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Group of Rapporteurs on Pollution and Energy (GRPE)

New Vehicle Regulation and Emissions of In-Use Vehicles: The U.S. Experience

By

Philip A. Lorang

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Technical Support Staff
Emission Control Technology Division
Office of Mobile Sources
Office of Air and Radiation
U. S. Environmental Protection Agency

1. INTRODUCTION

The United States was the first nation to regulate emissions from passenger vehicles and presently has the most stringent regulations in effect. The U.S. experience of the last 15 years may be useful to other nations as they consider what their own next regulatory step should be. This paper describes this experience, with emphasis on the results which the new vehicle regulations have achieved in terms of emissions from vehicles in general use by ordinary motorists.

Table 1 shows the exhaust emission standards for hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NOx) that have applied to vehicles sold in the U.S. each model year. The standards have been made more stringent in stages, with two or more years between changes in nearly all cases. This paper will show how emissions of in-use passenger vehicles have reflected the changes in the new car standards.

The new car standards are enforced initially by a program of pre-production design review, testing, and certification. However, there have been three other new car requirements which have influenced emissions of in-use vehicles. First is the requirement for new vehicles to pass audits conducted at the assemblyline, to ensure that vehicles as produced conform with standards. Second is the requirement that vehicle manufacturers recall and repair vehicles when the Environmental Protection Agency (EPA) finds that a substantial number of similar vehicles fail to meet new car standards in-use even when properly maintained and operated. This recall program reduces in-use emissions both through repair of vehicles subject to an EPA recall order and through greater manufacturer efforts on all vehicles to avoid the need for such EPA orders. Third is the requirement, first applied to 1981 vehicles, that carburetors on new vehicles be equipped with devices to make adjustment of the idle air/fuel ratio very difficult. The effects of the audit and recall programs are difficult to separate from the effect of the new car emission standards themselves; both programs became fully operational in the late 1970's, as standards were being made more stringent. This paper will not attempt to make this difficult separation. The paper will examine the separate effect of the requirements regarding the adjustability of the idle air/fuel mixture.

2. HYDROCARBONS AND CARBON MONOXIDE

2.1 Steps in Regulation

The U.S. has regulated passenger car emissions since the 1968 model year, but the first HC and CO standards representing significant control took effect in 1972 and remained in effect through 1974. The exhaust limits were 3.4 grams per mile of hydrocarbons and 39 grams per mile of carbon monoxide. For the first time, the test procedure used a fully transient driving cycle, mass measurement of emissions, and included collection and measurement of emissions during a cold start. Vehicle manufacturers complied with the 1972-1974 standards by calibrating carburetors leaner to reduce engine-out emissions of HC and CO, by using air pumps to inject secondary air into the exhaust stream to promote further oxidation of HC, and by retarding spark timing to raise the exhaust temperature to also promote oxidation in the exhaust stream.

The second step in regulating HC and CO emissions was taken in 1975. The standards of 1.5 grams per mile HC and 15.0 grams per mile CO established for that year remained in effect through 1979. These standards caused all domestic and most foreign manufacturers to apply noble metal, oxidation catalysts in the exhaust stream. On about two-thirds of new vehicles produced in these five years, exhaust oxygen needed to allow combustion of HC and CO in the catalyst was achieved solely through lean carburetor calibrations. Air pumps were used on the remainder. With the catalyst to control HC emissions, it was not necessary to retard spark timing and so timing calibrations were restored back towards their optimum values with respect to fuel economy. Of course, lead-free fuel was required for these catalyst-equipped vehicles. During the period between 1975 and 1979, electronic (point-less) ignition systems also became standard equipment on most vehicles.

In 1980 the third step was taken, with the HC standard reduced to 0.41 grams per mile and the CO standard reduced to 7.0 grams per mile, for one year only. The very small number of vehicles which earlier did not have catalysts were sold with catalysts in 1980. In addition, virtually all vehicles were equipped with one of two forms of secondary air injection: an air pump system like that used on many earlier models or the newer pulse air system which uses pressure fluctuations in the exhaust ports to draw in air through a one-way valve. Pulse air systems are cheaper and do not take power from the engine. Secondary air injection was necessary because lean carburetion was no longer sufficient to meet the reduced standards. Other changes in control methods were limited to minor calibration adjustments.

In 1981, standards changed again. The HC standard remained 0.41 grams per mile. The CO standard was reduced to 3.4 grams per mile for some vehicles, while many were allowed to remain at 7.0 until 1983. The more important change was in the NOx standard, from the 2.0 grams per mile which was in effect from 1977 through 1980 to only 1.0 grams per mile. This level made catalytic aftertreatment of NOx essential for most cars, so three-way catalysts were adopted. In most cases, closed-loop fuel control via an exhaust gas oxygen sensor and digital computer was also incorporated to keep the exhaust gas composition in the range within which three-way catalysis is possible. Most vehicles retained some form of secondary air injection, for at least the cold start portion of operation.

2.2 In-Use Emissions

The first three steps described above have had very evident impacts on in-use emissions. Each of these steps towards more stringent regulation of new car emissions has reduced in-use emissions correspondingly. Figures 1 and 2 compare the in-use emissions of HC and CO of vehicles produced in 1972-1974, 1975-1979, and 1980. EPA's estimates of the HC and CO emissions of pre-standards (pre-1968) vehicles are also shown.

The lines in the figures are derived using linear regression analysis of data from EPA's In-Use Emission Factor Surveillance Program. This program periodically borrows vehicles of various ages from their owners and tests them with the standard test procedure. Thus, the program measures emissions of vehicles as they are actually operated and maintained in-use. Emission data from 5,848 1972-1980 vehicles are represented in the figures.

Figures 1 and 2 show that each group of vehicles emits less than the preceding group. In particular, the catalyst technology used on 1975-1979 vehicles reduced HC and CO emissions at low mileage by 50 percent or more compared to the 1972-1974 vehicles. However, these vehicles do not perform satisfactorily in comparison to their new car standards. CO emissions even at low mileage exceed the 15.0 grams per mile standard. Both HC and CO show rapid increase with accumulated mileage. EPA investigated the causes of this behavior as soon as it was noticed, and determined that incorrect adjustment of idle air/fuel mixture performed after shipment from the factory was the major cause. By the time vehicles were one year old, one-third had been incorrectly adjusted and the fraction was clearly increasing as vehicles grew older. Rich air/fuel mixtures caused by incorrect adjustment increase formation of HC and CO in the engine and prevent the catalyst from operating due to lack of sufficient oxygen in the exhaust. EPA therefore initiated regulatory action to restrict the adjustability of the mixture setting. This action will be discussed in more detail in Section 2.5 below.

Figures 1 and 2 show that the 1980 vehicles are also substantially lower emitting than the 1975-1979 vehicles. The rate of increase of emissions with age also appears to be reduced. This improvement came from rather limited and inexpensive changes in emission control hardware, discussed previously, and was therefore lower in new vehicle cost per gram of reduction than the improvement which occurred in 1975. If other countries require control to the level of the 1980 U. S. standards, they would probably do well to spend less time at the intermediate step (1975-1979 U. S. standards) than did the U. S.

EPA has tested 1981 and 1982 vehicles in its surveillance program, but at present the low mileage of these vehicles makes EPA reluctant to draw firm conclusions for HC and CO. Although not shown in the figures, the HC and CO data from these model years are very similar to the lower mileage data from 1980 vehicles. EPA has found that 1981 and 1982 vehicles can emit large quantities of HC and CO under certain operating malfunctions but at present the number of such malfunctions is small.

Trends in ambient pollutant levels are the ultimate test of whether an air pollution control program has been successful. Because CO is primarily an automotive pollutant, ambient CO levels are the best indicator of the success of the U.S. program of new vehicle regulation. The trend in U.S. CO levels since 1975 confirms the improvements suggested by Figures 1 and 2. From 1975 to 1981, the second highest 8-hour levels of CO have declined by 26 percent. An even greater improvement was observed in the estimated number of exceedances of the 8-hour standard, which decreased 84 percent. These improvements generally reflect CO levels at traffic-saturated monitoring sites in the centers of U.S. cities, which have experienced little or no change in the volume of traffic in their vicinity. Consequently, the improvements in CO levels can be attributed only to reductions in vehicle emissions.

Ozone levels, which are partially attributable to automotive emissions of HC, have also declined in the U.S. From 1975 to 1981, the decline was 14 percent. It is understandable that the decline in ozone has been smaller than the decline in CO, since many industrial, commercial and other sources of HC had not been controlled as of 1981.

2.3 Fuel Economy Trends

The effect of emission standards on fuel economy is a topic of intense interest, as even a small fuel economy penalty from more stringent standards can be larger than the cost of the hardware necessary to comply with the standards. Not surprisingly, predictions of reduced fuel economy have preceded nearly all new or more stringent emission standards in the U. S. Such predictions are troublesome, since the claimed penalty may be small enough to be within the range of uncertainty but still large enough to be of social concern.

A retrospective look at fuel economy of U. S. vehicles may be helpful for other countries. Figure 3 shows actual fuel economy for each U. S. model year, and the average vehicle weight for each year. Vehicle weights have not been constant, which obscures true trends in engine efficiency. Figure 4 therefore adjusts each model year to the mix of vehicle weights from 1978, an arbitrary year.

Figure 4 shows a slight decline in fuel economy from pre-standard years through 1974. This is attributable to reduced compression ratio and to the need to retard spark timing for control of HC emissions. There was a sudden rise in fuel economy in 1975, when the use of exhaust catalysts allowed engine parameters to be recalibrated for better efficiency. The fact that there was a larger improvement in 1975 than the decline in the previous seven years suggests that the penalty from spark timing retard and other calibration compromises was sizable but had been masked for several years by other efficiency improvements. The increase in fuel economy recurred to a lesser extent in 1976 and 1977, as manufacturers learned the degree to which they could safely restore optimum engine settings.

When the standards changed again in 1980, fuel economy again improved after small declines in 1978 and 1979 in contradiction to predictions that the 0.41 grams per mile hydrocarbon standard would again require compromises with optimum spark timing for fuel economy.

It must be admitted that a comparison of fuel economies from year to year cannot rule out the possibility that the fuel economy increase in a given year might have been larger if the emission standards had not changed. If the standards had not changed in 1975 and if manufacturers had adopted catalysts anyway, they would certainly have achieved at least as much of a fuel economy improvement during 1975 to 1977 and perhaps more. Indeed, from the buyer's perspective the cost of the catalyst would have been well worth the fuel savings it achieved. This possibility does not refute the fact that catalyst technology itself does not harm fuel economy.

In other countries in which emission standards have resulted in non-catalyst vehicles with suboptimal engine calibrations, catalyst technology can be expected to open the door for fuel economy improvements worth far more than the additional cost of the catalyst itself. Catalysts can, of course, be forced into use with more stringent standards provided unleaded fuel is available. However, market demand for fuel efficient vehicles could by itself also lead manufacturers to adopt catalysts, again provided unleaded fuel is available. Accurate fuel economy ratings of new vehicles are essential for market forces to lead manufacturers towards greater fuel economy.

Countries in which emission standards are so lenient that no compromises with optimal engine calibrations have been necessary can adopt catalyst-forcing standards without fear of a fuel economy penalty, since the catalyst will allow optimal calibrations to be maintained.

2.4 Improper Use of Leaded Gasoline

In the U. S., the continued public availaility of leaded gasoline priced lower than unleaded gasoline by $0.05 - 0.07 (U.S.) and with higher octane rating (89 vs 87 typically) has created an environmental problem. EPA estimates that presently, about 12 or 13 percent of passenger vehicles originally equipped with catalysts refuel with leaded gasoline often enough to seriously and irreversibly damage the catalyst. Furthermore, improper use of leaded fuel appears to be more frequent as vehicles get older, so the overall rate will probably increase as the 1975 and later U. S. fleet ages towards an equilibrium.

This problem is occurring despite efforts to control it. Introduction of leaded fuel into a catalyst vehicle by a fuel station operator is subject to a federal fine of $10,000, but effective enforcement requires more resources than have yet been devoted to it. All catalyst vehicles have devices to prevent leaded fuel nozzles from being inserted into the fuel inlet pipe. These devices are easily overcome, however.

The rate of use of leaded fuel and its effect on catalyst performance are not so severe as to negate the emissions benefit of the catalysts that remain operatative. The step to catalysts in 1975 therefore did have a real environmental benefit. Nevertheless, the problem of improper use of leaded fuel needs to be addressed more effectively in the U. S., and other countries should consider how to limit it effectively from the outset.

2.5 Recent Regulations Concerning Adjustment of Idle Air/Fuel Mixture

After EPA discovered that improper adjustments of idle air/fuel mixture settings were causing significant increases in HC and CO emissions of in-use vehicles, it initiated a rulemaking action to address this problem. The rulemaking was completed in January 1979, and applied to all 1981 and later passenger cars and light-duty trucks. The new regulation, known in the U. S. as the Parameter Adjustment Regulation, gave EPA authority to adjust the idle setting (within its adjustable range) on manufactuers' prototype vehicles before performing the official pre-sale certification emissions test. To prevent EPA from doing so, manufacturers sealed the idle air/fuel adjustment screw. The setting made at the factory can be changed after shipment only with considerable difficulty.

The new requirement has greatly reduced the frequency of idle air/fuel mixture adjustments. EPA's surveillance programs show that only a few percent of 1981 and 1982 vehicles have received adjustments after shipment from the factory. In previous model years, the percentage was over fifty within two or three years of sale, and most adjustments were done incorrectly. Since 1981, most U. S. passenger vehicles are equipped with closed-loop fuel metering systems that control idle air/fuel mixture automatically, so external adjustment points would have been mostly obsolete anyway. Therefore, the experience with restrictions on adjustment of 1981 and newer vehicles in the U.S. is not immediately relevant to countries which do not have similar closed-loop vehicles.

However, there is earlier U.S. experience which is more relevant to other countries. General Motors Corporation (GM) complied with the new regulations on adjustability earlier than required, in 1979 and 1980. Comparing these GM vehicles to earlier GM vehicles and to their contemporaries from other manufacturers indicates the advantage of preventing improper adjustment of oxidation catalyst vehicles. The 1979 and 1980 vehicles were manufactured to much different HC and CO standards, so two separate examples are available. The 1979 GM vehicles, like the 1978 GM vehicles, were manufactured to standards of 1.5 grams per mile HC and 15 grams per mile CO and virtually none were equipped with secondary air injection. The 1980 GM vehicles all were equipped with secondary air injection to meet the more stringent 0.41 gram per mile HC and 7.0 gram per mile CO standards. It is very rare for the idle mixture on 1979 and 1980 GM vehicles to be adjusted after shipment from the factory. Less than five percent have been found to have the seals on the adjustment screws removed.

Figures 5 and 6 compare the HC and CO emissions of 1979 GM vehicles to those of 1978 GM vehicles and of 1979 vehicles made by other manufacturers. The lines in the figures are calculated from data collected in EPA's Emission Factor Surveillance Program. The 1979 GM vehicles are substantially lower in HC and CO emissions than either 1978 GM vehicles, or 1979 vehicles produced by other manufacturers. General Motors and other vehicles from 1979 have approximately the same emissions at low mileage, but the 1979 GM vehicles suffer from slower increases in emissions as they get older.

Figure 7 and 8 compare HC and CO emissions of 1980 vehicles made by GM and all other manufacturers. The low rate of increase of emissions with increasing age is especially notable for the GM vehicles. This makes the GM vehicles lower emitting overall even though at low mileage emissions from the two groups are about equal. The combination of an oxidation catalyst, secondary air injection, and an inaccessible idle air/fuel mixture adjustment appears to be extremely effective for HC and CO control.

In countries in which manufacturers are accustomed to vehicle owners and dealers being able to reset idle adjustments after assembly, manufacturers have limited incentive to make adjustments correctly during assembly. If seals are placed on the adjustment mechanism during assembly, it will be important both for owner satisfaction and air quality that adjustments be made correctly during assembly. The 1980 GM vehicles show that this is technically feasible in mass production.

Since most of the adjustments made on U. S. vehicles after assembly (i.e., in the field) were incorrect and resulted in rich air/fuel mixtures, preventing them from occurring is believed to have had a beneficial effect on fuel economy. Studies have shown that the typical improper adjustment reduces fuel economy in city driving about three percent, and that at least one-third of vehicles were misadjusted. The fuel economy benefit should therefore be at least one percent.

3.0 OXIDES OF NITROGEN

3.1 Steps in Regulation

The first U. S. NOx standard was 3.0 grams per mile in 1973, measured with the 1972 test procedures. When the test procedure was changed in 1975, the NOx standard was changed to 3.1 grams per mile to compensate. Manufacturers complied with both standards by using exhaust gas recirculation (EGR). The standard was changed to 2.0 grams per mile in 1977, and remained at that level through 1980. Manufacturers improved the effectiveness of their EGR systems to achieve this lower standard. During the period of 1973 through 1980, manufacturers made numerous improvements to reduce the adverse effect of EGR on driveability and fuel economy. In 1981, most manufacturers added three-way catalysts for additional NOx control to meet the 1.0 grams per mile standard.

3.2 In-Use Emissions

Figure 9 shows the NOx emissions of in-use U. S. passenger cars for pre-standard, 1973-1974, 1975-1980, and 1981-1982 groups. There has been steady reduction. Figure 4 shows that there was no fuel economy reduction with the progressively more stringent NOx standards.

3.3 Disablement of EGR Systems

Figure 9 reflects the occurrence of deliberate disablement of EGR systems on in-use vehicles. The EGR systems on 1973 and 1974 vehicles were crude by current standards, and often had a noticeable negative effect on driveability and fuel economy. This led to high rates of disablement by owners and service personnel. The belief that EGR systems degrade vehicle performance has unfortunately lingered in the consciousness of U. S. motorists and mechanics, even though major improvements have been made. Recent EPA surveillance of in-use vehicles has found that about 10 percent of 1975-1982 vehicles have had the EGR system deliberately disabled. Disablement increases as vehicles get older.

All manufacturers selling in the U. S. market have by now developed sophisticated EGR systems which limit recirculation only to those modes of operations and flow rates necessary for effective NOx control without driveability penalty. Therefore, another country adopting an NOx standard which required EGR systems would probably avoid the unfortunate experience of the U. S. with crude EGR systems in 1973 and 1974. Therefore, public attitudes towards EGR systems should be less negative in other countries, and the disablement rate lower.

Table 1

U. S. Standards
For Exhaust Emissions From New Gasoline-Fueled
Passenger Vehicles

Year	Test Procedure [1]	Hydrocarbons	Carbon Monoxide	Oxides of Nitrogen
1968- 1969	7-mode			
	50-100 CID	410 ppm	2.3%	-
	101-140 CID	350 ppm	2.0%	-
	over 140 CID	275 ppm	1.5%	-
1970	7-mode	2.2 g/mi	23 g/mi	-
1971	7-mode	2.2 g/mi	23 g/mi	-
1972	CVS-72	3.4 g/mi	39 g/mi	-
1973- 1974	CVS-72	3.4 g/mi	39 g/mi	3.0 g/mi
1975- 1976	CVS-75	1.5 g/mi	15 g/mi	3.1 g/mi
1977- 1979	CVS-75	1.5 g/mi	15 g/mi	2.0 g/mi
1980	CVS-75	0.41 g/mi	7.0 g/mi	2.0 g/mi
1981 and later	CVS-75	0.41 g/mi	3.4 g/mi[2]	1.0 g/mi[3]

[1] Different test procedures have been used since the early years of emission control which vary in stringency. The appearance that the standards were relaxed from 1971 to 1972 is incorrect. The 1972 standards are actually more stringent because of the greater stringency of the 1972 test procedure.
[2] Carbon monoxide standard can be waived to 7.0 gpm for 1981-82 by the EPA Administrator.
[3] Oxides of nitrogen standard can be waived to 2.0 g/mi for American Motors Corporation for 1981 and 1982 only.

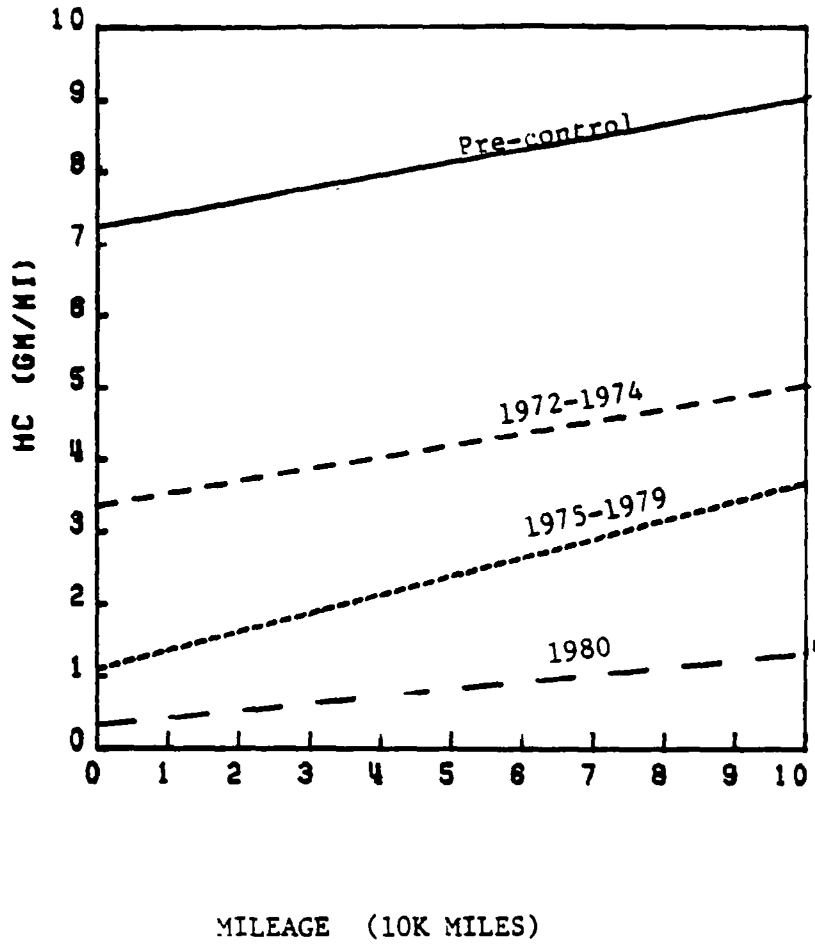

Figure 1 - Hydrocarbon (HC) Emissions of In-Use Vehicles Produced Under U.S. Emissions Standards

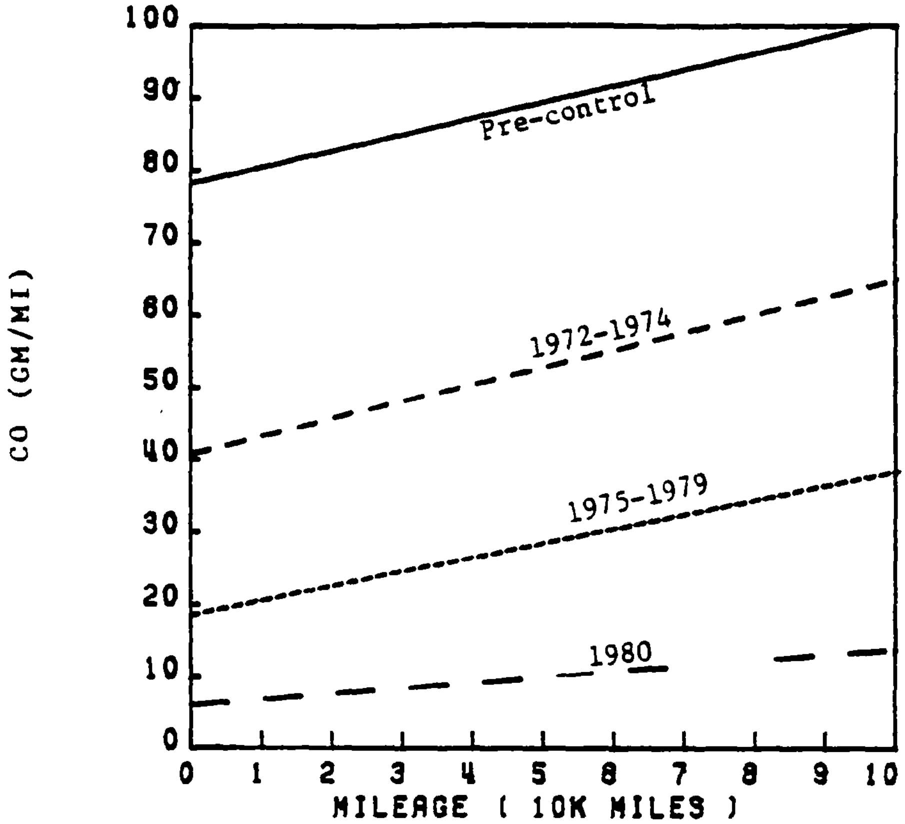

Figure 2 - Carbon Monoxide (CO) Emissions of In-Use Vehicles Produced Under U.S. Emissions Standards

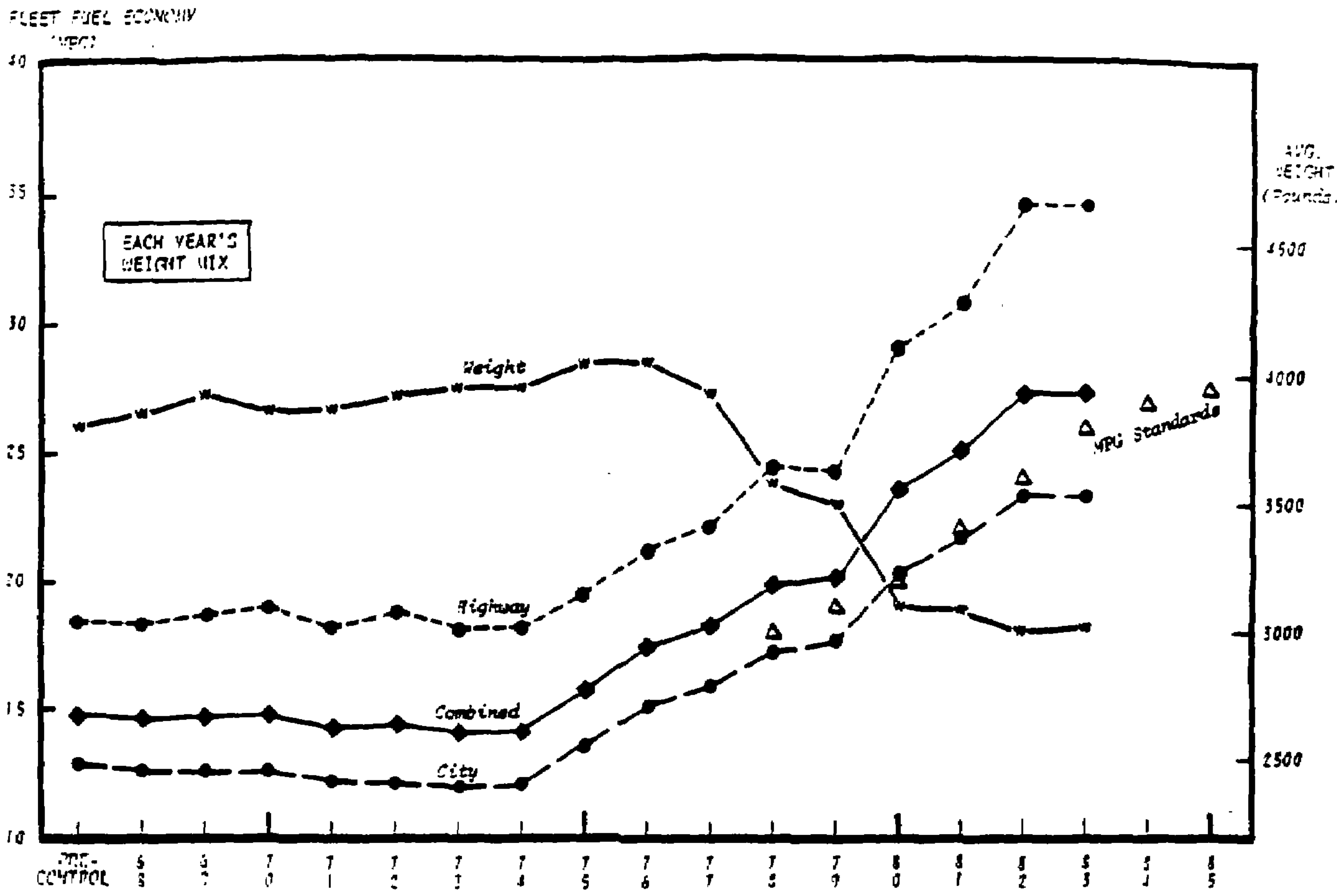

Fig. 3 - Fleet MPG and average weight from Pre-emission control through 1983

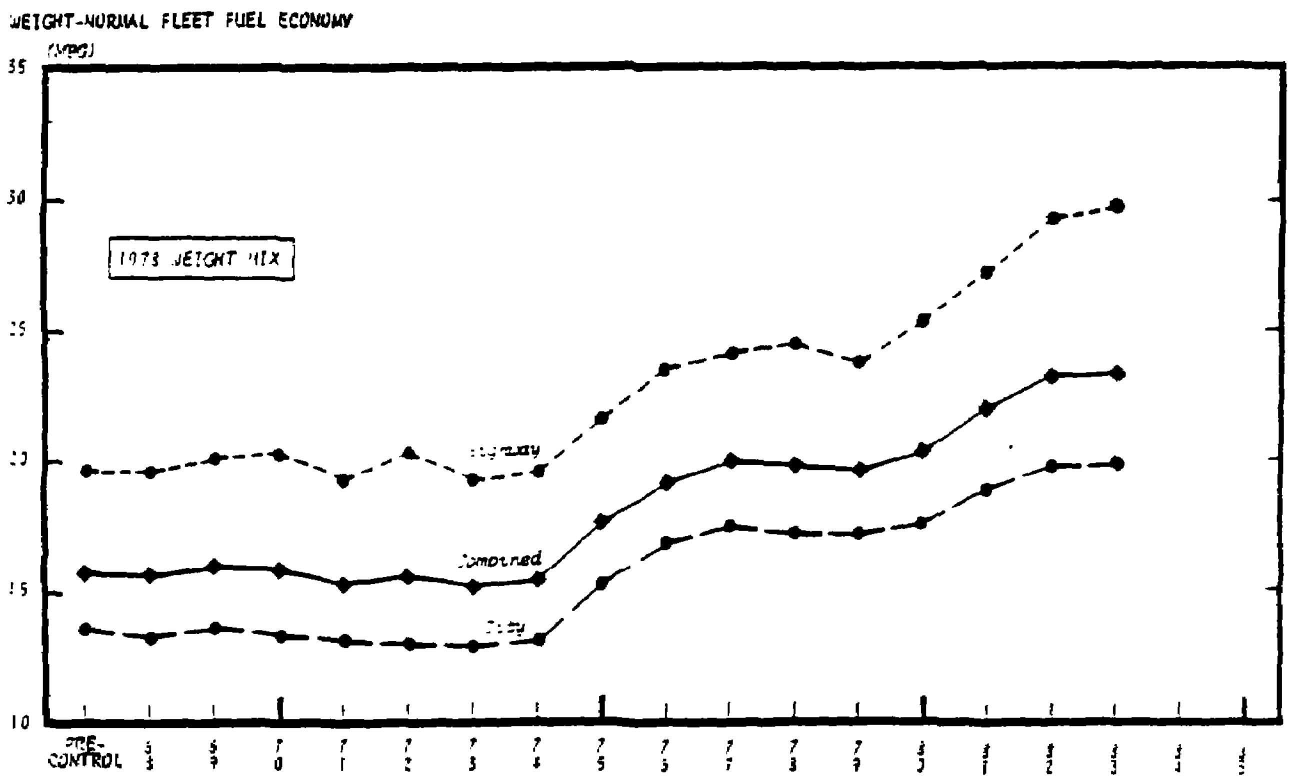

Fig. 4 - weight-normalized fleet MPG, from Pre- ission control through 1983

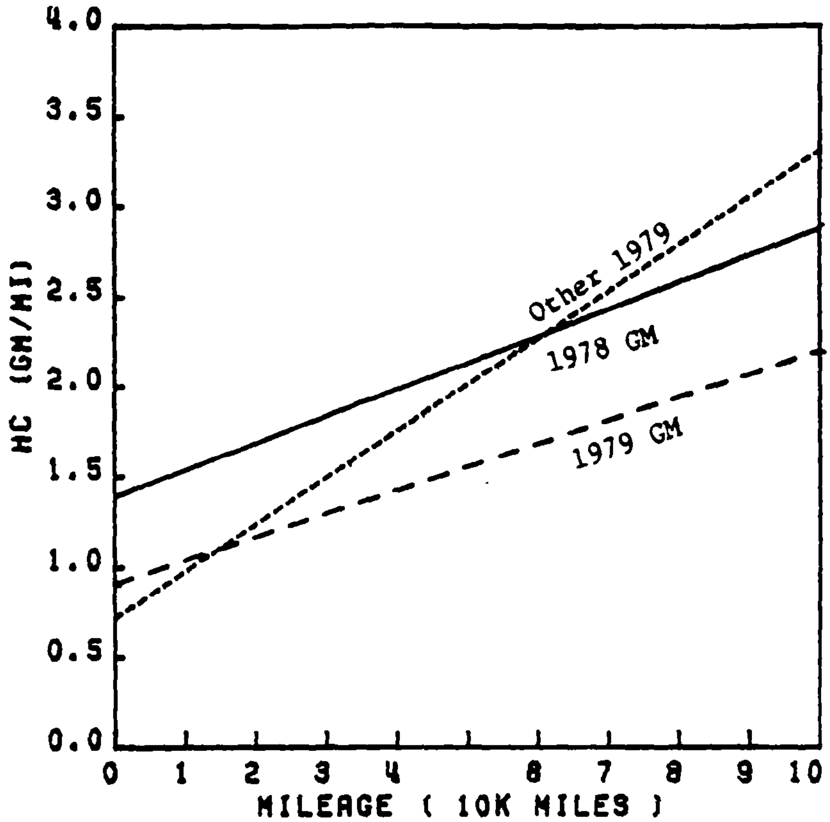

Figure 5 - Hydrocarbon (HC) Emissions of 1978 General Motors (GM) Vehicles, 1979 GM Vehicles, and Other 1979 Vehicles in the U.S.

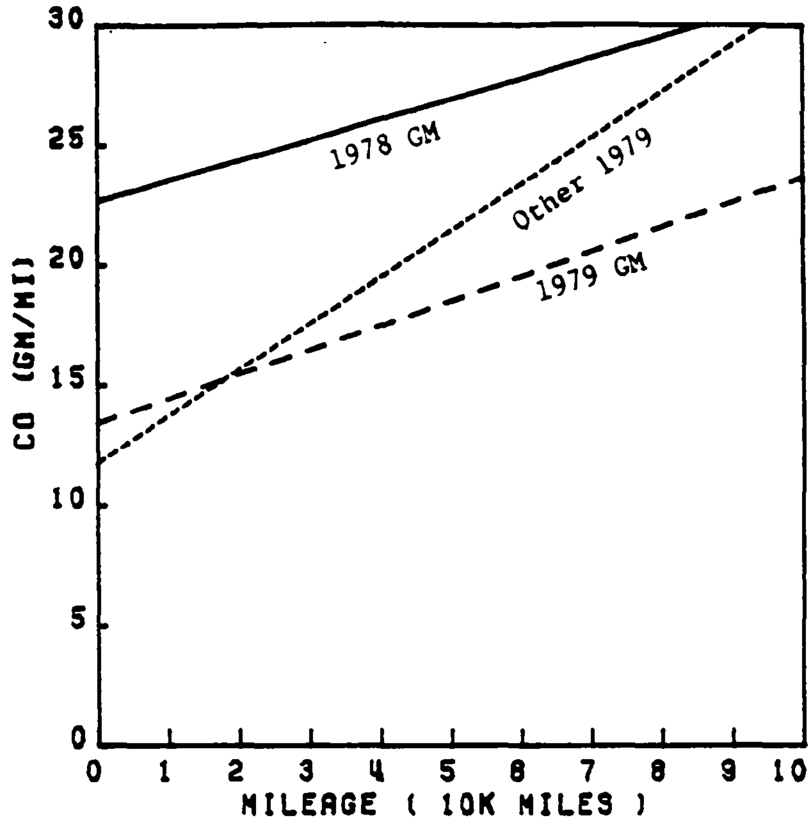

Figure 6 - Carbon Monoxide (CO) Emissions of 1978 General Motors (GM) Vehicles, 1979 GM Vehicles, and Other 1979 Vehicles in the U.S.

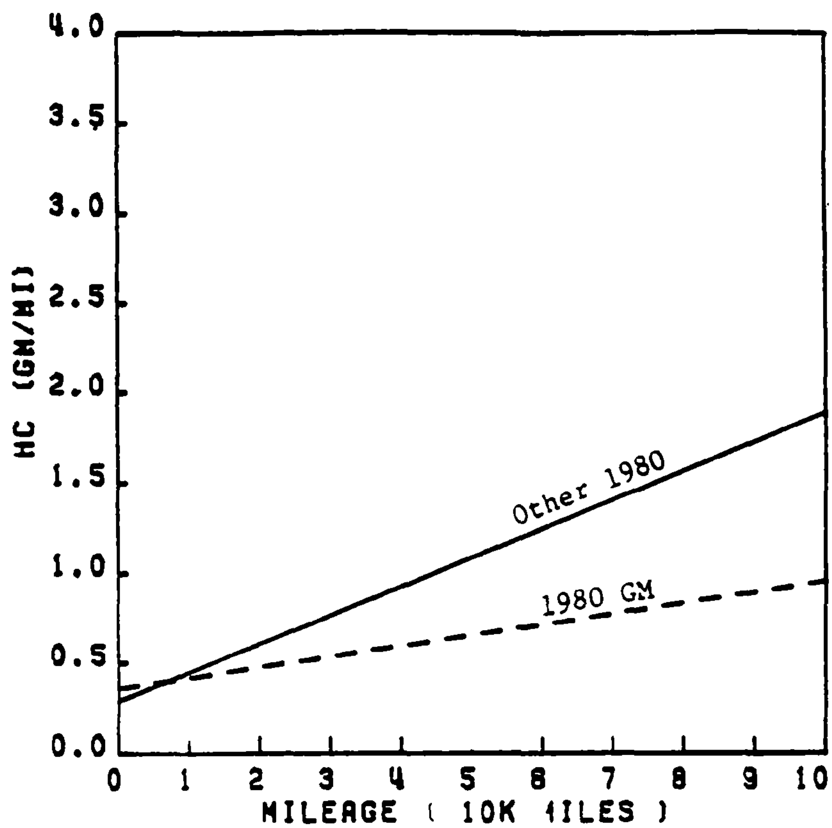

Figure 7 - Hydrocarbon (HC) Emissions of 1980 General Motors (GM) Vehicles and Other 1980 Vehicles in the U.S.

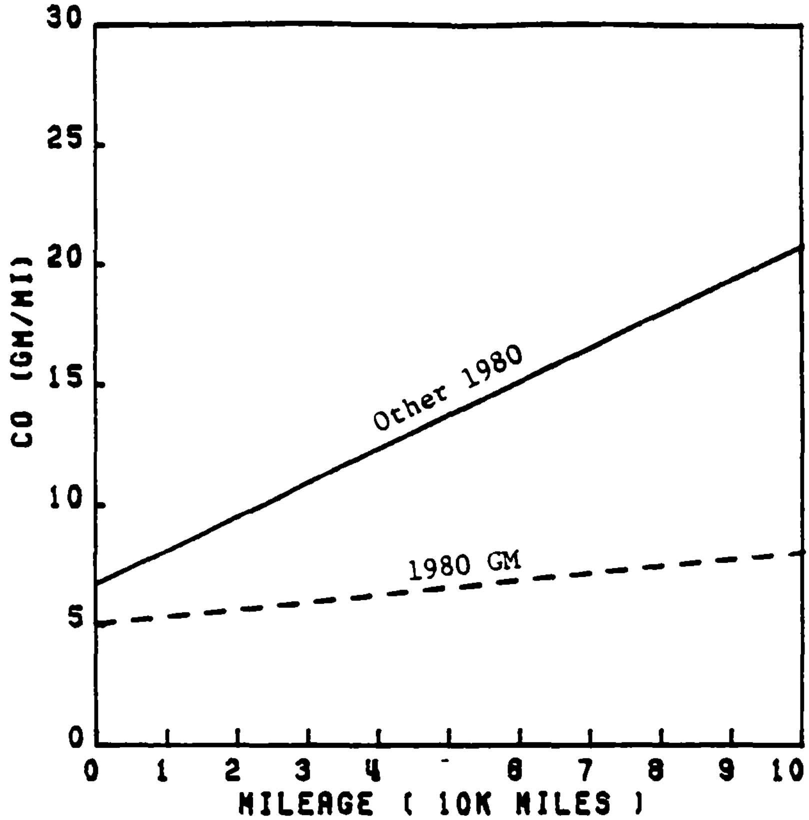

Figure 8 - Carbon Monoxide (CO) Emissions of 1980 General Motors (GM) Vehicles and Other 1980 Vehicles in the U.S.

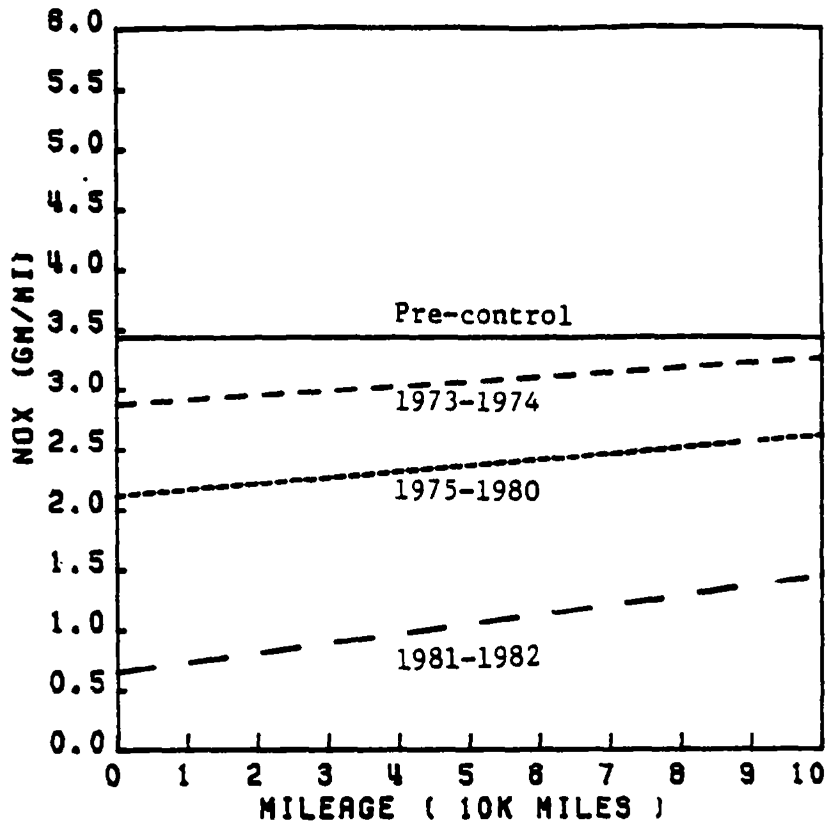

Figure 9 - Oxides of Nitrogen (NOx) Emissions of In-Use Passenger Vehicles Under U.S. Emissions Standards