

AUTOMOBILE EMISSIONS AND ENERGY CONSUMPTION

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For Presentation at the
Air Pollution Control Association
Spring Seminar
Montebello, Quebec
May 20-22, 1974

The impact of automobile emission control on fuel economy is a subject receiving increasing attention by the public, industry and Government. Many schemes have been promoted in the interest of achieving reduced fuel consumption by the passenger car population. Some of the more popular schemes are:

1. Vehicle miles traveled (VMT) reductions (using gas rationing or other approaches).
2. Shifting new car production to small cars.
3. Removing emission controls from existing cars.
4. Relaxing automobile exhaust emission standards.

To determine the impact on both emissions and fuel economy of the latter two schemes, the U.S. Environmental Protection Agency's (EPA) Emission Control Technology Division (ECTD) has performed extensive evaluations. Further studies have also

considered the impact of vehicle weight and other parameters on automobile fuel economy.

DATA SOURCES & CALCULATION PROCEDURES

Input data for EPA's fuel economy studies come from four major sources:

1. New car certification testing
2. In-use car surveillance testing
3. Prototype vehicle testing
4. Special projects testing

The new car certification testing is run by EPA at the Motor Vehicle Emission Laboratory in Ann Arbor, Michigan. Over two thousand vehicles are submitted annually by the automobile manufacturers for testing. Most of these vehicles are tested after 4,000 miles of operation but many vehicles are tested at mileages as high as 50,000 miles.

In-use surveillance testing is done for EPA by various contractors located throughout the United States. This

ABSTRACT

U.S. automobile emission standards have resulted in a 12% loss in sales-weighted fuel economy for model year 1974 vehicles due the types of control systems the industry has chosen to use. Increasing concern over fuel economy is causing some manufacturers to adopt control techniques for model year 1975 which will result in improved economy

and lower emissions simultaneously. Techniques appear to be available which will allow this trend to continue into future model years. The extent of the improvements possible will depend on the demands of the market, the response of the industry, and the existence of fuel economy related regulations or legislation.

program is run to determine the actual emission levels from the vehicles in the hands of the public. Vehicles are randomly selected from registration lists and a variety of model years and vehicle makes are included in the program.

Prototype vehicle testing is routinely performed at the Ann Arbor laboratory. Many vehicles are volunteered to EPA for testing by automobile manufacturers and independent developers who may be interested in either lab-to-lab correlation at low emission levels or in public disclosure of their developments through the test reports which ECTD publishes on the prototype testing. Other vehicles are solicited by EPA from automobile manufacturers and independent developers for testing. These vehicles are ones that have not been volunteered but in which EPA has some particular interest.

Special projects testing is done by EPA for a variety of reasons. Examples of extensive special projects in the past are:

1. A study of the effects of tampering with emission controls.
2. A study of fuel economy characteristics of rotary engine-powered vehicles versus conventional engine-powered vehicles.

Most of the relevant data from the four major sources was accumulated using either the 1972 Federal Test Procedure (FTP) (1) (2)* or the 1975 FTP (3). In this paper the fuel economy values calculated from the 1975 FTP were converted to the equivalent 1972 FTP value to maintain consistency.

The FTP is a chassis dynamometer test performed indoors, in a closely controlled environment. The driving cycle followed, which is often referred to as the "LA4", represents a 7.5 mile trip in an urban area. Average vehicle speed over the cycle is approximately 20 miles per hour (mph) and the vehicle makes 2.4 stops per mile.

The speed range encountered during the LA4 cycle is from zero (idle) to 57 mph. The details of the speed vs. time trace, which the driver of the vehicle follows, reflect the irregularities in speed which actually occur in customer driving. Essentially no driving is done at exactly steady state conditions. The use of the chassis dynamometer makes the use of this realistic and detailed driving cycle possible. Even with the use of a driver's aid, such cycles are difficult to repeat during road or track testing where traffic and road conditions are not constant. Each cycle is run from a cold start. That is, the vehicle is parked for at least 12 hours in a 68-86°F ambient prior to the start of the simulated trip.

Fuel economy data derived from the FTP are obtained by the carbon balance method. Basically this involves using the unburned hydrocarbon (HC), carbon monoxide (CO), and carbon dioxide (CO₂) emissions measured during the test to calculate the amount of fuel consumed during the test. This method is based on the fact that the HC, CO and CO₂ emissions are essentially all of the carbon containing compounds emitted by the vehicle and the fuel itself consists of hydrocarbon compounds. Knowing the carbon emitted in the form of HC, CO and CO₂, one can calculate the carbon that was used in the form of gasoline. A more detailed explanation and a derivation of the carbon balance technique can be found in reference (4). The same reference also shows the correlation of the carbon balance technique and weigh methods. Good engineering practice in both the running of the emission test and the fuel weighing results in excellent correlation.

When more than one test is used to determine the average fuel economy for a vehicle or a group of vehicles, the reciprocal economies are averaged. In statistical terms the harmonic mean of the individual test data, rather than the arithmetic mean, was used. This procedure results in the average

*Numbers in parentheses designate references at the end of the paper.

economy values reflecting the total miles traveled during the testing divided by the total gallons used. A more detailed explanation of the significance of the harmonic mean to average fuel economy data can be found in reference (5).

EMISSION CONTROL TECHNIQUES

There are three separate sources of emissions from most uncontrolled passenger cars:

1. evaporative emissions
2. crankcase emissions
3. exhaust emissions

Evaporative emissions have been reduced with the use of sealed gas tank caps, revised air cleaner geometry and activated charcoal traps connected to fuel system vents.

Crankcase emissions have been essentially eliminated with installation of positive crankcase ventilation (PCV) systems which recycle to the intake manifold the blowby gases that were formerly vented to the ambient.

Many different techniques have been developed to reduce exhaust emissions. Modifications have been made upstream of the combustion chamber, in the combustion chamber, and downstream of the combustion chamber.

Upstream of the combustion chamber, modifications can include intake air heating systems, improved chokes, recalibrated and improved carburetion, and redesigned intake manifolding. On many vehicles, combinations of these modifications are used to obtain leaner combustion, which results in decreased HC and CO emissions. Exhaust gas recirculation (EGR) systems can be used to achieve oxides of nitrogen (NOx) reductions. The recirculated exhaust gas reduces NOx formation during the combustion process by lowering peak flame temperatures and reducing oxygen concentration in the cylinder.

Combustion chamber-related modifications can include revised geometry, lowered compression ratio and retarded spark timing. These modifications are used to obtain a lower surface to volume ratio (S/V) at the time of the combustion. Reduced S/V results in lower unburned hydrocarbon emissions because wall quenching is reduced. Retarded spark timing also results in higher exhaust gas temperatures (due to the reduced expansion occurring after combustion) which promotes post cylinder oxidation reactions in the exhaust system. Valve timing modifications have been made to create "internal EGR" on some engines. Other engines, however, have had valve timing changes made to reduce the amount of internal EGR so that HC and CO emissions would be lowered.

Post combustion chamber modifications can include air injection, revised exhaust manifold geometry, afterburners, thermal reactors and catalytic converters. These techniques are normally used to promote oxidation reactions in the exhaust gas to reduce the HC and CO content, but in a reducing atmosphere catalysts can also be used to reduce NOx.

EFFECT OF EMISSION CONTROLS

GENERAL EFFECTS - Contrary to popular belief, emission controls can affect fuel economy both positively and negatively. Table 1 summarizes the effects of the more common control approaches.

Spark retard is the control technique that has been most responsible for the negative economy impact that emission controls have on current (1974) models. The reduction in burned gas expansion and the reduced exposure of the charge to high temperatures which occurs with retarded timing may work very effectively to reduce HC and NOx emissions, but less work is extracted from the fuel. The degree to which fuel economy is adversely affected depends on the extent of the retard used. Many retard systems work only during transient conditions or during operation in lower transmission gears. This allows control of emissions during urban, stop and

go, operation without adverse fuel economy effects during highway cruising.

Reduced compression ratios are less effective at reducing HC and NOx emissions and have been used mainly to allow the use of low lead or unleaded fuels which are generally of lower octane rating. A reduction in compression ratio from 9:1 to 8:1 results in an economy loss of about 3.5% in urban driving (4).

Rich air/fuel ratios are sometimes used to promote oxidation reactions in the exhaust manifold. Rich calibration, however, results in poor fuel utilization in the cylinder, as there is insufficient oxygen available to completely burn all of the fuel. Rich ratios also reduce the ratio of specific heats (k) of the intake charge, which reduces efficiency. Rich calibrations are sometimes used to offset the poor driveability induced by the use of EGR systems that recycle excessive amounts of exhaust gas during light load operation. Excessive EGR can reduce flame speed which reduces engine efficiency.

Lean air/fuel ratios used on many current models improve economy by reducing the throttling required for a given engine load (thereby reducing pumping losses) and increasing the ratio of specific heats of the intake charge. Quick

warm-up systems and intake air heaters extend the degree of enleanment possible.

Proportional EGR (PEGR) systems do not recirculate excessive amounts of exhaust gas during light loads where the engine least needs and can least tolerate EGR. PEGR systems recirculate exhaust gas in proportion to the intake air flow. Some systems employ even higher percentage flow rates at high loads than light loads. This type of EGR system can be used to provide significant NOx reductions with a simultaneous fuel economy improvement (6). The benefits are due to reduced throttling losses and an increase in the specific heat ratio of the intake charge. Most current (1974) vehicles do not use proportional EGR systems, but several systems are fully developed and may be installed on some 1975 models.

Catalytic converters and thermal reactors are often associated with changes in fuel economy but in themselves they have essentially no effect. Any related fuel economy effect is due to engine calibrations made to optimize the performance of these after-treatment devices. Both positive and negative overall effects are possible, depending on the specific type of catalyst or reactor used.

TABLE 1
Fuel Economy Effect of Various
Emission Control Techniques

Positive Effect	Little or no Effect	Negative Effect
Lean Air/Fuel Ratios	Catalysts	Rich Air/Fuel Ratios
Proportional EGR	Thermal Reactors	Conventional EGR
Quick Warm-up Systems	Air Injection	Spark Retard
Intake Air Heaters	Evaporative Emission Controls	Reduced Compression Ratio
	Positive Crankcase Ventilation	

Air injection systems require some engine power to drive the air pump but the effect on economy is very small.

EFFECT ON THE 1974 MODELS - The effect of the 1974 Federal emission standards (3.4 grams per mile [gpm] HC, 39 gpm CO, 3.1 gpm NOx) on fuel economy depends on the combination of control techniques a manufacturer uses. The choice of control techniques can be dictated by cost constraints, the desire to retain high performance and high economy, and by the extent of control required to meet the standards. Not all cars require equivalent control on a percentage basis to meet a given standard. Lighter vehicles, because of the lower exhaust volumes, emit less HC and NOx emissions than heavier cars (7) and, therefore, need less control. This allows the manufacturers of lighter vehicles to more easily avoid the use of control techniques that adversely affect economy.

Figure 1 shows that the lighter vehicles have avoided fuel economy penalties due to emission standards. Figure 1 is based on 654 tests of uncontrolled (1957-1967 model year) vehicles and 464 tests of 1974 models. Most new cars in inertia weight¹ (IW) classes 3500 pounds and below achieve superior fuel economy in urban driving to uncontrolled cars of equal weight. Vehicles in weight classes 4000 pounds and above, however, have suffered severe penalties, ranging from 13% to 21% on the average.

Not all models have followed the trend indicated in Figure 1. Some manufacturers have developed more sophisticated systems. The adoption of improved fuel metering systems, like electronic fuel injection,

¹"Inertia weight" is equal to the vehicle's curb weight plus 300 pounds load rounded to the nearest class.

FIGURE 1
PERCENT CHANGE IN FUEL ECONOMY BETWEEN UNCONTROLLED AND '74 MODELS vs. INERTIA WEIGHT

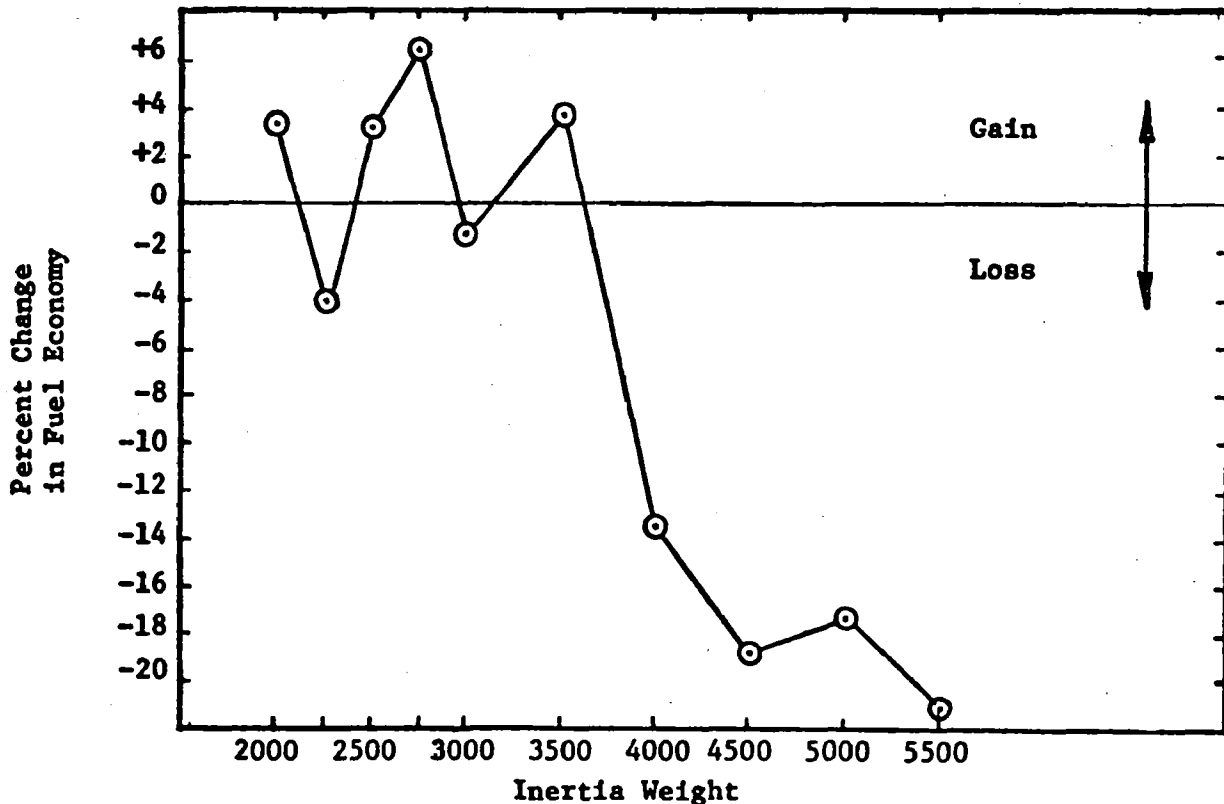
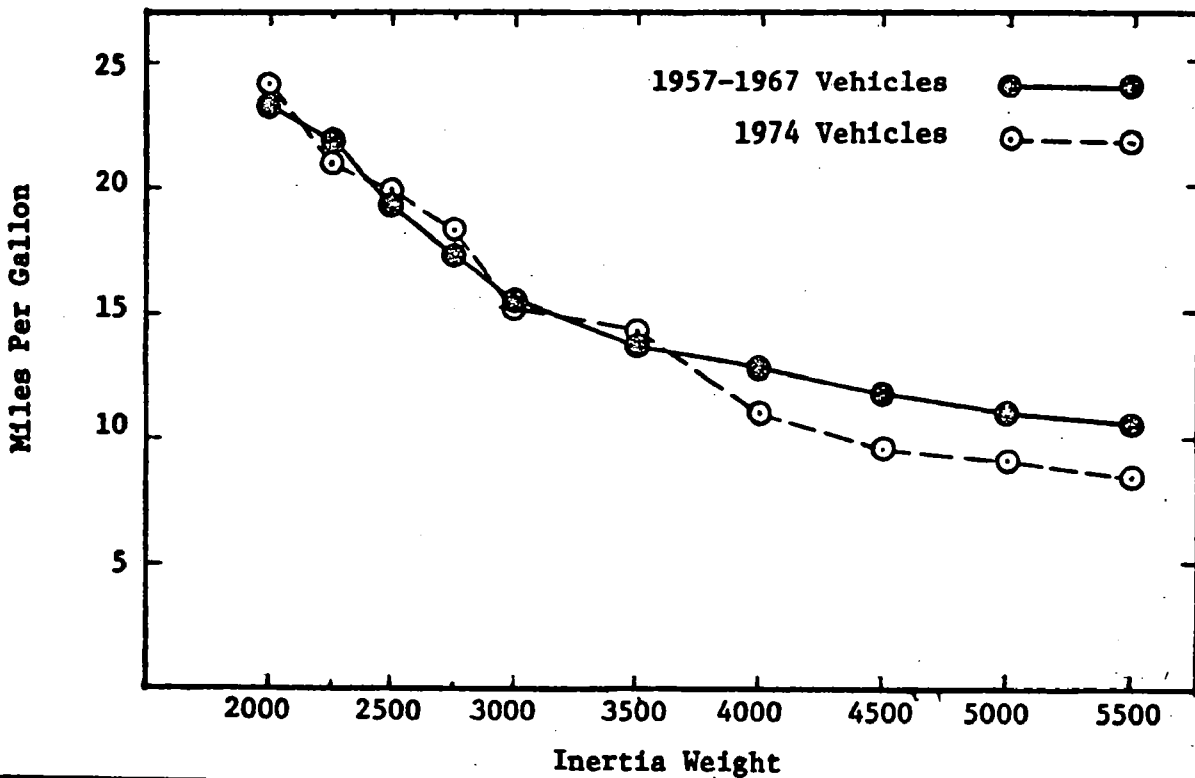


FIGURE 2
FUEL ECONOMY vs. VEHICLE WEIGHT



by some manufacturers is an example of what can be done to reduce emissions and improve fuel economy and performance simultaneously. Some manufacturers, however, have done worse than indicated in Figure 1 by choosing low cost or no cost systems (e.g., massive spark retard) at the sacrifice of economy and performance.

Figure 2 presents additional information about the comparison of 1974 models to uncontrolled cars. Fuel economy is plotted vs. inertia weight class for both data sets. The reduced power requirements of the lighter vehicles result in superior fuel economy. The advantage of the light cars is even more pronounced for the 1974 models, as the heavier models have suffered fuel economy penalties due to emission controls.

Sales Weighted Effect - Since the effect of emission controls has not been the same for all weight classes of vehicles, the overall effect of the 1974 Federal standards can be determined only by

considering the effect on various weight classes. To avoid the confounding effects of market shifts it is necessary to select a fixed sales distribution to be used in determining the change in fuel economy due to emission controls from one model year to another. If the sales distribution (by weight class) of uncontrolled cars was used to determine the sales-weighted economy of uncontrolled cars, and the sales distribution of 1974 cars was used to determine the sales-weighted economy of 1974 cars, the difference in sales-weighted fuel economy would include not only the effect of emission controls but the effect of market shifts in the various weight classes. The effect of market shifts have been avoided in our analysis of the data by fixing the sales distribution (at that experienced for model year 1973) for both uncontrolled and 1974 model year vehicles. The 1973 sales distribution was selected because it is the most recent one available. This distribution has been reported in reference (8) and is also shown in Appendix A.

Using the 1973 sales distribution, the change in sales-weighted fuel economy from uncontrolled cars (1957-1967 average) to the 1974 models is -12.3%. Sales-weighted fuel economy for the 1974 models is 11.4 miles per gallon (mpg) and 13.0 mpg for the '57-'67 average. Figure 3 shows the trend in sales-weighted economy (fixed '73 sales distribution) from uncontrolled to 1974. The average loss for the controlled model years, 1968-1974, is 7.0%.

EFFECT OF TAMPERING

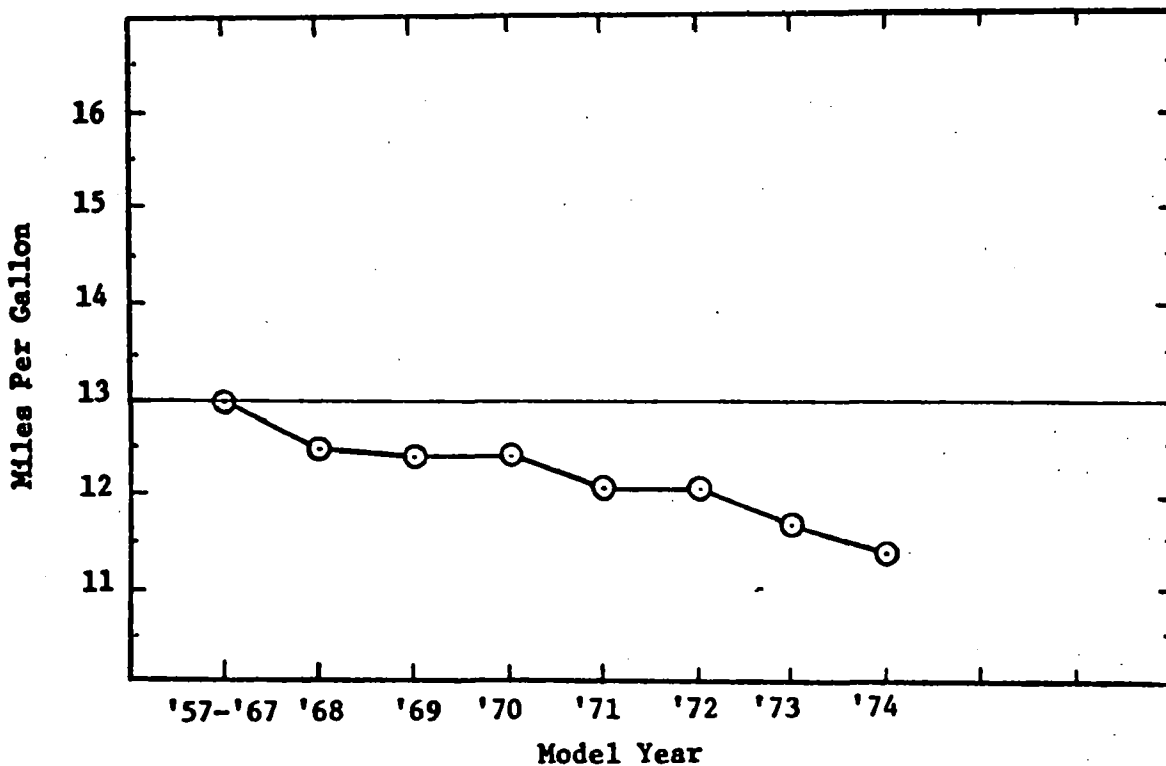
In response to suggestions that removal of emission controls from in-use vehicles could result in significant improvements in fuel economy, an in-house program was run to investigate the effects of tampering with emission control systems. It is obvious that many emission control techniques are difficult to eliminate. Changing camshafts, compression ratios, distributors, carburetors, and cylinder heads would be extremely costly. It is also apparent that

many techniques used to reduce emissions also improve economy. Keeping these things in mind, the program was designed to achieve maximum fuel economy at minimum cost.

A total of ten late model vehicles (1973 and 1974) were procured for the evaluation. Sub-compact, compact, intermediate, and full-size cars were included. Vehicles were tested according to the following plan:

1. Tune to manufacturer's specifications.
2. Test for emissions and fuel economy.
3. Optimize for fuel economy.
4. Test for emissions and fuel economy.
5. Tune to manufacturer's specifications.
6. Send out to independent garage or tune-up shop for fuel economy optimization.
7. Test for emissions and fuel economy.

FIGURE 3
FUEL ECONOMY vs. MODEL YEAR



Fuel economy optimization done by EPA included EGR removal, vacuum advance restoration, initial advance optimization, idle speed reduction, and air pump removal. Intake air preheaters, evaporative control systems and PCV systems were intentionally not altered.

Fuel economy optimization done by the eight independent garages and tune-up shops often consisted of the same modifications made by EPA (done somewhat differently) and sometimes included valve adjustments, leaner idle settings, richer idle settings, altered centrifugal advance, leaner main metering jets, and air cleaner inversion.

The results of the tampering done by EPA and the independent garages and tune-up shops were quite different as shown in Table 2. Both EPA and the independent garages and tune-up shops were successful in causing significant increases in exhaust emissions, but only EPA achieved fuel economy improvements. Changes which the independent garages and tune-up shops made that tended to improve economy were often offset by changes that caused fuel penalties. The percent change in fuel economy resulting from the independent garage tampering ranged from -15.5% to +9.0%. Only four of the thirteen attempts showed any improvement. Of significant note, the one garage of the eight that advertised its expertise

in emission control removal failed to improve economy on both cars sent to it. Despite the fact that this garage was unable to improve economy, the modifications made resulted in an increase in emissions. On the average, HC was up 16%, CO up 50% and NOx was up 50%.

Although the results of the EPA program may be too limited to establish firm estimates for the effects of large scale tampering, it appears that the gains in fuel economy would be modest at best while the adverse impact on exhaust emissions would be substantial.

FUTURE TRENDS

1975 MODEL YEAR - Future fuel economy trends will depend on many factors. The choice of emission controls used will have a significant effect. General Motors (GM) has stated (9) that its decision to use the catalytic converter to achieve the 1975 Federal Interim Standards (1.5 gpm HC, 15 gpm CO, 3.1 gpm NOx) will result in fuel economy improvements. Preliminary GM data (9) indicated that, for some models, 20% improvements in fuel economy could be achieved simultaneously with 50% reductions in HC and CO emissions. GM has also reported (10) that on the average it expects a 13% increase in economy for 1975.

TABLE 2
SUMMARY OF TAMPERING RESULTS
ON FUEL ECONOMY AND EMISSIONS

	Change from Manufacturer's Specifications			
	HC	CO	NOx	MPG
EPA Tampering	+65%	+21%	+116%	+7.0%
Tune-up Shop Tampering	+39%	+89%	+63%	-3.5%

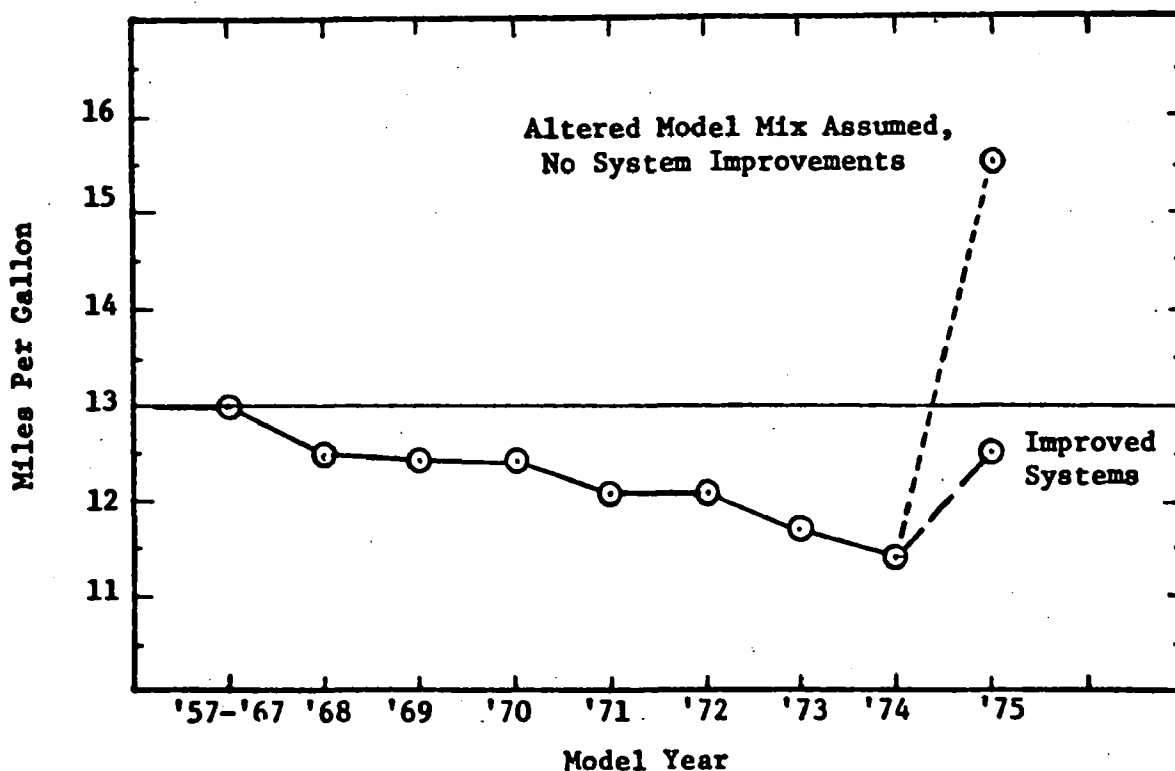
While the catalytic converter itself has essentially no effect on fuel economy, the catalyst can reduce HC and CO emissions enough so that control techniques which reduce economy can be eliminated. With engine calibrations essentially optimized for best economy, the use of a good catalyst system can allow the vehicle to meet stringent emission standards.

Part of the fuel economy optimization done on some 1975 models includes the use of proportional EGR. Contrary to popular belief, the installation of a good EGR system can result in improved economy (10). A little known advantage of proportional EGR systems is that they allow the use of higher compression ratios, as recirculated exhaust gas has anti-knock qualities. These anti-knock qualities are not realized with the EGR systems on current (1974) models because insufficient EGR flow rates

are provided during operation at higher load where knock can be a problem.

While GM will be using the catalyst system to optimize for economy in 1975, other manufacturers will be achieving improvements without catalysts. Saab, for example, reported (11) improved fuel economy due to the use of improved fuel metering systems. It appears unlikely that all manufacturers will experience fuel economy improvements for 1975, but with GM expecting significant improvements and representing nearly half of the U.S. market it is not unreasonable to anticipate an improvement of approximately 10% due to changes being made to emission control systems. Figure 4 shows the historical economy trend from the years of uncontrolled cars to 1974 and the effect on sales-weighted economy if a 10% improvement due to improved systems is realized in 1975. The point labeled "Improved Systems" and the points for model years 1974 and earlier are all based on 1973 sales fractions.

FIGURE 4
FUEL ECONOMY vs. MODEL YEAR

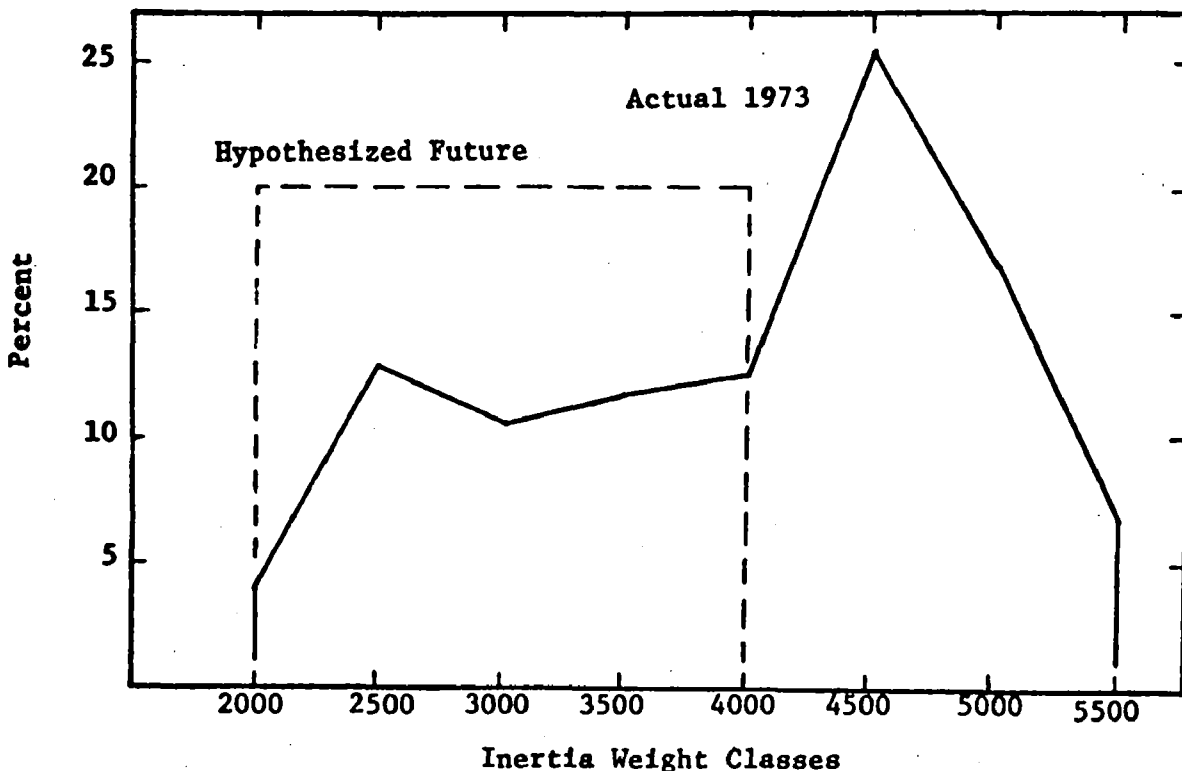


POST-1975 - Fuel economy trends beyond 1975 are difficult to predict at this time because of uncertainty over future emission standards and the uncertainty over future public demand for improved economy. The time table for future standards can be expected to have significant effect. Several prototype control systems being designed to meet the "statutory" HC and CO levels of .41 gpm HC and 3.4 gpm CO have shown potential for fuel economy improvements over 1974 cars, at NOx levels near .4 gpm. The "3-way" catalyst approach, which employs fuel injection modulated by an oxygen sensor in the exhaust stream, has been reported by Volvo (12) to give 8% better fuel economy than the corresponding 1974 model. Gould has reported (13) fuel economy data that indicate dual catalyst type systems can also achieve .41 gpm HC, 3.4 gpm CO and 0.4 gpm NOx with fuel economy superior to 1974 model cars. The use of advanced control systems like those currently under investigation by Volvo and Gould could depend on the need for such systems to meet stringent emission standards in the future.

EFFECT OF MARKET SHIFTS - Large improvements in fuel economy are possible without improving engine efficiency if the market shifts toward the lighter weight classes. Figure 4 shows the effect of a hypothetical redistribution of vehicles sales. The actual sales distribution of the 1973 models is shown with the solid line in Figure 5. The dashed line is the distribution that would result if the 4500 pound and heavier classes were eliminated and sales were distributed evenly between the 2000 and 4000 pound classes. This change in sales distribution would cause the average inertia weight to drop from 3970 pounds to 3000 pounds. With no improvement in engine efficiency the increase in sales-weighted economy over the 1974 case would be 37%.

The hypothetical shift in sales distribution could be accomplished without sacrifices in passenger room and comfort. Recent analysis (14) has shown that functionally designed automobiles, a rarity in the current market, offer substantially more interior room

FIGURE 5
SALES DISTRIBUTION



than heavier cars designed with "styling" in mind. Reference (14) showed that the new Volkswagen Dasher compared to the new Ford Mustang II has essentially equivalent room for the front seat passengers but 14% more rear leg room, 25% more rear shoulder room, and 158% more luggage room, despite the fact that the Mustang is 27% heavier and two inches longer than the Dasher.

ALTERNATE ENGINES - The use of alternate engine technology can also result in substantial fuel economy improvements in the future. The alternate engines with the greatest potential are those employing unthrottled internal combustion operation. Three types of engines that can operate in this manner are:

1. stratified charge
2. variable displacement Otto cycle
3. Diesel

Open chamber stratified charge engines have demonstrated significant advantages over conventional engines when they are not throttled, but without throttling they have difficulty achieving stringent emission standards. Unless the engine is throttled exhaust temperatures drop because of the greater heat capacity of the charge per unit of fuel during the very lean conditions that exist at low power levels. Low exhaust temperatures make thermal or catalytic reactions in the exhaust system difficult. More development work appears to be required before stratified charge engines will be able to meet the dual requirements of low emissions and improved fuel economy.

Variable displacement engines offer significant fuel economy potential because of their theoretical ability to maintain nearly peak efficiencies throughout the load and speed range of the engine. Unlike the exhaust of the unthrottled stratified charge engine, the exhaust of the unthrottled variable displacement engine stays hot enough to be compatible with after-treatment systems. The exhaust remains hot at low power outputs because power is reduced by reducing the intake air volume (by engine displacement reduction) as well as the fuel volume. The

development status of variable displacement engines is significantly behind stratified charge and Diesel engines.

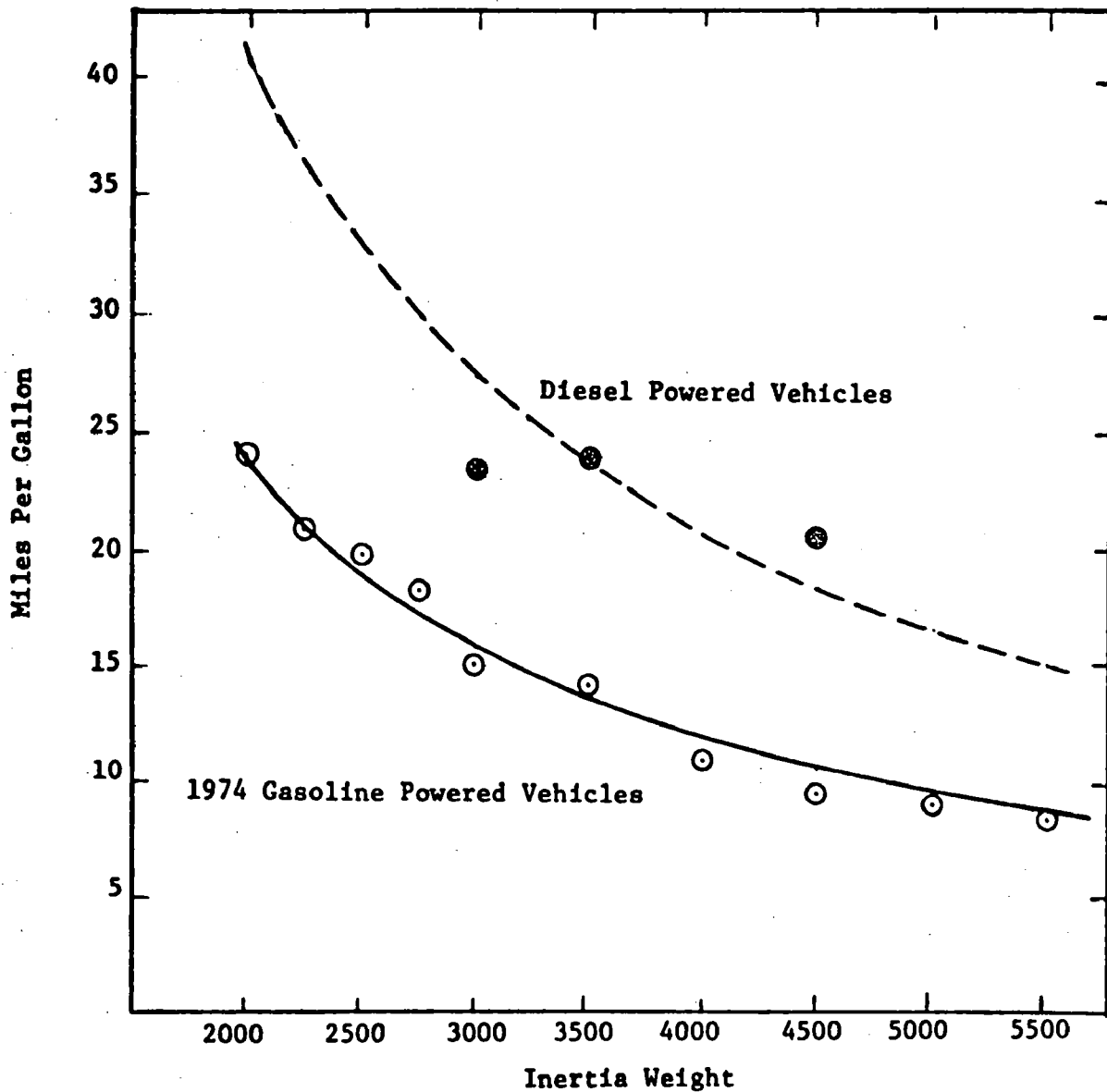
The Diesel engine appears to be the only alternate engine capable of meeting stringent emission standards and giving significantly better fuel economy in the short term. Tests reported by EPA (15) and others (16) show that pre-chamber Diesel-powered passenger cars, currently available on the world market, have demonstrated the ability to meet levels below .41 gpm HC, 3.4 gpm CO and 1.5 gpm NO_x with no emission controls. Fuel economy of the Diesel cars currently available is much better than conventional cars of equivalent weight.

Figure 6 shows the EPA data on the 1974 model gasoline-powered vehicles compared to Diesel-powered vehicles tested by EPA. The 3000 IW class Diesels were the Opel Rekord 2100D and the Peugeot 504D. The 3500 class Diesels were the Mercedes 220D, Mercedes 240D and the Nissan (Datsun) 220C. The 4500 class data point is based on data from a Ford pick-up truck retrofitted with a six-cylinder Nissan engine. All fuel economy results shown in Figure 6 are on the basis of the 1972 FTP.

Through the two sets of data points in Figure 6 are drawn the best fit curves of the form $(\text{mpg}) \times (\text{IW}) = C$, where "C" is a constant. Previous work (17) has shown this equation provides a good fit for the miles per gallon versus inertia weight data from a representative population of passenger cars. The dashed curve through the Diesel data points was used to calculate a sales-weighted fuel economy for a hypothetical "all Diesel" model year using 1973 sales fractions. The resultant sales-weighted economy for the all Diesel case was 20.5 mpg compared to 11.4 mpg for the all gasoline engine case. This analysis indicates a potential for a 79% improvement in sales-weighted fuel economy due to a complete shift to Diesel cars with no change in model mix.

It should be pointed out that the Diesel vehicles used to generate the dashed curve in Figure 6 all had low power to weight ratios. Top speeds of

**FIGURE 6
FUEL ECONOMY vs. VEHICLE WEIGHT
FOR CONVENTIONAL & DIESEL POWERED VEHICLES**



these vehicles averaged 80-85 miles per hour (mph) and zero to 60 mph acceleration times were in the 25 second bracket. Reference (4) showed that the fuel economy advantage of the Diesel is approximately cut in half if it is compared to gasoline-powered cars of equivalent performance instead of being compared to the average gasoline-powered cars. Reference (4) also pointed out, however, that the Diesel engine has the capability to have its performance increased substantially without suffering economy losses

through the use of supercharging. It may not be necessary to sacrifice vehicle performance to obtain the fuel economy advantage shown in Figure 6.

SUMMARY AND CONCLUSIONS

The systems used to meet the Federal light duty emission standards in effect since 1968 have been responsible for an average 7% loss in fuel economy. The 1974 models have suffered most with a 12.3% loss. Recently increased

concern over fuel economy, however, is causing a reversal of the downward trend. Improved emission control systems, both catalytic and non-catalytic, being developed for 1975 are likely to result in significant fuel economy improvements being made simultaneously with significant emission reductions. For some of the catalytic systems it appears that a relaxation of the 1975 Federal Interim Standards would do nothing to improve economy further.

The potential for fuel economy improvements by tampering with the emission control systems installed in current cars does not appear to be significant and large emission increases result when tampering is done.

Future fuel economy trends could be greatly influenced by a shift in sales distributions. A drop in average car weight of 1000 pounds could result in a 37% improvement in fuel economy. Dramatic improvements also appear to be possible if the usage of the Diesel engine is expanded. The effect of future emission standards appears to be insignificant when compared to the effect of market shifts or increased Diesel usage.

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Corrected

APPENDIX A

Urban Fuel Economy of Uncontrolled and Controlled Passenger Cars

Fuel Consumption (Ci) in Litres/100 Kilometers (L/100 Km) for Various Model Years

⁷⁴f_i

IW Class	1973 Sales Fractions (f _i)		'74	'73	'72	'71	'70	'69	'68	'57-'67
2000	.0128	.0074	9.8	9.9	10.2	10.4	10.1	10.6	12.2	10.2
2250	.0438	.0460	11.3	10.7	10.7	11.0	12.2	11.6	11.5	10.8
2500	.0573	.0483	11.9	11.9	12.0	12.2	13.4	12.5	12.1	12.3
2750	.0945	.0625	12.9	13.4	11.8	12.8	12.7	12.0*	12.0	13.7
3000	.0577	.1317	15.5	15.1	16.4	15.9	14.8	15.3	14.8	15.3
3500	.1181	.1182	16.8	16.9	17.6	19.2	17.7	17.7	17.7	17.4
4000	.1221	.1040	21.6	21.8	21.3	20.2	19.5	19.7	19.6	18.7
4500	.2545	.2138	24.8	23.4	22.0	22.0	21.5	20.9	20.8	20.2
5000	.1681	.1705	26.1	25.3	24.6	24.6	23.4	25.9	25.3	21.7
5500	.0681	.0979	28.3	27.2	25.3	21.7	23.7	21.8	21.8*	22.4
sales weighted fuel consumption (Σf _i c _i) in L/100 km			20.7	20.1	19.5	19.4	19.0	19.0	18.9	18.1
sales weighted fuel economy (235.2 / Σf _i c _i) in miles per gallon			11.4	11.7	12.1	12.1	12.4	12.4	12.5	13.0

*No data available, corresponding value from '68 or '69 used.

NOTE: IW class 1750 was deleted from the analysis because of its low sales fraction (.0030) and a lack of fuel economy data.