient conditions.

This report discusses the step-by-step calculation of I/M benefits in the Appendix N model and the assumptions upon which the calculations are based. In addition, where possible, model predictions and assumptions are compared with California's experience with operating I/M programs. Where appropriate, suggestions are made for improving the model and its applicability to California.

Section 2 of this report presents an overview of the Appendix N model, highlighting its main features and assumptions; Section 3 describes the model in detail, while Section 4 presents an analysis of key elements of the model. Recommendations for changes to the Appendix N model are included in Section 5.

2. Overview of the Appendix N Model

The Appendix N simulation model is used to calculate I/M emissions credits for use as input to MOBILE2. The way MOBILE2 is constituted requires that these credits be in the form of fleet average percent reductions which can be applied to the emission factors for each model year during each calendar year in which the I/M program is operating. Credits are calculated only for hydrocarbon and carbon monoxide emissions. With a moderate effort and adequate data, NOx emission benefits could be calculated as well. The simulation model requires that emissions test data be input for each of two emission control technologies: oxidation catalyst and non-catalyst. These technologies are assumed to apply to 1975-80 model years and 1968-74 model years, respectively. The relative contribution of these vehicle fleets to emissions in 1982 and 1987 are shown in Table 1. Pre-control vehicles are not covered by the model.

The model calculates I/M credits for various levels of I/M program stringency, vehicle age, age at first inspection, and pollutant (HC or CO), as well as in the presence or absence of mechanics' training.

To determine the I/M benefits, the model uses test vehicle input samples for each emission control technology. The data for the "as-received" (or before maintenance) fleet are generated by adjusting the observed emissions from the

TABLE 1

Vehicle Population and Miles Travelled
by Control Technology

Control Technology*	Population Fraction		Vehicle Miles Travelled Fraction	
	1982	1987	1982	1987
Pre-control vehicles (1965 and older)	0.03	0.01	0.01	0.003
Non-catalyst vehicles (1966-74 models)	0.28	0.07	0.13	0.03
Oxidation catalyst vehicles (1975-79 vehicles)	0.43	0.23	0.43	0.11
Three-way catalyst vehicles (1980 and newer)	0.26	0.69	0.43	0.86

*Based on model year groupings. Description titles are only generally accurate, and correspond to the titles used by EPA in the Appendix N model.

Reference: "Supplement 2 to Procedure and Basis for Estimating On-Road Motor Vehicle Emissions." California Air Resources Board (June 1981).

sample based on "target" emissions and mileage levels, initially derived from MOBILE2. Next, by "inspecting" the fleet based on idle emissions, the total fleet is divided into pass and fail subfleets. Then, by simulating the maintenance of vehicles which fail inspection, reconstituting the total fleet, and simulating the deterioration of vehicle emissions over a one year period, the model generates adjusted average emissions for a composite fleet. These composite numbers serve as the "target" emissions levels for the next program year.

This sequence is repeated for each year up to 19 years after the first vehicle in the fleet is inspected. For example, the simulation is repeated for 19 years for vehicles which are new when the I/M program is first started. For vehicles which are ten years old when the I/M program begins, the simulation is repeated for nine years. Thus, for the fleet as a whole, a 20 year matrix of emissions levels is created.

Next, based on the average "as received" emissions levels (essentially the MOBILE2 emissions factors) and the "after repairs" emissions levels for each relative age and I/M program year, the model calculates the percent reductions due to I/M as of January 1 of each calendar year of the emissions history. Finally, a matrix containing these emissions reductions is formed for use as input to MOBILE2.

3. Model Description

In order to understand how the model works, it is important to visualize how the matrix of input data is transformed into the output table of I/M credits. As an example, the collection of input data for the non-catalyst and catalyst fleets is symbolically shown in Figure 1. Each "X" represents a cell which includes all of the data for a specific model year which was collected during the specific surveillance program. For example, the cell where FY77 and the 1969 model year intersect would include all of the data from 1969 model year passenger cars which were tested during EPA's fiscal 1977 surveillance program.

The data are organized separately for the non-catalyst and catalyst fleets. The following sequence is first applied to the non-catalyst fleet, and then to the catalyst fleet.

After the data is organized, the average FTP emissions and odometer readings are calculated for each cell. Next, the individual FTP and odometer readings for each vehicle are adjusted to conform to average target levels which, in turn, are based on MOBILE2 predictions and the calculated cell averages. Then, for the entire fleet, each individual vehicle's idle emissions are compared with inspection cutpoints, and each vehicle is assigned to one of four pass/fail subfleets. The average emissions and

Figure 1

Organization of Input Data
for the Appendix N Model

MODEL YEAR	Surveillance Program - Non-Catalyst Fleet FY 71	FY 72	FY 73	FY 74	FY 75	FY 76	FY 77	FY 78	FY 79	FY 80
1968	X	X	X	X	X	X	X	X	X	X
1969	X	X	X	X	X	X	X	X	X	X
1970	X	X	X	X	X	X	X	X	X	X
1971	X	X	X	X	X	X	X	X	X	X
1972	X	X	X	X	X	X	X	X	X	X
1973		X	X	X	X	X	X	X	X	X
1974			X	X	X	X	X	X	X	X

MODEL YEAR	Surveillance Program - Catalyst Fleet FY 71	FY 72	FY 73	FY 74	FY 75	FY 76	FY 77	FY 78	FY 79	FY 80
1975				X	X	X	X	X	X	X
1976					X	X	X	X	X	X
1977						X	X	X	X	X
1978							X	X	X	X
1979								X	X	X
1980									X	X

Note: Data from non-catalyst and catalyst-equipped vehicles are similarly, but separately, organized.

odometer readings are next computed for <u>each</u> of the four <u>subfleets</u>, and these <u>average</u> levels are subject to a simulated repair. The after repair levels for each subfleet are combined to determine the average after repair emissions for the entire fleet. Finally, the before and after repair emission levels for the entire fleet are compared, and the percent reduction due to I/M is calculated. This number forms <u>one</u> element of the I/M credits table, which is symbolically shown in Figure 2.

The I/M credits table is the final output from the Appendix N model. A separate table is computed for each combination of control technology (catalyst or non-catalyst), stringency factor, and mechanics' training (with or without). The table is organized by the age of vehicle subject to inspection, and the age of the vehicle when it received its first I/M inspection. The model first calculates the I/M credit for a one year old vehicle which receives its first inspection at one year (the top-left cell in Figure 2). The model next repeats the entire credit calculation for a <u>two</u> year old vehicle which received its first inspection at one year, and then a three year old vehicle, and so on moving across the first row in Figure 2. The process is then repeated across the second row, and so forth. Thus, each series of calculations would be like following a group of vehicles (which are all the same age) through a series of annual inspection and repair cycles.

Figure 2

Organization of Output Data (I/M Credits)
for the Appendix N Model

Age at First Inspection (years) \ Vehicle Age (years)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
6						X	X	X	X	X	X	X	X	X	X	X	X	X	X
7							X	X	X	X	X	X	X	X	X	X	X	X	X
8								X	X	X	X	X	X	X	X	X	X	X	X
9									X	X	X	X	X	X	X	X	X	X	X
10										X	X	X	X	X	X	X	X	X	X
11											X	X	X	X	X	X	X	X	X
12												X	X	X	X	X	X	X	X
13													X	X	X	X	X	X	X
14														X	X	X	X	X	X
15															X	X	X	X	X
16																X	X	X	X
17																	X	X	X
18																		X	X
19																			X

Note: Separate matrices are created for non-catalyst and catalyst-equipped vehicles.

This technique allows the model to simulate the benefits of repeated I/M cycles over several years.

It is difficult to understand how one of the input cells in Figure 1 relates to one of the output cells in Figure 2 until you realize that all of the input data from all of the cells in Figure 1 are used to determine the value in each output cell in Figure 2. (As noted above, however, the catalyst and non-catalyst fleets are treated separately.) Data from vehicles of differing ages and model years are combined into one fleet each for catalyst (1975-80 model years) and non-catalyst (1968-74 model years) fleets.

The following subsections describe, in the same general order as the model operates, the composition of the input data (Section 3.1); how it is organized and adjusted (Section 3.2); the simulation of I/M inspections and repairs during the first year of an I/M program (Section 3.3); and the change in the fleet emissions due to subsequent I/M cycles (Section 3.4). In addition, Section 3.5 describes how the model calculates I/M benefits for vehicles which are more than one year old when the I/M program begins, and Section 3.6 describes how the entire benefit calculation is repeated for catalyst vehicles.

3.1. Vehicle Input Data

For each emission control technology a sample of up to 2678 cars is input into the model. This number was based on the size of the emission factor data base at the time the model was originally created. Fairly simple program modifications could be made to provide for the use of larger data sets.

EPA used data sets obtained from their 1971-1980 Emission Factors Programs to perform the model simulation. These data are for vehicles tested "as received" from customer service. Other data sets can be used in addition to or in place of the EPA data, as long as the formats are consistent.

For each vehicle in the sample, the input data consists of the odometer reading, the FTP emissions levels for HC and CO, idle concentrations for HC and CO, engine size (CID), the calendar year in which the vehicle was tested, and the model year.

3.2. Adjustment of Vehicle Data

Although vehicles of differing ages and model years should be analyzed separately for each twenty-year emissions simulation, dividing the available data into that many categories could produce many small or null sample sizes.

This, in turn, could result in test results from just a few cars having an unrepresentatively large impact on the analysis. Therefore, in order to fill in for incomplete data, the model uses the entire vehicle input sample to simulate "equivalent" fleet idle and FTP emissions for each vehicle age-I/M program year combination. This adjustment process is described as follows.

Initially (i.e., for the first year of an inspection program), the mean odometer readings and HC and CO FTP emissions are calculated for each combination of vehicle model year and surveillance program year. (Program year refers to the calendar year in which the vehicle was tested during the Emissions Factor Test Program. The age of the vehicle is roughly equal to the program year less the model year.) A matrix of average emissions and odometer levels is created, as shown in Table 2. The mean values are simple arithmetic means based on the observed values in the data sets for each technology.

These mean values are combined with target mean odometer readings and FTP emissions predicted by MOBILE2 to give adjusted odometer and FTP means for each car in the fleet using the following equation:

$$\text{ADJUSTED FTP} = \text{VEHICLE FTP} \times \frac{\text{MOBILE2 AVERAGE FTP FOR AGE1ST}}{\text{ACTUAL AVERAGE FTP FOR SUBGROUP}}$$

Table 2

Example of the
Matrix of Average Vehicle Emissions
and Mileage

	Surveillance Program Year			
Model Year	FY 71	FY 72	FY 73	etc.
1968	5.42 (28,297)	5.69 (36,392)	6.01 (43,122)	...
1969	5.30 (16,427)	5.41 (25,391)	5.78 (37,222)	...
1970	3.82 (12,623)	4.53 (19,379)	4.97 (29,427)	...
etc.	...	...	...	...

The top number represents average HC or CO FTP emissions. The bottom number of each pair, in parentheses, represents the average mileage.

where AGE1ST is the age at first inspection for which this scenario is being run and SUBGROUP refers to the program year/model year combination in which the individual vehicle is contained. (The same equation is used to adjust odometer readings.)

As an example, the first scenario computed by the model is for a fleet of one year old vehicles which is subjected to its first I/M inspection. The procedure described above would adjust the data from each car in the (non-catalyst or catalyst) fleet so that the <u>average</u> emissions and odometer levels for that fleet are equal to what MOBILE2 would predict for a one year old car.

This adjustment procedure forces the total fleet average value to be identical to MOBILE2 values for a vehicle whose age is equal to AGE1ST, regardless of the sample size, actual observed values, or the age and odometer readings for individual vehicles. Individual observed values are forced to be closer to, but not necessarily the same as, the MOBILE2 target levels. If a particular model/program year subgroup contains only one vehicle, the MOBILE2 values are used instead of observed data. Unless the target means stored in the simulation model are changed each time there is a change to the MOBILE2 factors, this adjustment becomes meaningless.

In addition to the adjustments for FTP emissions and odometer, idle emissions are adjusted as well. First, predicted idle emissions for HC and CO for each car in the sample are determined from a multiple linear regression based on the observed vehicle mileage, the observed FTP emission levels, and the vehicle engine size. The equation for predicting idle emissions is given by:

(1) PREDICTED IDLE = $B_1+B_2xODOM+B_3xFTP_{HC}+B_4xFTP_{CO}+B_5xCID$

Values for the coefficients B_{1-5}, as well as sample predictions for typical and extreme combinations of variables, are shown in Table 3. Some of the regression coefficients do not appear to coincide with what one might expect based on engineering experience. In particular, the coefficients would predict that idle emissions from catalyst vehicles decrease very slightly, with time, when one would intuitively expect these levels to increase as vehicles become older.

In addition, the model constrains the predicted idle levels to lower limits of 1.0 ppm and 0.01% for HC and CO, respectively. However, as the extreme values shown in Table 3 indicate, it is unlikely that these constraints would ever be applied.

Next, the ratio of observed to predicted idle concentrations for each car and pollutant are calculated.

TABLE 3

EPA Regression Equation for Predicting
Idle Emissions Before First Inspection

$$\text{Predicted Idle} = B_1 + B_2 \times \text{ODOM} + B_3 \times \text{FTPHC} + B_4 \times \text{FTPCO} + B_5 \times \text{CID}$$

Technology	Pollutant	B_1	ODO B_2	HC B_3	CO B_4	CID B_5
Non-catalyst	HC	140.36	6.17	76.32	-1.18	-0.30
Non-catalyst	CO	2.3972	0.0120	0.0532	0.0472	-0.0055
Ox. catalyst	HC	11.12	-1.65	102.23	-0.32	0.03
Ox. catalyst	CO	0.4258	-0.0118	0.0843	0.0681	-0.0017

Typical Values

Technology	ODO	FTPHC	FTPCO	CID	Predicted Idle HC	Predicted Idle CO
Non-catalyst	25,000	2.50	25.0	350	212 ppm	1.82%
	75,000	4.25	63.0	120	401 ppm	5.03%
Ox. catalyst	10,000	0.4	7.0	250	56 ppm	0.50%
	25,000	0.8	15.0	350	94 ppm	0.89%
	75,000	1.5	45.0	120	141 ppm	3.32%

Extreme Values

Non-catalyst (high HC)	150,000	20.0	20.0	78	1712 ppm	4.16%
(low HC)	10,000	1.0	40.0	500	26 ppm	1.60%
(high CO)	150,000	15.0	225.0	78	1089 ppm	13.57%
(low CO)	10,000	1.0	10.0	500	61 ppm	0.18%
Ox. catalyst (high HC)	10,000	20.0	20.0	500	2063 ppm	2.61%
(low HC)	50,000	0.2	20.0	78	19 ppm	1.61%
(high CO)	10,000	15.0	225.0	78	1473 ppm	16.87%
(low CO)	150,000	1.0	10.0	500	100 ppm	0.16%

Then, using the adjusted mileages and FTP emissions (instead of observed values), equation (1) is again applied.

Finally, the adjusted idle emissions are multiplied by the idle ratios to produce new idle levels which are "consistent" with the MOBILE2 adjustments to vehicle mileage and FTP emissions.

Put another way, the adjusted idle concentrations for each vehicle are:

$$\text{Adjusted idle} = \text{Observed idle} \times \frac{\text{Predicted (based on adjusted values)}}{\text{Predicted (based on observed values)}}$$

During the second and subsequent years of an I/M program, a different set of coefficients are used. These coefficients, as well as typical and extreme values, are shown in Table 4. Once again, some of the coefficients predict that idle emissions decrease slightly over time, and the adjusted, predicted idle emissions are again restricted to the 1.0 ppm/0.01% lower limits. Note from Table 4, however, that this time the regression will frequently predict negative values for idle HC, and occasionally predict negative idle CO values as well. Thus, the lower limits will be used for several vehicles.

TABLE 4

EPA Regression Equation for Predicting
Idle Emissions Based on Adjusted Data

Predicted Idle = $B_1 + B_2 \times ODOM + B_3 \times FTPHC + B_4 \times FTPCO + B_5 \times CID$

Technology	Pollutant	B_1	B_2	B_3	B_4	B_5
Non-catalyst	HC	-131.35	24.94	28.08	11.20	-1.00
Non-catalyst	CO	0.6558	-0.0206	0.0382	0.0642	-0.0051
Ox. catalyst	HC	-11.64	-2.18	59.22	1.31	0.12
Ox. catalyst	CO	0.4796	-0.0672	0.0398	0.0655	-0.0011

Typical Values

Technology	ODO	FTPHC	FTPCO	CID	Predicted Idle HC	Predicted Idle CO
Non-catalyst	25,000	2.50	25.0	350	-69 ppm	0.52%
	75,000	4.25	63.0	120	761 ppm	4.10%
Ox. catalyst	10,000	0.4	7.0	250	49 ppm	0.61%
	25,000	0.8	15.0	350	92 ppm	0.94%
	75,000	1.5	45.0	120	134 ppm	2.85%

Extreme Values

Technology	ODO	FTPHC	FTPCO	CID	Predicted Idle HC	Predicted Idle CO
Non-catalyst (high HC)	150,000	20.0	225.0	78	3246 ppm	15.16%
(low HC)	10,000	1.0	10.0	500	-466 ppm	-1.23%
(high CO)	10,000	20.0	225.0	78	2897 ppm	15.45%
(low CO)	150,000	1.0	10.0	500	-117 ppm	-1.52%
Ox. catalyst (high HC)	10,000	20.0	225.0	500	1525 ppm	15.40%
(low HC)	50,000	0.2	7.0	78	8 ppm	0.52%
(high CO)	10,000	20.0	225.0	78	1475 ppm	15.86%
(low CO)	50,000	0.2	7.0	500	58 ppm	0.06%

3.3. I/M Simulation

This portion of the model simulates the inspection and maintenance of a fleet of vehicles subjected to an I/M program. The I/M simulation, which is based on an assumed set of inspection standards, includes an inspection to identify those vehicles which need maintenance, and repairs for those vehicles which fail the inspection. The assumed effect of the repairs on emissions is different, depending on which idle cutpoint (or cutpoints) which caused the failure.

3.3.1. Inspection Standards (Cutpoints)

The HC and CO cutpoints used in the simulation model are stored in data statements located at the end of the computer program. The cutpoints were calculated by adjusting the input data sample, using the technique described in the previous section, to simulate vehicles with ages ranging from one to nineteen years. For each age, the adjusted idle levels were searched to determine the point at which 10% of the fleet would fail, 20% would fail, etc., through 50%.

However, a minimum of two parameters must be specified when searching distributions for two pollutants and attempting to identify cutpoints which result in a prescribed overall failure rate. This is because there are an infinite number of combinations of HC and CO cutpoints which could combine to create a specified failure rate. Therefore, in addition to the stringency factor, EPA used an algorithm to relate the HC and CO cutpoints in order to develop a unique combination of HC and CO cutpoints for each stringency level. This algorithm required that one of the two following conditions be satisfied:

1) if the CO cutpoint is greater than or equal to 3.0%, the HC cutpoint (in ppm) is 100 times the CO cutpoint;

2) if the CO cutpoint is less than 3.0%, the HC cutpoint (in ppm) is 150 plus 50 times the CO cutpoint.

Separate inspection standards, or cutpoints, were identified in this way, by trial and error, for each pollutant, stringency level (overall failure rate), technology group, and age.

The cutpoints used by the model for each scenario are based on the age at first inspection, rather than the age when the inspection actually occurs. Thus, as the vehicle fleet "ages" through multiple I/M cycles, the cutpoints remain unchanged.

Table 5 applies the algorithm used by EPA to the CO cutpoints currently used in the California Vehicle Inspection Program and compares the results with California's actual HC cutpoints. As the data show, this algorithm results in substantially less stringent HC

TABLE 5

Comparison of California I/M Cutpoints
with Cutpoints Based on EPA Algorithm

Inspection Category	Model Year	Emission Controls	No. of Cylinders	Idle Emission Standards CARB CO	CARB HC	EPA HC*
1	1955-65	---	5 or more	8.50	800	850
2	1966-70	w/air	"	5.00	450	500
3	1966-70	w/o air	"	7.00	550	700
4	1971-72	w/air	"	4.00	300	400
5	1971-72	w/o air	"	6.50	450	650
6	1973-74	w/air	"	3.50	200	350
7	1973-74	w/o air	"	6.50	400	650
8	1955-67	---	4 or less	8.00	1200	800
9	1968-70	w/air	"	5.50	400	550
10	1968-70	w/o air	"	7.50	900	750
11	1971-72	w/air	"	5.50	400	550
12	1971-72	w/o air	"	6.50	400	650
13	1973-74	w/air	"	4.50	300	450
14	1973-74	w/o air	"	6.50	350	650
15	1975+	no cat.	All	3.00	150	300
16	1975+	cat. w/o air	All	4.00	200	400
17	1975+	cat. w/air	All	1.00	100	200
18	1975+	3-way cat.	All	1.00	80	200
	Population Weighted Average**			4.49	352	477

*This is the HC cutpoint calculated by applying EPA's algorithm to CARB's CO cutpoint.
**Based on first quarter 1983 data from the Southern California I/M program.

cutpoints for most vehicle categories than are currently applied in California. This, in turn, means that for a given failure rate, the cutpoints used in the simulation model result in a relatively higher fraction of CO-related failures, and a relatively lower fraction of HC-related failures, than the cutpoints actually used in California. On a population-weighted basis, the EPA algorithm produces HC cutpoints which are 36% higher than the actual California standards. The effect of this difference on I/M credits is discussed later in Section 4.

This difference is not surprising, since the California cutpoints are based on an algorithm designed to maximize the cost effectiveness (minimize the $/pound) of the cutpoints based on the HC reductions, while the simulation model uses HC cutpoints which are simple ratios of the CO cutpoints. Since the cutpoints are stored in the program as data, they can be changed and based on any algorithm the user chooses.

3.3.2. Inspection

At the start of each inspection cycle, each vehicle in the fleet is checked for idle HC and CO emissions. The previously adjusted idle emissions are compared with the applicable cutpoints, and each vehicle is assigned a subfleet code as follows:

1 = passed HC and CO idle emission tests

2 = failed HC idle test only

3 = failed CO idle test only

4 = failed both idle tests

For each of these subfleets, average adjusted mileage and FTP emissions are calculated for later use. Both overall failure rates (failure groups 2,3, and 4) and individual pollutant failure rates (group 2 for HC, 3 for CO) are found by dividing the number of cars in each appropriate group(s) by the number of cars in the sample. In addition, the adjusted FTP emissions rates for HC and CO are compared with the applicable standards:

FTP Standards	HC(gpm)	CO(gpm)
Technology 1 (non-catalyst)	3*	34*
Technology 2 (catalyst)	1.5	15

This test, in combination with the results of the idle tests, are used to determine the errors of commission and omission for each pollutant and technology group. An error of commission is defined to occur when a vehicle fails the idle test but passes the FTP test. Conversely, an error of

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*For the 1975 model year, the FTP emissions testing procedure was changed. Previous standards (CVS 72) are typically adjusted to produce the equivalent standards shown under the new testing procedure (CVS 75). The usual adjustment for CO would result in an equivalent standard of 28 gm/mi, rather than the 34 gm/mi in the model. This difference does not impact the I/M credits calculations, since the FTP standards are only used to determine errors of commission and omission.

omission is defined to occur when a vehicle passes the idle test but fails the FTP test. This contrasts with previous applications of these error terms in California, which have often been based on the presence or absence of certain emissions-related defects or malfunctions. This calculation of errors is performed for informational purposes only, and is not used elsewhere in the model.

3.3.3. Maintenance

Once vehicles in the total (catalyst or non-catalyst) fleet are inspected and organized into subfleets, simulated maintenance is performed on those vehicles in the subfleets which fail the idle emissions test. The maintenance portion of the simulation model is designed to reduce FTP emissions to "acceptable" levels. Different maintenance algorithms are applied to each failure group (subfleet) based on the pollutant failed as well as the control technology and presence of a mechanics' training program. The maintenance simulation is performed on the average values for each failure group, rather than on every individual vehicle in the sample.

The simulation model uses a linear regression equation to determine the after maintenance idle emissions levels for each subfleet-pollutant-technology combination. The equation is:

$$AM\ IDLE = A_1 + A_2 \times AVGMIL + A_3 \times CUTPT_{CO}$$

where AM IDLE refers to after maintenance idle emissions, AVGMIL is the average odometer reading (divided by 10,000) for the subfleet, and $CUTPT_{CO}$ is the applicable CO cutpoint. According to EPA, the coefficients A_{1-3} were derived from after maintenance reinspection tests from Portland and New Jersey I/M programs*. (The coefficients are shown in Table 6. Typical values for a fleet of vehicles are shown in Table 7.)

In addition, because the Portland and New Jersey programs on which the model is based require <u>all</u> vehicles to pass on reinspection, the model constrains after maintenance idle levels to be at or below the appropriate cutpoints. This is equivalent to assuming that an inspection program has no provisions for waivers. A waiver algorithm could be added to the model if one is desired.

Although the program constrains after maintenance idle emissions to be below the cutpoints, the regression coefficients don't appear to allow the predicted levels to even approach the cutpoints. As shown in Table 7, for non-catalyst cars the regression coefficients result in average HC concentrations which are consistently about one-third of the applicable cutpoints, and average CO

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*The Portland study involved 320 tests of 1975-77 model year cars. In New Jersey, 1333 tests performed in 1975-79 were used.

TABLE 6

EPA Regression Equation for Predicting
After Maintenance Idle Emissions Levels

$$AM\ IDLE = A_1 + A_2 \times AVGMIL + A_3 \times CUTPTCO$$

Technology	Pollutant	A_1	A_2	A_3
Non-catalyst	HC	59.396	8.2111	12.106
Non-catalyst	CO	-0.6596	0.0615	0.4658
Ox. catalyst	HC	27.814	4.6612	18.517
Ox. catalyst	CO	-0.2716	0.0	0.3905

TABLE 7

Predicted After Maintenance Idle Emissions
(30% Stringency Factor, First I/M Program Year,
1979 Calendar Year)

Model Year	Fleet Fraction*	AVGMIL*	HC CUTPT	CO CUTPT	Predicted A/M Idle HC ppm	(%)	CO%	(%)
1978	0.1087	10,784	272.2	2.44	78	(29%)	0.68	(28%)
1977	0.0993	24,809	303.9	3.04	96	(32%)	0.92	(30%)
1976	0.0763	38,331	350.5	3.50	110	(31%)	1.10	(31%)
1975	0.0987	51,284	398.1	3.98	125	(31%)	1.28	(32%)
1974	0.1106	63,709	604.5	6.04	185	(31%)	2.55	(42%)
1973	0.0957	75,631	631.3	6.31	198	(31%)	2.74	(43%)
1972	0.0767	86,984	655.4	6.55	210	(32%)	2.93	(45%)
1971	0.0710	97,809	679.3	6.79	222	(33%)	3.10	(46%)
1970	0.0637	108,131	703.3	7.03	233	(33%)	3.28	(47%)
1969	0.0515	117,884	725.7	7.26	244	(34%)	3.45	(48%)
1968	0.0376	127,109	748.1	7.48	254	(34%)	3.61	(48%)
1967	0.0323	135,831	767.1	7.67	264	(34%)	3.75	(49%)
1966	0.0248	143,984	786.9	7.87	273	(35%)	3.89	(49%)
1965	0.0162	151,609	804.1	8.04	281	(35%)	4.02	(50%)
1964	0.0107	158,731	820.4	8.20	289	(35%)	4.14	(50%)
1963	0.0059	165,284	834.1	8.34	296	(35%)	4.24	(51%)
1962	0.0027	171,309	847.6	8.48	303	(36%)	4.34	(51%)
1961	0.0018	176,834	859.3	8.59	309	(36%)	4.43	(52%)
1960	0.0157	181,856	870.0	8.70	314	(36%)	4.51	(52%)
AVERAGE		73,992	550.4	5.47	178.0	(32%)	2.33	(43%)

*From MOBILE2 for vehicles aged 2-20 years.

concentrations which are about 45-50% of the applicable cutpoints. For oxidation catalyst vehicles the predictions are roughly one-third the applicable cutpoints for both HC and CO.

These ratios were compared with California's experience to determine whether the maintenance simulated by the model goes beyond what is actually occurring.

Table 8 shows the average after maintenance idle emissions for vehicles subject to the South Coast Air Basin I/M program during the second quarter of 1979. The EPA regression predicts the CO concentrations (relative to the applicable cutpoints) reasonably well when compared with the California data; however, the same data suggest that the HC predictions are consistently low. Instead of after maintenance idle HC emissions being about one-third the applicable cutpoints, California data suggest they should be closer to one-half the cutpoints.

Although the model predicts after maintenance idle CO levels fairly well, there are areas where EPA's regression approach weakens. First, the regressions were not based on data where the inspection cutpoints were varied for similar vehicles. That is, all vehicles of the same general model year were inspected using the same cutpoints (either the Portland or New Jersey cutpoints). Thus, EPA's analysis cannot distinguish the effects on after maintenance idle

TABLE 8

After Maintenance Idle Emissions
South Coast Air Basin I/M Program

2nd QUARTER 1979

STANDARD CATEGORY	MODEL YEAR	EMISSION CONTROL SYSTEM	NO. OF CYLINDERS	SAMPLE SIZE	HC STD	AM HC	CO STD	AM CO
1	1955-65	none	≥5	6174	1200	449	9.00	3.47
2	1966-70	w/AI	≥5	2800	450	218	3.00	1.47
3	1966-70	w/o AI	≥5	11201	600	309	7.00	2.58
4	1971-74	w/AI	≥5	3864	250	181	2.25	1.38
5	1971-74	w/o AI	≥5	6929	450	267	6.00	2.37
6	1955-67	none	≥4	2721	1850	867	8.00	3.87
7	1968-70	w/AI	≥4	927	500	234	3.00	1.78
8	1968-70	w/o AI	≥4	2774	1000	512	7.00	3.48
9	1971-74	w/AI	≥4	2051	350	271	2.25	1.62
10	1971-74	w/o AI	≥4	5772	500	285	6.00	2.74
11	1975-79	No cat.	All	2331	350	159	3.00	1.31
12	1975-79	Cat. w/o AI	All	2662	250	127	2.00	0.67
13	1975-79	Cat. w/AI	All	4345	250	84	2.00	0.49
14	1975-79	3-way Cat	All	0	250	---	2.00	----
				54,551	622	305 (49%)	5.44	2.28 (42%)

Source: Bureau of Automotive Repair

emissions of the cutpoints from the effect of different model years (or control technologies) beyond the general catalyst/non-catalyst distinction. This, in turn leads to questions about the extrapolation of the analyses to stringency factors different from those actually used in Portland and New Jersey, or to different sets of cutpoints.

Second, although after maintenance idle CO levels may tend to follow the CO cutpoint closely, the relationship with idle HC levels is more tenuous. Regardless of the actual cause of failure, adjustment of the idle mixture is the most common I/M repair, and there is a natural tendency to adjust the idle mixture just enough to allow the vehicle to pass the CO cutpoint. Thus, the lower the CO cutpoint, the lower one would expect after maintenance idle CO levels to be. However, for HC-related problems, particularly ignition problems, repairs typically consist of cleaning or replacing parts. Consequently, the after maintenance idle HC levels would be expected to be more closely related to the nature of the problem and its repair than to the cutpoint. There would be no reason to expect that the replacement of a misfiring spark plug would result in lower after maintenance idle HC levels when the HC cutpoint was 200 ppm than if it was 400 ppm.

For the reasons discussed above, there may be some error in the benefits calculated by the model for alternative stringency factors. Because the model treats after maintenance idle emissions as a function of the CO cutpoint, when the stringency is increased and the cutpoints are lower, not only do more vehicles fail, but it is assumed that each vehicle which is repaired is cleaner than if it had failed at a lesser stringency. Although this may be true to a certain extent for CO, it is a more questionable assumption for HC levels.

In addition, since (as noted earlier) the cutpoints are assumed to remain constant through a series of I/M cycles for each "age at first inspection," the after maintenance idle emissions for a fleet of vehicles are affected only by the mileage coefficient in Table 6. Thus, the after maintenance idle emissions are increased by the following amounts over the 100,000 mile life of a vehicle fleet:

	HC (ppm)	CO (%)
Non-catalyst	82 ppm	0.6
Ox. catalyst	47 ppm	0.0

The increases would be proportionately smaller over shorter mileages (or fewer I/M cycles).

To compute the after maintenance FTP emissions, the model assumes that the reduction in FTP levels is related to after maintenance idle emissions. In the absence of mechanics training, this relationship is given by:

$$AM\ FTP = K \times [C_1 + C_2 \times AVGMIL + C_3 \times AM\ IDLE_{HC} + C_4 \times AM\ IDLE_{CO}]$$

where the coefficients K and C_{1-4} were estimated from the Portland* data and are given in Table 9. In addition, for each failure group and pollutant, the after maintenance FTP emissions are tested to insure that they are no greater than the before maintenance FTP emissions.

As noted above, the model appears to underestimate after maintenance idle HC emissions. Since these levels are used in the equations which predict after maintenance FTP values, the underestimate would show up in the FTP levels as well.

In order to quantify this underestimate, we first looked at the range of cutpoints used by the model. For non-catalyst vehicles, the HC cutpoints range from 480 ppm to 870 ppm at a 30% stringency factor. Our earlier analysis indicated that the EPA model predicted after maintenance idle HC levels which were approximately one-third the applicable cutpoint, or 160 ppm to 290 ppm. (33% x 480 = 160; 33% x 870 = 290.) Actual data from the Southern

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*For non-catalyst cars, 159 tests of 1972-74 model year cars were used. For catalyst cars, 386 tests of 1975-77 model cars were used.

TABLE 9

EPA Regression Equation for Predicting
After Maintenance FTP Emissions

$$\text{AM FTP} = K \times [C_1 + C_2 \times \text{AVGMIL} + C_3 \times \text{AM IDLE HC} + C_4 \times \text{AM IDLE CO}]$$

Technology	Sub- fleet	Pol- lutant	K	C_1	Mileage C_2	Idle HC C_3	Idle CO C_4
Non-catalyst	2	HC	0.96569	2.8093	0.0	0.0	0.0
		CO	0.65245	41.933	0.0	0.0	0.0
	3	HC	1.0647	2.4490	-0.20922	0.012067	0.0
		CO	0.99755	23.007	1.3794	0.0	6.6541
	4	HC	1.1575	1.0398	0.21054	0.004185	0.0
		CO	1.0489	43.096	0.0	0.0	0.0
Ox. catalyst	2	HC	1.1237	1.0906	0.0	0.00464	0.0
		CO	1.0771	16.275	0.0	0.0	28.224
	3	HC	0.92395	0.80638	0.21934	0.0	0.0
		CO	0.91849	14.391	1.3610	0.0	-0.021437
	4	HC	1.0792	1.0855	0.14956	0.0014085	0.0
		CO	1.0095	16.379	1.7465	0.0	9.6023

Subfleet codes

2: failed HC idle test only
3: failed CO idle test only
4: failed both HC and CO idle tests

California I/M program suggest that after maintenance idle HC levels should be closer to one-half the applicable cutpoint, or 240 ppm to 435 ppm. (50% x 480 = 240; 50% x 870 = 435.) Thus, the underestimate in idle HC emissions ranges from 80 ppm to 145 ppm (240-160 = 80; 435 - 290 = 145).

To see how this underestimate affects the after maintenance FTP hydrocarbon emissions, one would multiply the range of the idle HC error (80-145 ppm) by the regression coefficients shown in Table 9 for idle HC (coefficient C_3). This coefficient is zero except for the FTP HC equations for subfleets 3 and 4. The range of the error in FTP hydrocarbon levels is from (80 x 0.004185) = 0.3 gm/mi to (145 x 0.012067) = 1.7 gm/mi. Thus, as a result of the model's underestimate of after maintenance idle HC levels, it also underestimates after maintenance FTP HC levels by 0.3-1.7 gm/mi.

For catalyst cars, the analysis is similar. The range of HC cutpoints is 270 ppm to 850 ppm at a 30% stringency factor. The model's predicted after maintenance idle HC levels would be one-third of these cutpoints, or 90 ppm to 283 ppm. The California I/M data would suggest the idle levels should be one-half the cutpoints, or 135 ppm to 425 ppm. The difference, or underestimate, ranges from 45 ppm to 142 ppm. When this range is applied to the appropriate regression coefficients in Table 9, the range of the error in FTP HC levels is 0.1-0.7 gm/mi.

For typical gm/mi values for pass and fail subgroups, these errors could result in overestimates of I/M HC credits of just a few percentage points at the low end of the range, or 10-15 percentage points at the high end of the range. That is, an I/M HC credit predicted by the model to be 30% may actually be as high as 27-28%, or as low as 15-20%. The exact degree of the error could only be determined by replacing the after maintenance idle regression equation in the model with observed values for each subfleet and technology.

All of the previous discussion regarding potential errors in the I/M benefits calculations presumes the validity of the regression which calculates after maintenance FTP emissions based on mileage and after maintenance idle values. Using the current SCAB I/M idle cutpoints to determine subfleets, and data from a recent ARB surveillance program (Series 5), the EPA regression was applied to the first twenty vehicles in the program which failed one or both idle cutpoints. The results of this comparison, shown in Table 10, suggest that the regression is accurate to at least within 20% of the observed values for the fleet as a whole. A more extensive comparison of actual surveillance data with the regression predictions would strengthen that estimate.

3.3.4. Mechanics Training

The model also simulates the presence of a mechanics training program. When the model calculates the I/M

TABLE 10

Application of EPA Regression Equations
for After Maintenance FTP Emissions
to Typical Vehicles

Vehicle Number	Mileage	After Maintenance Idle Emissions HC (ppm)	After Maintenance Idle Emissions CO (%)	After Maintenance FTP Emissions (gm/mi) HC Predicted	HC Observed	CO Predicted	CO Observed
			- - - Non-Catalyst: Subfleet 2 - - -				
9	51,307	14	0.88		3.91		34.79
41	104,726	321	3.46		3.20		38.27
59	60,068	200	0.28		1.57		8.16
77	35,426	581	2.36		2.72		45.79
79	119,217	38	0.40		2.10		26.00
110	60,439	19	0.40		2.58		17.86
171	180,105	169	4.32		2.73		28.28
Subfleet Average	87,327	192	1.73	2.71	2.69	27.36	28.45
			- - - Non-Catalyst: Subfleet 3 - - -				
16	109,993	127	0.94		2.74		23.95
194	75,052	105	2.52		2.19		33.17
Subfleet Average	92,522	116	1.73	2.04	2.47	47.17	28.56
			- - - Non-Catalyst: Subfleet 4 - - -				
32	72,328	159	2.36		5.44		104.63
172	83,619	310	3.55		2.12		24.22
Subfleet Average	77,974	234	2.96	4.24	3.78	45.20	64.43

TABLE 10 (continued)

Vehicle Number	Mileage	After Maintenance Idle Emissions HC (ppm)	CO (%)	After Maintenance FTP Emissions (gm/mi) HC Predicted	HC Observed	CO Predicted	CO Observed
- - - Oxidation Catalyst: Subfleet 2 - - -							
29	37,346	81	0.82		2.82		36.22
122	59,885	52	0.17		2.60		32.43
158	47,095	42	0.17		1.70		6.95
Subfleet Average	48,109	58	0.39	1.53	2.37	29.39	25.20
- - - Oxidation Catalyst: Subfleet 3 - - -							
30	44,235	14	0.11		0.75		10.91
164	63,730	57	0.52		0.92		13.12
Subfleet Average	53,998	36	0.32	1.84	0.84	19.96	12.02
- - - Oxidation Catalyst: Subfleet 4 - - -							
4	58,232	52	0.28		7.64		8.85
118	57,116	9	0.11		2.26		26.53
128	24,949	9	0.06		0.27		1.23
182	22,030	14	0.00		0.65		3.47
Subfleet Average	40,582	21	0.11	1.86	2.71	24.76	10.02
Fleet Average	68,345	119	1.19	2.36 (7% low)	2.55	30.17 (15% high)	26.24

benefits for a program which includes mechanics training, it restricts the after maintenance FTP emissions to be the lower of the following two values:

(a) after maintenance FTP values without a mechanics training program, as predicted by the regression equations in Table 9

(b) AM FTP = $D_0 + D_1 \times$ AVGMIL

where the empirical coefficients D_1 and D_0 are found from Portland test results and given in Table 11.

The mechanics training factor assumes that if a training program is implemented, the emissions levels after maintenance will be solely a function of mileage, control technology (catalyst or non-catalyst), and subfleet. The equation appears to predict extremely low emissions levels for most of the vehicle categories. For example, the average HC and CO emissions at 50,000 miles for non-catalyst vehicles are estimated at 3.4 gm/mi and 39 gm/mi, respectively. These are roughly the certification standards for 1973-74 models. Catalyst vehicles are also projected to have 50,000 mile emission levels close to their 1.5/15 standards, except for subfleet 4, where CO emissions are projected to be 26.5 gm/mi at 50,000 miles.

TABLE 11

EPA Equation for Predicting After Maintenance Emissions with a Mechanics Training Program

$$AM\ FTP = D_0 + D_1 \times AVGMIL$$

		D_0	D_1	50,000 mile Value
Non-catalyst Vehicles				
Subfleet 2	HC	3.7504	-0.0624	3.44
	CO	37.49	0.33	39.14
Subfleet 3	HC	3.7504	-0.0624	3.44
	CO	37.49	0.33	39.14
Subfleet 4	HC	3.7504	-0.0624	3.44
	CO	37.49	0.33	39.14
Oxidation Catalyst Vehicles				
Subfleet 2	HC	1.4671	0.0243	1.59
	CO	11.358	0.0	11.36
Subfleet 3	HC	0.32275	0.20266	1.34
	CO	5.1816	1.2501	11.43
Subfleet 4	HC	1.2418	0.16849	1.41
	CO	17.687	1.7631	26.50

Subfleet Codes: 2 = failed HC only

3 = failed CO only

4 = failed both HC and CO

In addition, for non-catalyst cars, FTP HC emissions are projected to slightly decrease as mileage increases. Thus, as the simulation program continues with mechanics training, FTP HC levels for repaired vehicles get lower and lower. This decrease partially offsets the annual deterioration discussed in the next section.

At this point in the model, the vehicles in each subfleet which failed the idle emissions test for at least one pollutant have had simulated maintenance performed to reduce their idle and FTP emissions. Those vehicles which passed the idle test retain their existing idle and FTP emissions. Next, composite FTP emissions for the total fleet of passed and failed vehicles are computed, as is the percent reduction in FTP emissions due to maintenance.

3.3.5. Deterioration

Before the first inspection and between each subsequent inspection, the vehicle fleet's emissions deteriorate (i.e., increase). Before the initial inspection, the mean FTP emissions of the fleet are assumed to deteriorate linearly according to MOBILE2 predictions. After each year on the road, the average fleet mileage is estimated to increase by assumed amounts derived from MOBILE2 and test data from the Portland I/M program.

The deterioration of the fleet's emissions is based on the assumption that, after failed vehicles are repaired, their emissions deteriorate back to the level they would have been at in the absence of an I/M program after a certain number of miles. The mileages assumed by EPA are based on an analysis of the Portland data:

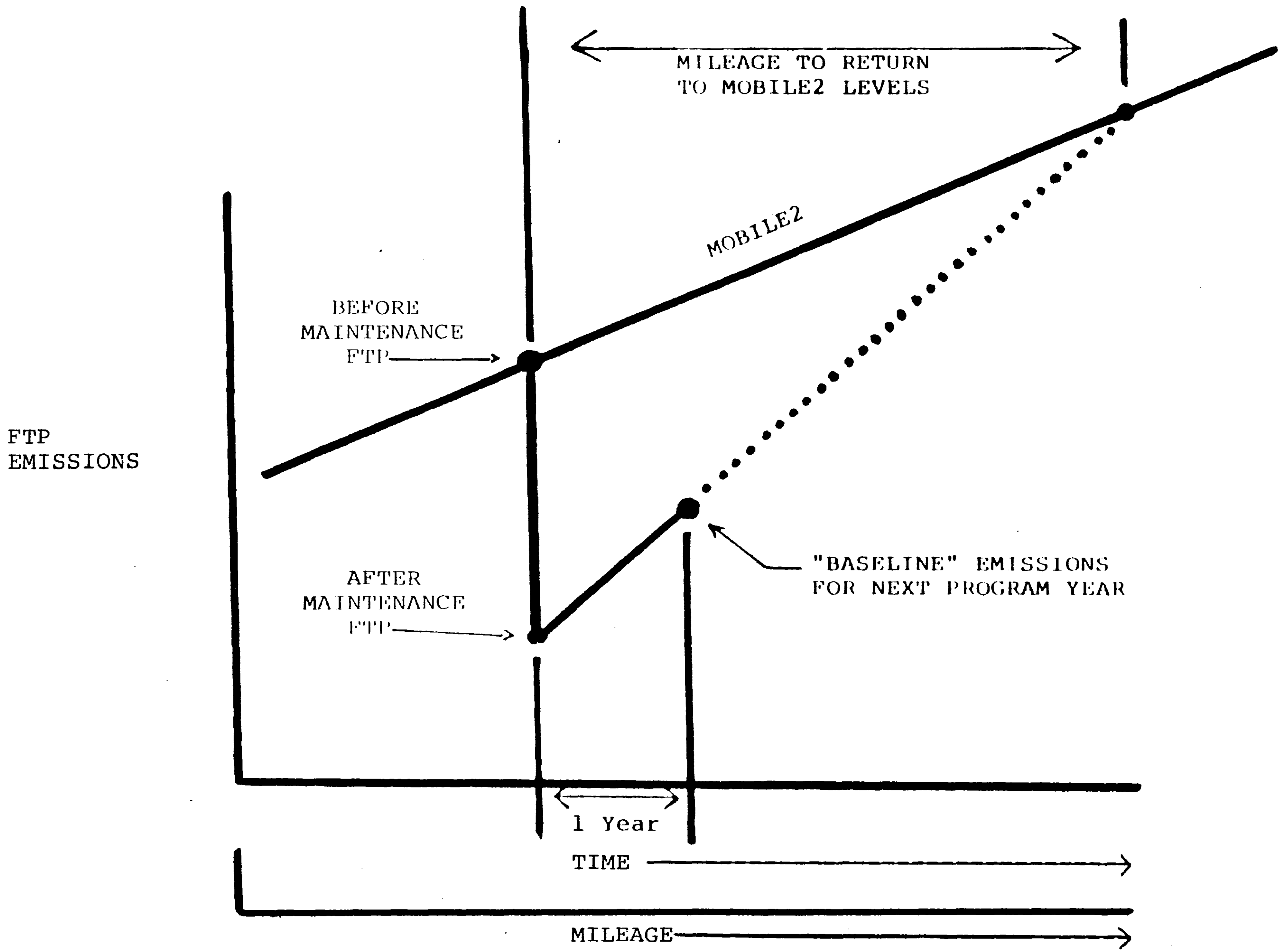
	Hydrocarbons	Carbon Monoxide
Non-catalyst	7,400 miles	40,000 miles
Oxidation catalyst	27,000 miles	57,200 miles

For example, emissions from the catalyst fleet would deteriorate back to MOBILE2 predicted HC levels after 27,000 miles, and to the predicted CO levels after 57,200 miles. Since the fleet would be reinspected the following year, the deterioration along these lines is stopped at the end of one year.

These assumptions regarding deterioration are shown in Figure 3. They represent one of the most significant reasons why the Appendix N model predicts increasing benefits as an I/M program continues. Of particular concern is the fact that these mileages are assumed to remain constant with vehicle age. While a relatively new car may accumulate 30,000 miles in two or three years, an older car may take six or seven years to accumulate the same mileage.

FIGURE 3

DETERIORATION CALCULATIONS



Since the deterioration assumption is applied to the fleet as a whole, not to individual vehicles, these mileages can be translated into time using fleet average mileages. In general, the oxidation catalyst fleet is assumed to take between two and five years to return to MOBILE2 predicted levels after each inspection cycle.

Because the model assumes that its takes longer than one year for a repaired vehicle to deteriorate back to MOBILE2 emission levels, the benefits of I/M are compounded. Although the overall concept behind EPA's approach may be valid, some of the average mileages used in the deterioration calculations may be high. Preliminary work performed by the ARB staff (as yet unpublished) suggests that the EPA mileages are too high by a wide margin.

This compounding appears to be responsible for a major portion of the predicted benefits of the program as time goes on. Re-estimation of the after repair deterioration rates using a different data base should improve confidence in the factors. Other large data bases which would show the after repair deterioration of vehicles in an ongoing I/M program can be found on data tapes from the current I/M programs in the Arizona, South Coast Air Basin, and other I/M programs. This data could be analyzed to identify the vehicles which have been subjected to multiple I/M cycles. Although FTP emissions results are not available for these vehicles, the change in idle emissions over time could be calculated for use as an indicator of the deterioration of after repair FTP emission levels from vehicles participating in an I/M program.

3.4. Subsequent Program Years

As noted above, the deteriorated FTP emissions levels from each simulation year are used as the target values for the next year. This means that the individual FTP measurements from the sample fleet, as adjusted during the previous year, are now adjusted so that the fleet average is identical to the new target. In addition, the observed idle concentrations are adjusted using the new FTP values and the equations described in Section 3.2 above. In all other respects, the model for subsequent years behaves as it does for the first year.

One serious problem the model has which affects California's ability to use it is that, as currently configured, it can only predict inspections on an annual cycle. However, the basic elements of the model could be changed to deal with less frequent inspections by randomly dividing the input fleet into two segments (for a biennial program), and allowing two years' deterioration between inspections of each segment instead of one.

Recently, EPA has modified the model for ARB to provide for either annual or biennial inspections. This newer version of the model should address this concern.

3.5. Subsequent Ages at First Inspection

After the preceding sequence has been completed for vehicles which are one year old at the time of their first inspection, the I/M cycle is begun for vehicles which are two years old at their first inspection, continuing for 18 I/M cycles. Then the sequence is repeated for vehicles which are three years old at their first inspection, continuing for 17 I/M cycles, and so on.

At the end of this process, a matrix of I/M credits has been computed, in the form shown previously in Figure 2.

3.6. Catalyst Technologies

After the I/M simulation has been completed for non-catalyst (1968-74 model year) vehicles, it is run for oxidation catalyst (1975-80 model year) vehicles. Except for the fact that the catalyst data sample and regression coefficients are used, the simulation is performed in the same manner as for non-catalyst vehicles.

4. Analysis

The net result of these adjustments and calculations is to produce a simulation model which is based on a number of assumed regressions derived from several different fleets of vehicles. One concern which arises is that the model corrects errors in some of the regressions by applying limiting constraints. However, the constraints apply only in a single direction: to increase the I/M credits calculated by the model. Errors in the regressions which might result in an extremely large predicted I/M reduction for a particular subfleet are ignored and assumed to be valid. For example, if the regressions predict after maintenance FTP emissions which are incorrectly low, no limit checks or constraints are applied. Yet, unusually high FTP levels are compared with the corresponding before maintenance levels in order to ensure that the I/M reduction is greater than or equal to zero. Although it is impossible to determine how large this bias may be without actually running the program with the EPA test car data sets, it would be fairly simple to deactivate the constraints and rerun the model to quantify this effect.

It should be noted that, as a general rule, none of the constraints applied by the model are unreasonable; for example, it is physically impossible for a vehicle to have negative idle emissions, and lower limits of 1.0 ppm and 0.01% are reasonable, physical constraints. However, the fact that the regression incorrectly predicts a negative idle concentration does not suggest that the correct value should be zero or even a low number. Furthermore, the incorrect prediction of a low value may likely be offset by similar incorrect predictions of high values, resulting in a generally unbiased (although perhaps inaccurate) set of predictions. By consistently constraining regression coefficients as the model has done, the resulting credits are consistently biased in the direction of increasing the benefits found for a given set of conditions. As noted earlier, however, the magnitude of this bias can only be assessed by running the model with the EPA data set.

In addition, some of the regressions produce somewhat dubious results. For example, after maintenance FTP emissions for non-catalyst cars which only failed the idle HC standard are projected to be 2.71 gm/mi HC and 27.4 gm/mi CO, regardless of model year, mileage, FTP emissions levels before maintenance, or idle emissions after maintenance. There are other instances, mentioned previously, in which the regressions predict that emissions (usually after repairs) would decrease with increasing mileage. Regressions which do not conform with good engineering judgment should either be better supported or replaced.

A third concern relates to the relative stringency of the HC and CO cutpoints used in the model as compared with the California I/M cutpoints.

The use of relatively less stringent idle HC cutpoints at each stringency level has no direct effect on the I/M credits calculations. This is because the after maintenance idle and FTP emissions are only dependent on the idle CO cutpoint and average mileage. In addition, the number of vehicles which fail the inspection is a function of the overall stringency factor, and not the relative stringencies of the HC and CO cutpoints.

However, the idle HC cutpoints indirectly affect the I/M benefits by determining which fail subfleet vehicles are placed in. Relatively less stringent HC cutpoints would tend to put few vehicles into subfleets 2 (fail HC only) and 4 (fail both HC and CO), while maximizing the number of vehicles in subfleet 3 (fail CO only).

Table 12 shows the after maintenance FTP levels predicted by the model for each subgroup, using typical idle concentrations and mileages. The data in the table suggest two different effects, one for non-catalyst vehicles and one for catalyst vehicles.

For the non-catalyst fleet, pushing more vehicles into subfleet 3 would tend to raise after maintenance FTP HC levels, thus reducing the calculated I/M benefits. However, the regression used for subfleet 3 predicts that HC levels decrease as mileage increases. Thus, although the problem

TABLE 12

Predicted After Maintenance FTP Levels
for Typical Idle Concentrations

		@ 20,000 miles		@ 60,000 miles	
		HC	CO	HC	CO
Non-cat.	2	2.71	27.36	2.71	27.36
	3	5.37	43.62	4.48	49.13
	4	2.90	45.20	3.88	45.20
Cat.	2	1.49	32.73	1.49	32.73
	3	1.15	15.71	1.96	20.71
	4	1.57	24.91	2.22	31.96

Note: Assumed idle concentrations are:
Non-catalyst fleet - 250 ppm HC, 2.7% CO
Catalyst fleet - 50 ppm HC, 0.5% CO

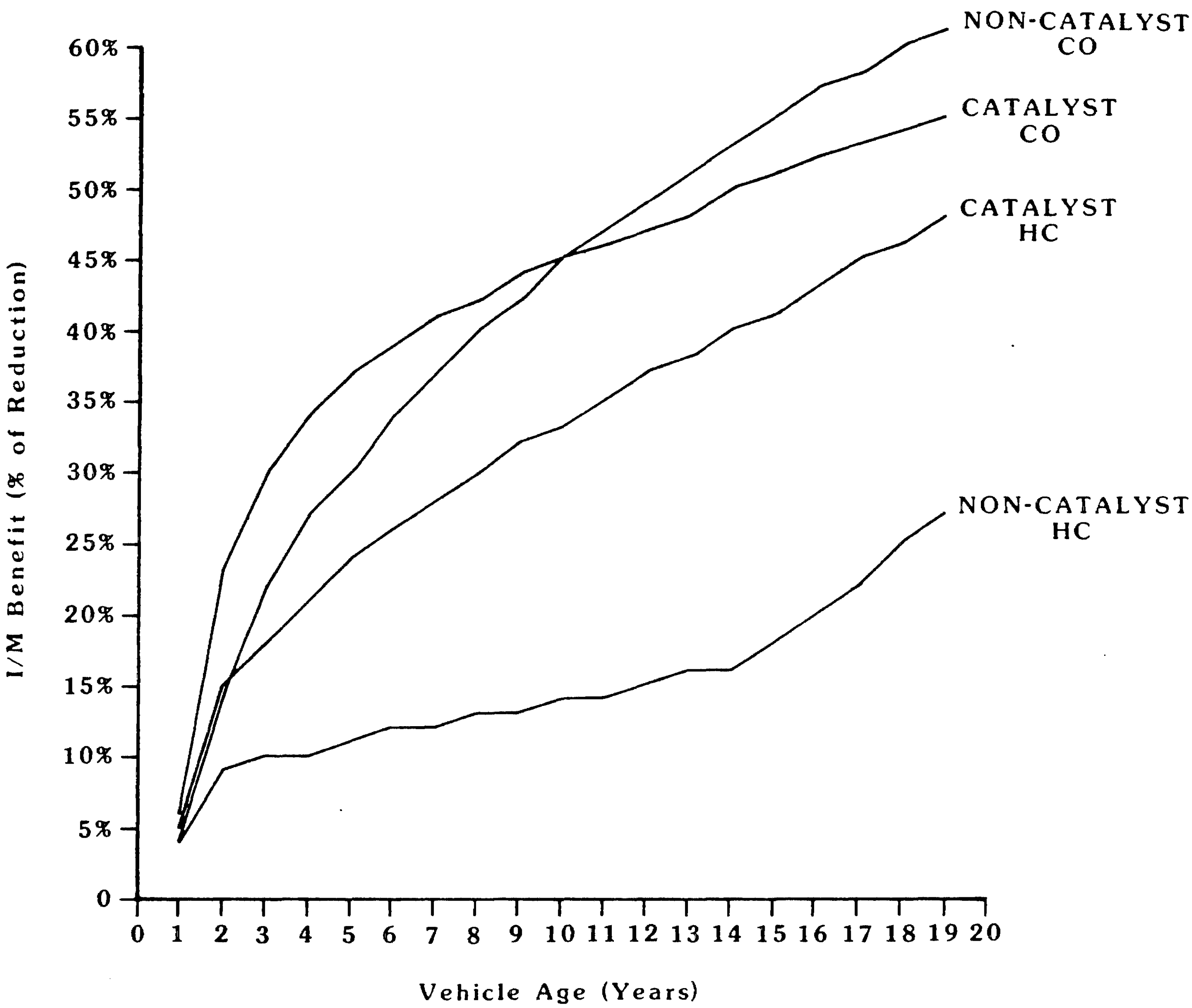
with the idle HC cutpoints would appear to decrease the calculated I/M credits for hydrocarbons, it would tend to result in increasing benefits in successive I/M program years.

For the catalyst fleet, up to approximately 35,000 miles, the idle HC cutpoint problem would tend to decrease after maintenance FTP HC and CO emissions, thus increasing the I/M credits calculated for both pollutants. At higher mileages, the problem would still increase the CO credits, while the effect on HC credits would be mixed.

There is also some concern that the benefits calculated by the model may be exaggerated as a result of the assumptions which have been made regarding deterioration of after repair emission levels. These deterioration assumptions play a major role in the "compounding" of I/M benefits in future years. The I/M credits computed by the model for a fleet of vehicles which is one year old at its first inspection is shown in Figure 4 for both catalyst and non-catalyst fleets. The data show that for hydrocarbons, I/M reductions start at 9-15% after the first inspection year, and increase to 27-48% after 19 years. For carbon monoxide, the reductions start at 14-23% after the first inspection year and increase to over 55-61% after 19 years.

Figure 4

I/M EMISSIONS BENEFITS PREDICTED BY THE APPENDIX N MODEL



NOTE: BASED ON 30% STRINGENCY FACTOR, WITHOUT MECHANICS TRAINING
ASSUMES VEHICLES RECEIVED FIRST INSPECTION AT AGE 1.

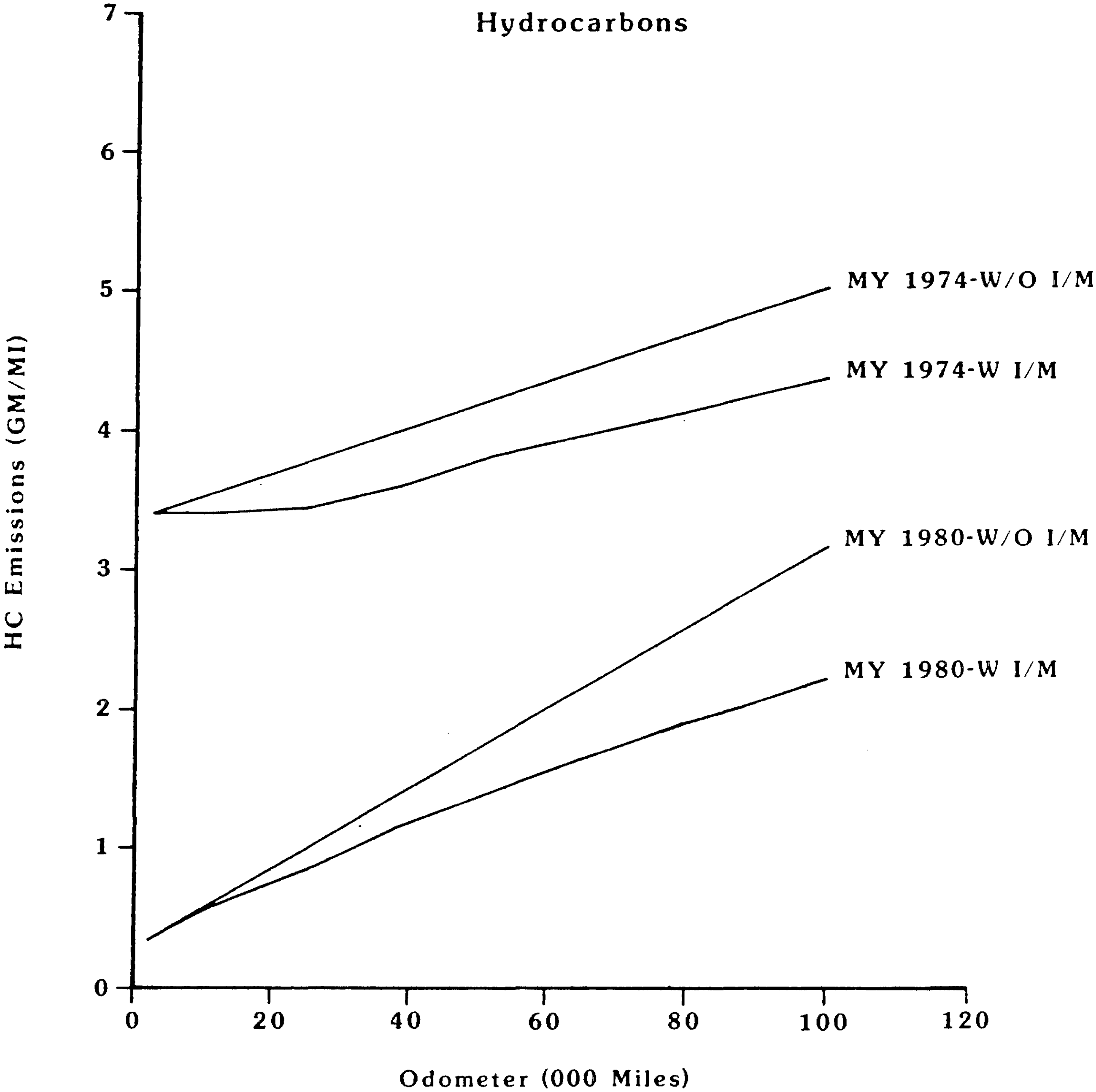
Figures 5 and 6 show how the calculated I/M benefits affect the projected HC and CO emissions from typical 1974 and 1980 model cars.

Given the significance of deterioration on the long-term benefits of I/M, additional data analysis should be conducted to evaluate the reasonableness of these estimates.

Most significant, perhaps, is the failure of the model to account for real world problems with I/M programs, such as waivers resulting in incomplete repairs. This assumption in particular can lead to incorrect results which, because of the nature of the model, compound themselves in each subsequent year.

Figure 5

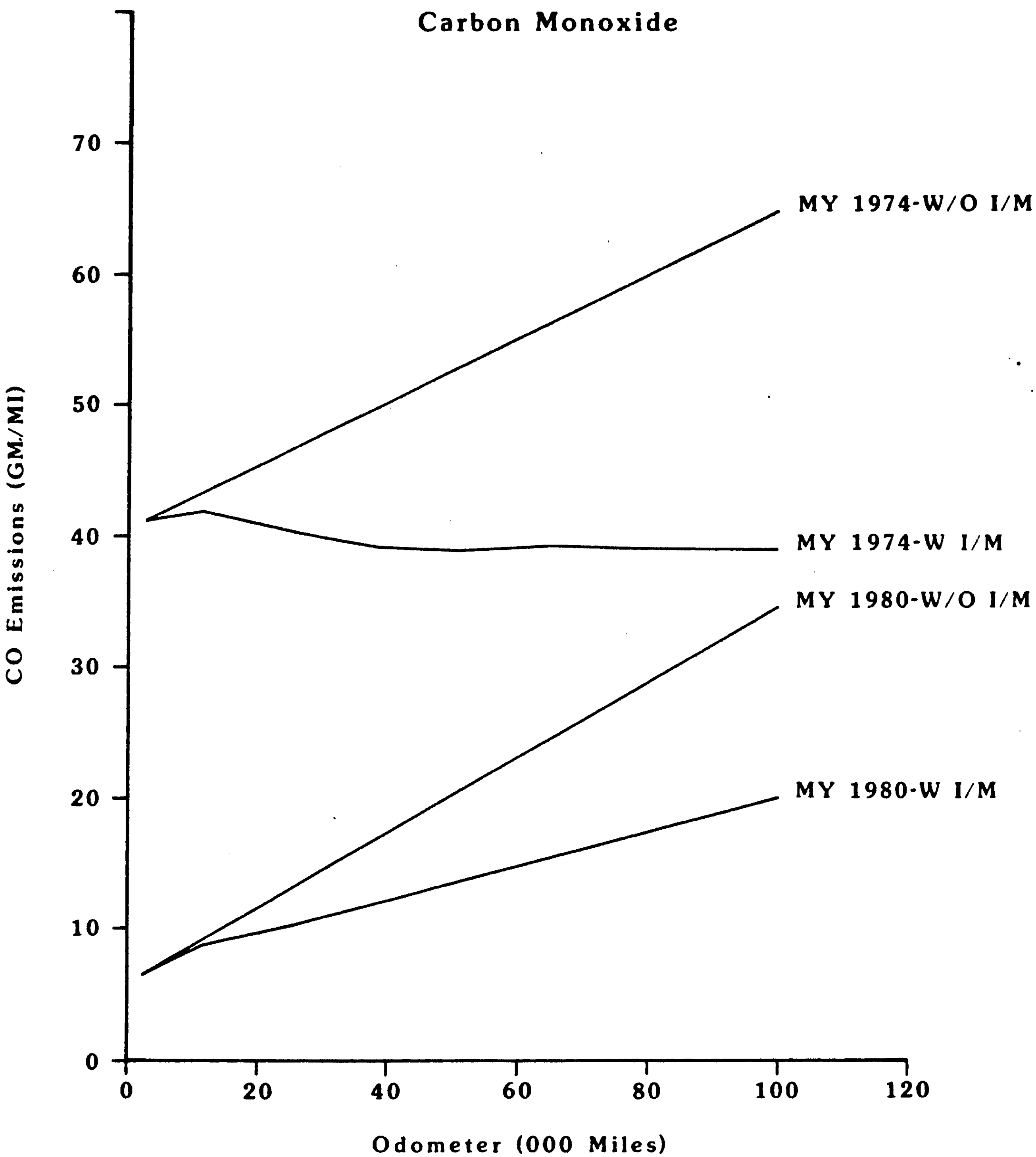
EMISSIONS LEVELS WITH AND WITHOUT I/M PREDICTED BY MOBILE 2.5 FOR PRE-1981 MODEL VEHICLES (49-STATE)



I/M ASSUMPTIONS: I/M STARTS WHEN VEHICLE IS ONE YEAR OLD, 30% STRINGENCY, NO MECHANICS TRAINING.

Figure 6

EMISSIONS LEVELS WITH AND WITHOUT I/M PREDICTED BY MOBILE 2.5 FOR PRE-1981 MODEL VEHICLES (49-STATE)



I/M ASSUMPTIONS: I/M STARTS WHEN VEHICLE IS ONE YEAR OLD, 30% STRINGENCY, NO MECHANICS TRAINING.

5. Recommended Changes to the Appendix N Model

Based on the foregoing analysis, the Air Resources Board should consider the following tests of assumptions and program changes before this model is applied to California.

1. The model does not predict NOx emissions credits for I/M programs. With a moderate level of effort and adequate data, NOx predictions could be added to the model.

2. The model uses as input data a sample of 1968-77 model year 49-state vehicles. With proper formatting, California test results could be used instead, or in combination with, the 49-state data.

3. The model uses several regression equations to adjust the data and "normalize" it to be consistent with average MOBILE2 predictions. If the data set was complete enough, these adjustments could be eliminated. Alternatively, missing or incomplete data should be replaced with average or typical values, while all other data should remain unadjusted.

4. The model uses lower limits to prevent several regressions from predicting negative numbers. An analysis of the regressions suggest that predictions of

negative emission levels are not uncommon for some equations. The lower limits should be removed and the model rerun to determine whether these constraints result in an inappropriate bias in the model's I/M credit predictions.

5. The model uses predetermined inspection standards which are stored in data statements at the end of the model. The five sets of standards (one for each stringency level, 10% to 50%) are based on a simple algorithm which express the HC standards as a function of the CO standards. This algorithm results in relatively less stringent HC standards than are found in the California I/M program. This algorithm should be changed to reflect actual California I/M standards.

6. The model simulates the maintenance of failed vehicles based on regression-based predictions of after maintenance idle and FTP emissions. The idle regressions, in particular, appear to provide overly optimistic estimates of after maintenance idle HC emissions which are then input to the FTP regressions. Substantially more accurate estimates of emissions after repair should be obtained by using actual data from ARB surveillance programs or from BAR data on after repair idle emissions.

7. Because the regression equations used in the model were developed based on data from the New Jersey and Portland I/M programs, which do not allow waivers for vehicles which fail the inspection, the model constrains average idle emissions after repairs to be lower than the applicable cutpoints. However, the California I/M program allows waivers for vehicles for which needed repairs exceed prescribed cost cutoffs. The model should be modified to take into account California waiver provisions.

8. The model constrains average after maintenance FTP emissions to be lower than the average before maintenance FTP emissions. Although this is generally true, this constraint should be deleted and actual after maintenance idle or FTP data should be used.

9. The model simulates a mechanics training program by assuming that after maintenance FTP emissions are predicted by a regression based only on control technology and average fleet mileage. Actual data from the Riverside Pilot Program, and the Portland I/M program, suggest that mechanics training provides only limited additional benefits. This factor needs to be better defined using all available data. The use of actual after maintenance data, as recommended above, would address this concern as well.

10. The model assumes that, after maintenance, the vehicle fleet deteriorates back to predicted MOBILE2 levels after specified fixed mileages, ranging from 7,400 miles to 57,000 miles depending on the pollutant and control technology. This assumption may be a significant reason why the model predicts significantly increasing benefits over the life of the I/M program. The model should be exercised to determine how sensitive the I/M benefits are to the assumed deterioration rates; if it is sensitive to this factor, the assumed deterioration rate should be subjected to more detailed analysis.

11. As presently configured, the model can only simulate an annual inspection cycle. A revised version of the model has been developed by EPA for ARB; this version has the capability to simulate biennial inspections. The technique used by EPA for this simulation should be evaluated; if reasonable, this would address this concern with the current model.