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ANALYSIS OF EMISSIONS DETERIORATION OF IN-USE VEHICLES, USING ARIZONA IM240 DATA

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Abstract

Computer models that forecast in-use vehicle air pollutant emissions (i.e. MOBILE and EMFAC) base assumptions of how vehicle emissions increase as they age on limited laboratory emissions tests. States' adoption of dynamometer-based testing as part of enhanced vehicle emission inspection and maintenance (I/M) programs has resulted in in-use emissions data on hundreds of thousands of vehicles. This paper analyzes how emissions increase as vehicles age, using data from the Arizona I/M program

Arizona I/M Data

Arizona is one of the first states to use the Enhanced I/M testing procedure recommended by EPA. The procedure involves testing vehicles on a treadmill-like device, called a dynamometer, which simulates the vehicle driving a 240-second speed-time trace, called the IM240, that tests emissions under varying vehicle operating conditions. The procedure was developed to simulate the detailed emissions testing manufacturers perform on new vehicles.

This analysis is based on initial IM240 tests conducted on in-use passenger cars in Arizona in 1995. Arizona's program allows the cleanest vehicles to pass inspection after only 30 seconds of testing (fast passes), and the dirtiest vehicles to fail after 94 seconds of testing (fast fails). Other vehicles can pass or fail at any time before the full 240 second test is completed. A random 2% sample of vehicles are given the full 240-second test, regardless of whether they pass or fail the test. In addition, a small number of vehicles are tested over the entire test without fast-passing or fast-failing. We included the fast pass/fast fail tests in our analysis.

There are two major drawbacks with using the fast pass/fast fail data. First, vehicles are tested over different portions of the IM240 cycle, resulting in inconsistent emissions values. This is particularly important for vehicles passed immediately after 30 seconds of testing, for two reasons: these vehicles represent from 40 to 60 percent of all cars of a given model year, and a given vehicle will have substantially higher gram per mile emissions at second 30 than at second 240. The second drawback is that long vehicle wait times may affect emissions measurements. The engines and catalysts of vehicles that wait 15 or more minutes prior to testing may have cooled down sufficiently, resulting in higher emitssion than if they were properly warmed up (or "preconditioned") prior to testing (Heirigs and Gordon, 1996). Consequently, inconsistent preconditioning of vehicles may overstate average gram per mile emissions.

However, there are benefits to using the fast pass/fast fail data, rather than limiting the analysis to the random sample of full IM240 tests. The sheer number of tests allow detailed analyses of emissions (for instance, by model year and mileage), without losing statistical significance. And the full dataset is likely more representative of the Arizona on-road fleet than the random sample.

Methodology

We made several refinements to the data to improve our analysis. First, we adjusted the reported test results to more accurately reflect results if each vehicle was tested on a full IM240. The contractor reports test results as total grams divided by the distance of the full IM240 test (1.96 miles). Our adjustment involved two steps: calculating actual grams per mile based on actual miles each vehicle was driven, and correcting for different test durations. We obtained from Ontario average second by second emissions data from 11,000 vehicles tested over the full IM240. Figure 1 shows the speed time trace of the IM240 (right scale), and the average gram per mile emissions fo the Ontario test fleet at each second of the test (left scale). For each second of the test, cumulative grams are divided by cumulative miles for each vehicle, and the results are averaged over the fleet. The highest average gram per mile values occur at second 30, and decrease as the test continues. The hardest acceleration in the IM240 occurs just before second 160; this

Figure 1. Average gpm Emissions at Each Second of IM240,
Ontario Data (n=11,000 full IM240 tests)

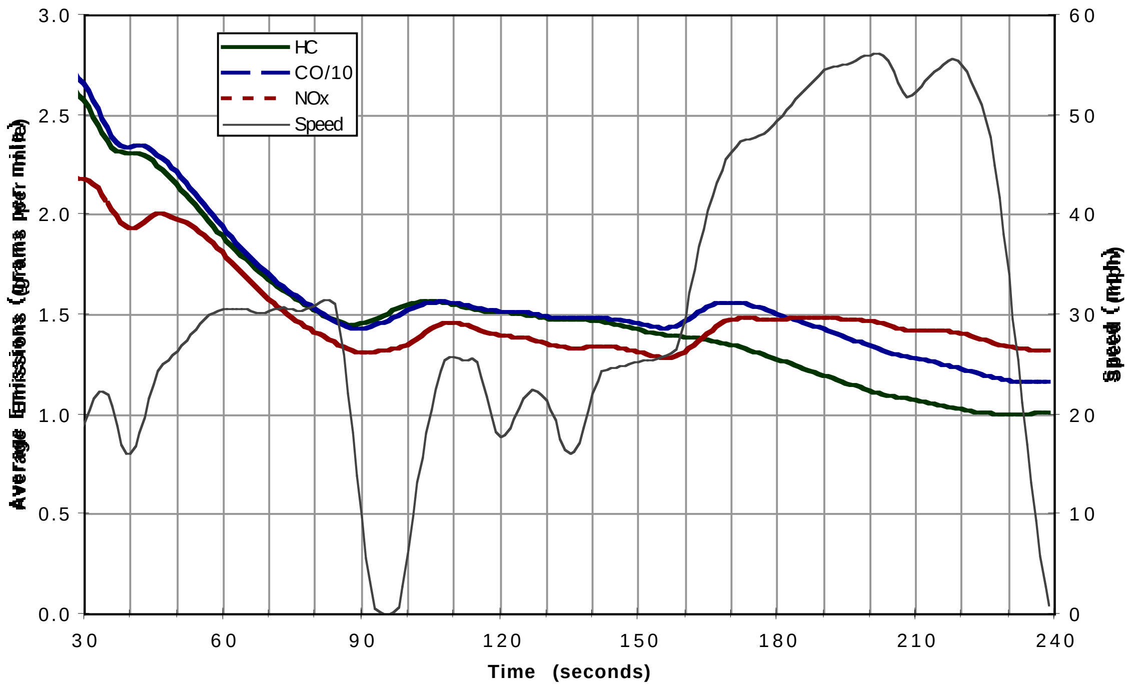
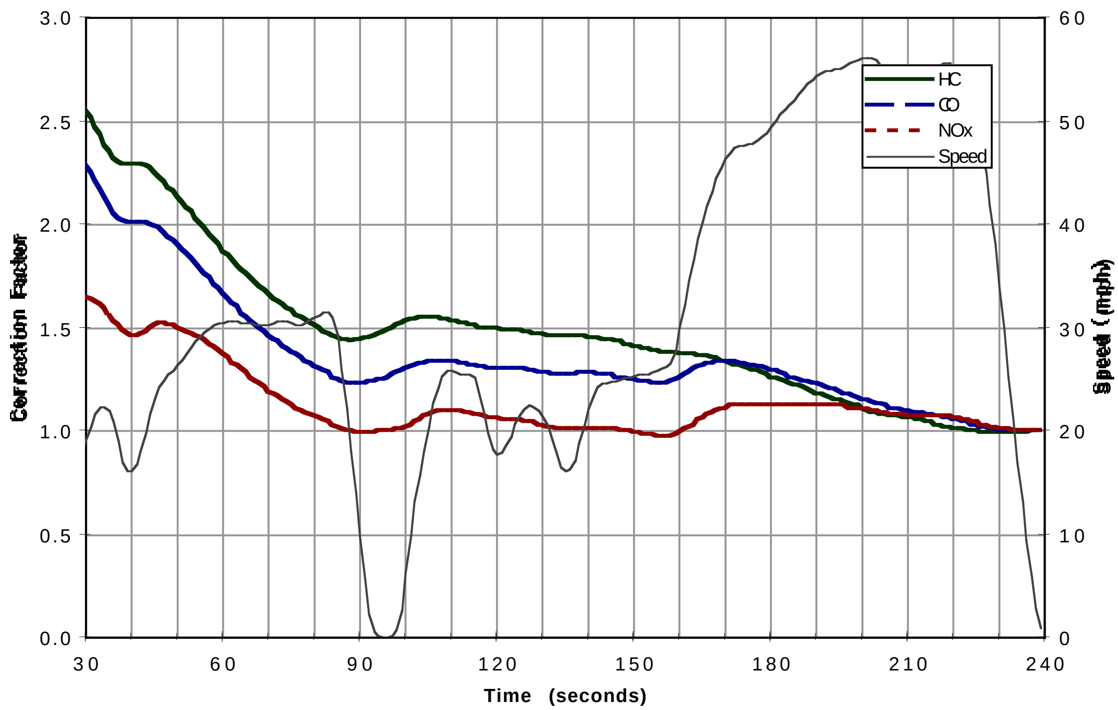


Figure 2. Emission Correction Factor for Each Second of IM240,
Ontario Data (n=11,000 full IM240 tests)



acceleration causes the cumulative average gram per mile values for CO and NOx to increase slightly.

We then developed a correction factor for each second of the test, for each pollutant, based on the ratio of the average emissions at each second to the average emissions for the full IM240. As shown in Figure 2, the correction factors are quite large for cars passed immediately after 30 seconds; for these cars we divided measured gram per mile values by 2.5 for HC to obtain full-IM240 equivalent emissions.

Figures 3 through 5 show the effect of our two adjustments on the test results reported by the contractor. The dashed lines represent converting the reported results into gram per mile values, and the heavy lines represent the downward adjustment of the gram per mile values to account for different test durations. In general, our adjustments substantially increase the reported emissions from cars tested on shorter portions of the IM240 (for example, emissions from cars passed after 30 seconds of testing are increased by a factor of 4 to 7, depending on the pollutant). Our adjustments resulted in smaller increases from reported emissions from cars tested over longer segments of the IM240.

We made no correction for the problem of inconsistent preconditioning, although we did attempt to identfy individual cars that may not have been properly warmed-up prior to testing. Arizona allows cars that fail the test a second chance to pass, based on the emissions over the second half (Phase 2) of the IM240, when the car has presumably been sufficiently warmed-up. We assumed that cars that failed the composite cutpoints, but passed the Phase 2 cutpoints, were not fully warmed-up; these cars represent less than 5 percent of the fleet tested.

Figure 3. Average HC Emissions By Test Duration, MY83-94 Cars
1995 AZ IM240 (n=366,000)

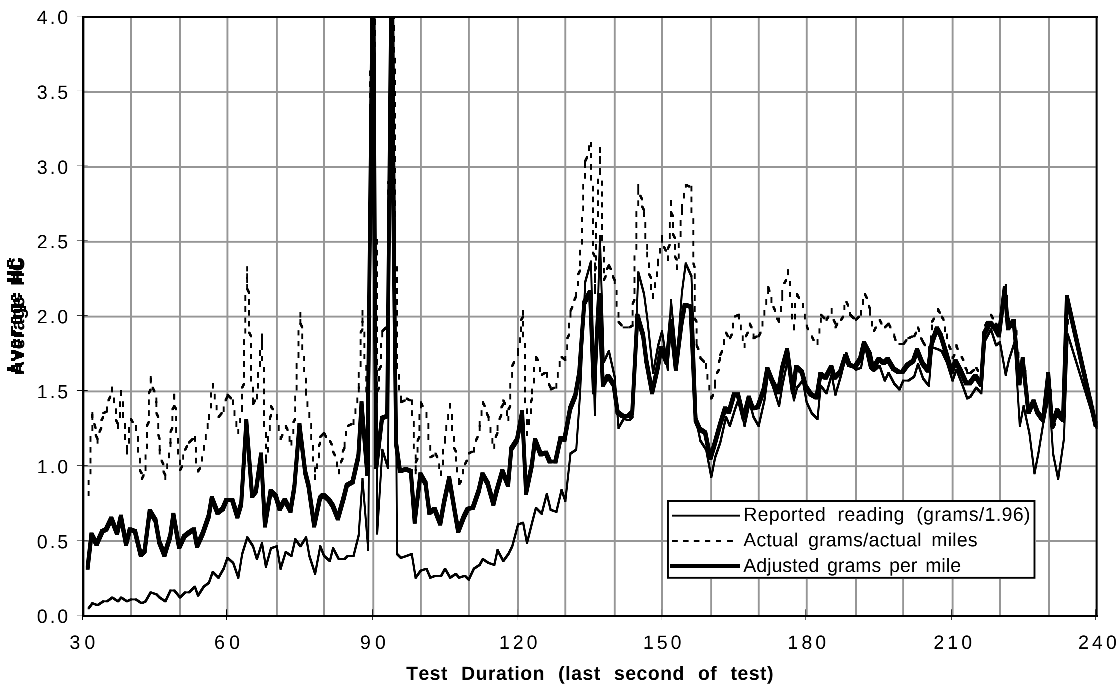


Figure 4. Average CO Emissions by Test Duration, MY83-94 Cars
1995 AZ IM240 (n=366,000)

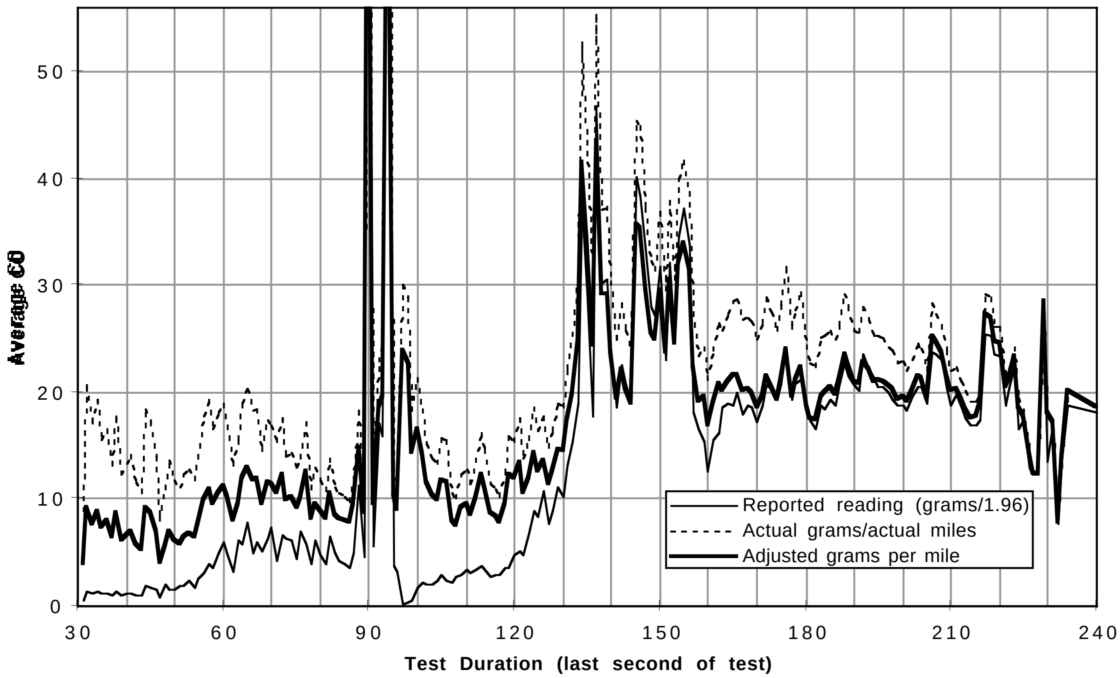


Figure 5. Average NOx Emissions by Test Duration, MY83-94 Cars
1995 AZ IM240 (n=366,000)

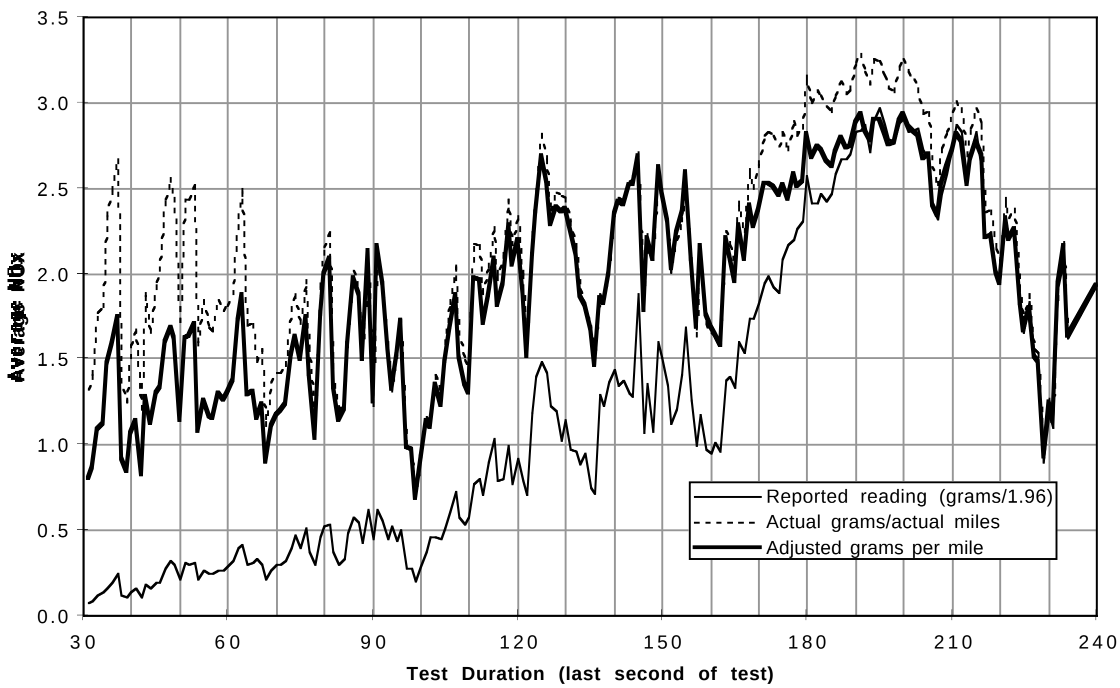


Figure 6 shows the distribution of cars by odometer reading. We found a large number of vehicles with zero and 100,000 mile odometer readings. We assumed these were misread odometers, and removed these cars from the analysis. That left us with the initial IM240 tests of 350,000 cars tested in 1995. We aggregated these cars into 10,000 mile odometer bins, and limited our analysis to those model year/mileage points with at least 600 cars.

Figure 7 indicates another problem with the data: we found many early model year cars with low mileages (under 100,000). One would expect the peaks of each model year distribution to move to the right with older model years; instead, the peaks for the older model years are all near 100,000 miles. We suspect that a large number of cars from these model years have 5-digit odometers, and that test technicians could not determine when an odometer had rolled over. Figures 8 through 10 show the effect the 5-digit odometers have on average emissions. For earlier model years, the average emissions of low mileage cars are higher than emissions of high mileage cars. To account for the 5-digit odometer problem, we disregard pre-87 cars, and some early model year/low mileage points on the curves.

Figure 6. Number of MY83-94 Cars by Odometer, 1995 AZ IM240

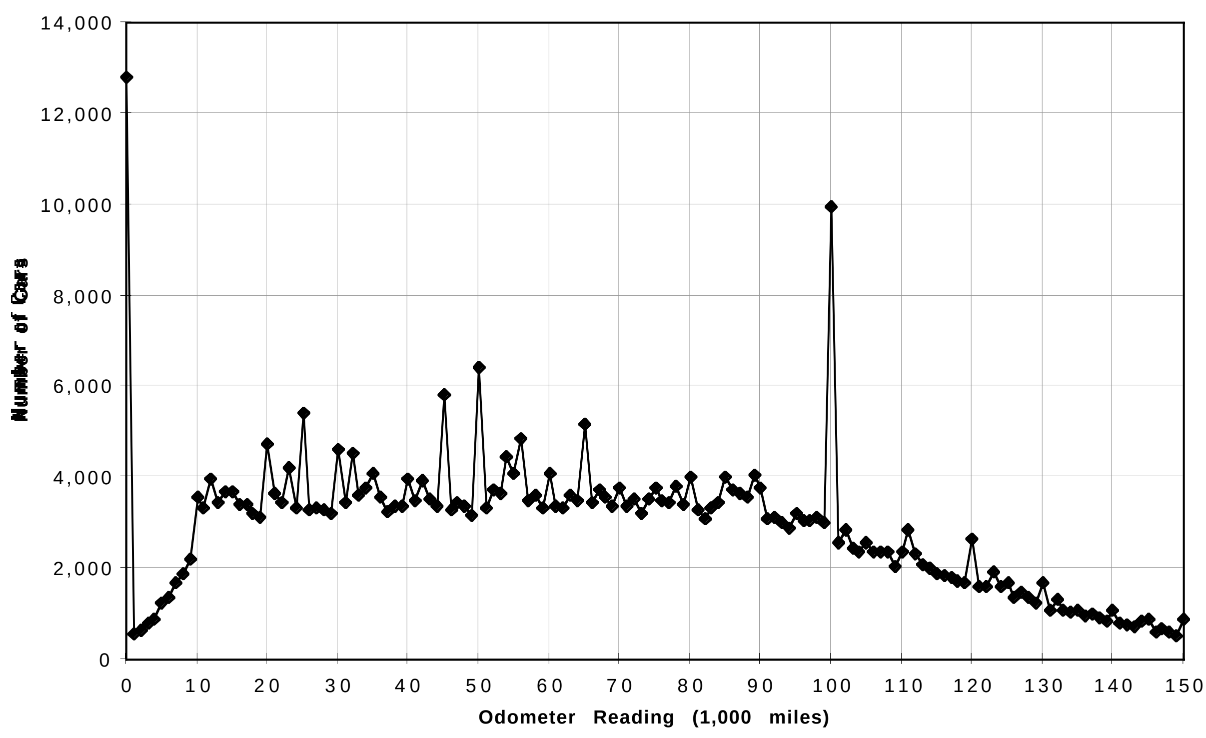


Figure 7. Number of Cars, by MY and Mileage, 1995 AZ IM240

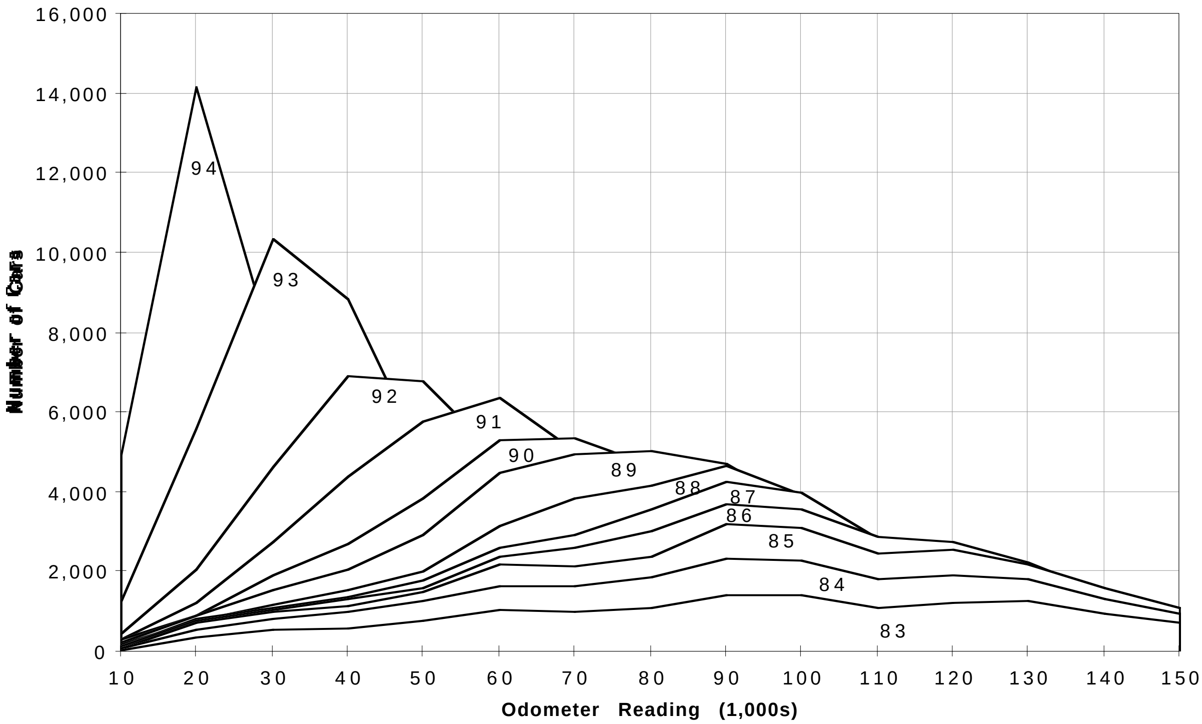


Figure 8. Average Car HC Emissions by MY and Mileage
1995 AZ IM240 (n=350,000, each point >600 cars)

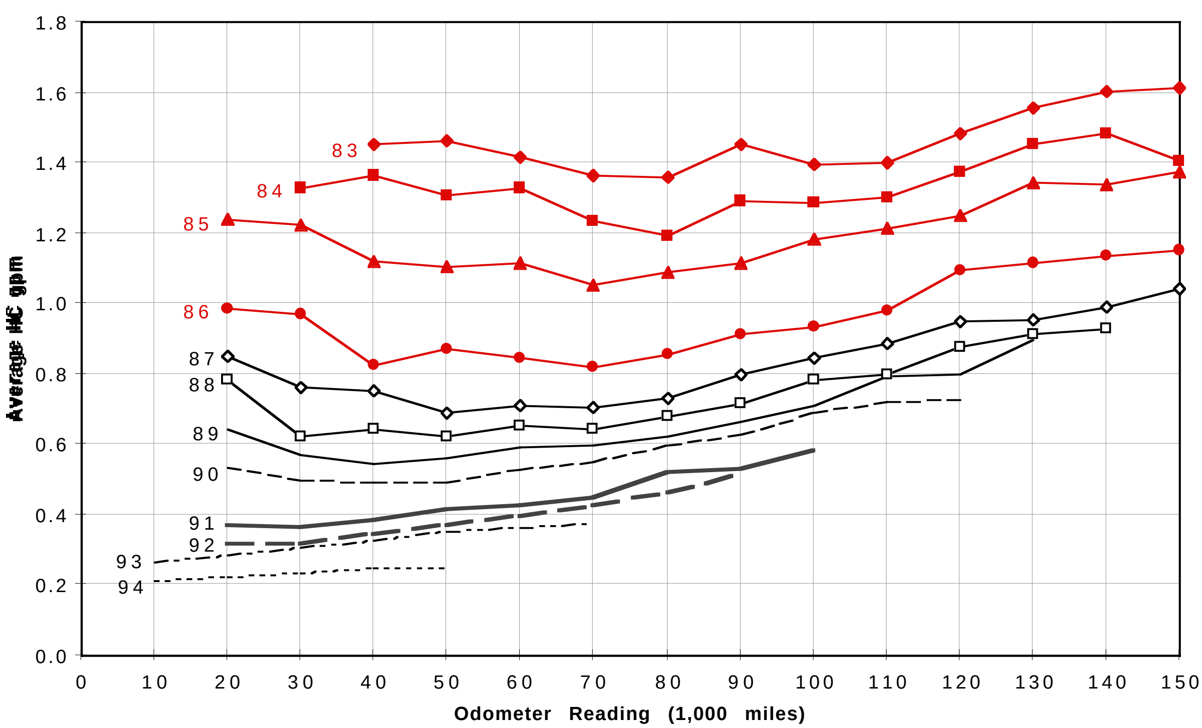


Figure 9. Average Car CO Emissions by MY and Mileage
1995 AZ IM240 (n=350,000, each point >600 cars)

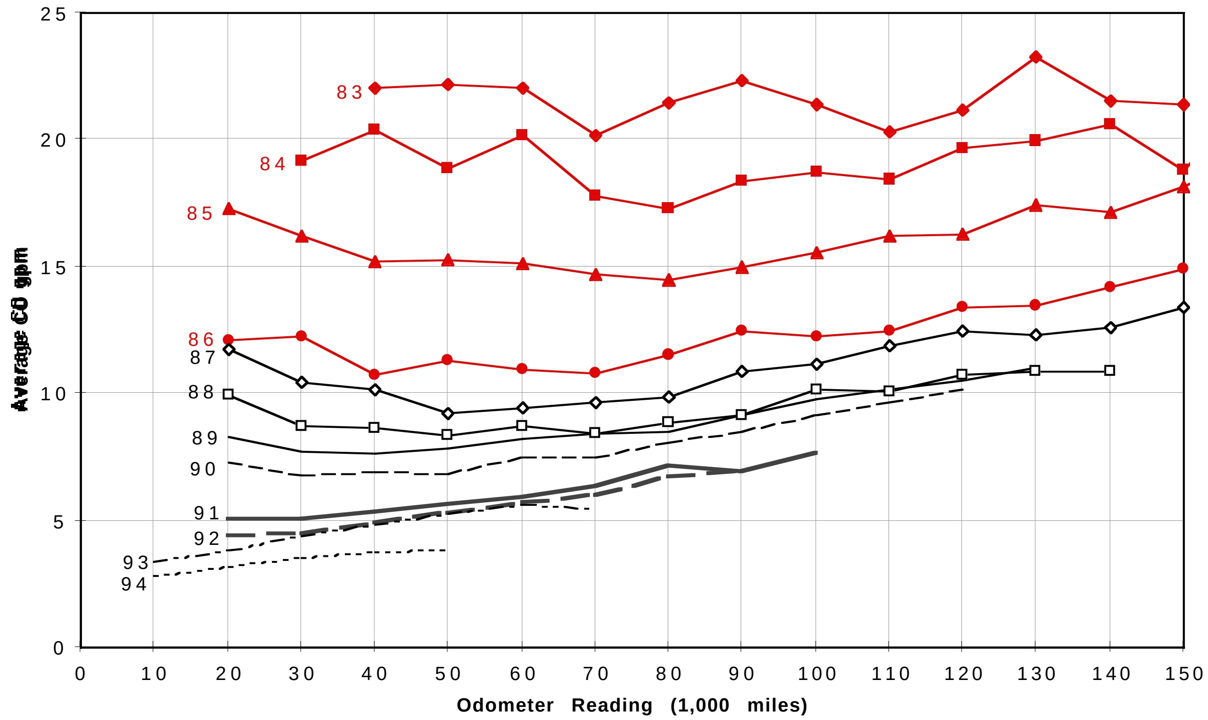
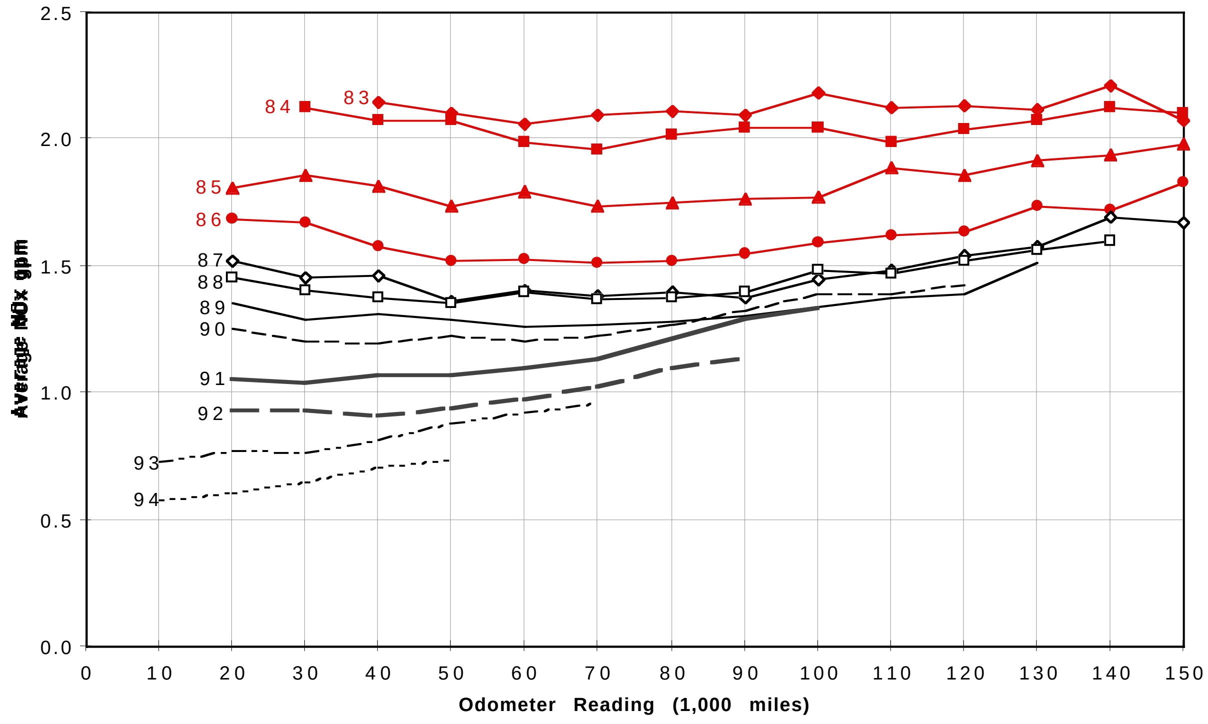


Figure 10. Average Car NOx Emissions by MY and Mileage
1995 AZ IM240 (n=350,000, each point >600 cars)



Results

Figures 11 through 13 show the emissions deterioration curves by model year and mileage. We make three observations about these curves: that emissions increase with increasing mileage; that emissions decrease with increasing model year; and that the emissions reduction by model year is greater in certain years.

Our first observation, that emissions increase with increasing mileage, is not surprising. However, we find that there is some evidence that emissions deterioration rates are lower for newer model years; for instance, newer model years have slightly shallower slopes for HC, while MY94 has a slightly shallower slope for CO. Slopes for NOx curves appear similar across all model years. All the deterioration curves by model year appear fairly linear, with no obvious changes in slope with increasing mileage, as MOBILE5 predicts. (Bows at early model year/low mileage appear to be caused by inaccurate odometer readings due to 5-digit odometers)

Our second observation, that emissions decrease with increasing model year, is somewhat surprising, in that the emissions decreases are rather large. For example, low mileage (50,000 mile) MY90 cars emit 2 to 3 times that of low mileage (10,000 mile) MY94 cars. An obvious explanation would be technological improvement that results in reduced emissions; however, if certification standards did not change between MY87 and MY93, can technological improvement by itself explain these large reductions? We speculate that aging of vehicles independent of mileage may also have an effect on emissions deterioration.

To test this, we compared 7 months of data from 1995 and 1996 to see if one year of aging has a noticeable effect on average emissions. We were surprised to find that, holding model year and mileage constant, HC and NOx emissions are consistently lower in 1996 than in 1995 (Figures 14 and 15); that is, one year older cars pollute less. CO emissions in these two years are about the same. This result is statistically significant for some model years, as shown in the figures. Since Arizona has a biennial inspection program, this reduction in emissions cannot be attributed to the effectiveness of I/M (the cars tested in 1995 are not the same as those tested in 1996). We speculate that changes in the IM240 testing, or perhaps a different mix of models in the fleets tested in 1995 and 1996, explain this difference. This surprising result does not support our claim that vehicle age affects emissions. On the other hand, one year may not be enough time to see an aging effect; clearly this issue needs more study.

Our third observation is that the trend in deterioration by model year is greater in certain model years. Figures 11 through 13 show fairly large decreases in emissions by mileage in MY91 for HC and CO (and in MY92 for NOx), and in MY94 for all pollutants. This result is likely caused by technological differences between model years. For instance over the 1980s, manufacturers replaced carburetors with fuel

injection; by 1990 virtually all vehicles have fuel injection technology. The shift between the average emissions curves by model year may be due to a dramatic shift in the fraction of vehicles using fuel injection technology between MY90 and MY91. The lower MY94 curve may be due to implementation of the stricter Tier 1 emission standards; half of each manufacturer's MY94 car fleet had to meet those standards. A second possible explanation is that the stricter IM240 cutpoints for MY91 and later cars are somehow affecting the emission averages by model year.

Factors Driving Deterioraton

Finally, we tried to determine what factors are driving overall emissions deterioration. There are basically three possibilities: increasing average emissions from clean cars (cars passing the IM240); increasing average emissions from dirty cars (cars failing the IM240); and the fraction of dirty cars (as measured by the IM240 failure rate). The following results are sensitive to the cutpoints we used. We used the final IM240 cutpoints from the Arizona program (and recommended by EPA), shown in Table 1 (Arizona did not adopt these cutpoints in 1997 as planned, in part because inconsistent preconditioning would have resulted in unacceptably high false failure rates). The table shows the ratio of final IM240 cutpoints to the standards used for the Federal Test Procedure (FTP) for new car certification. Final Arizona IM240 cutpoint for CO is high relative to those for HC and NOx, meaning that fewer cars fail for CO than for HC or NOx.

Table 1. Federal Test Procedure and Arizona Final IM240 Cutpoints

Pollutant	FTP composite standards (gpm)	Final IM240 cutpoints (gpm)	Ratio of IM240 to FTP
HC	0.41	0.8	2:1
CO	3.40	15.0	4:1
NOx	1.00	2.0	2:1

Figures 16 through 21 show data from MY93 cars, representing cars at low mileages, in the left panel of each figure, and MY88 cars, representing cars at high mileages, in the right panel of each figure. We use these two model years since combined they provide emissions data on cars with odometers from 10 to 140,000 miles. The figures include the percentage deterioration rate for each curve, as well as the percent difference between each MY88 and MY93 curve. The right panel represents the worst case future for MY93 cars when they accumulate mileage; that is, that they will behave like MY88 cars at high mileage.

Figures 16 through 18 show average emissions from all cars (filled squares) and from passing cars (open squares). The difference between the two curves is the effect of failing cars on the overall emissions deterioration. We find that passing cars account for most of overall deterioration in MY93/low mileage cars; the overall deterioration rate is only slightly higher than the passing car deterioration rate. We

also find that failing cars account for over half of HC, and about half of CO and NOx, deterioration in MY88/high mileage cars. The difference between the MY88 and MY93 curves at 70,000 miles represents the effect of improved technology, or vehicle age, on emissions. Technological improvement has a much bigger effect on overall emissions than on passing car emissions

Figures 19 through 21 examine the 2 components of emissions from failing cars: average emissions on the left scale, and failure rates on the right scale. Average emissions (indicated by filled squares) from failing cars increase slightly with increasing mileage; failure rates (open diamonds) show greater increases with increasing mileage. But failure rates increase dramatically by model year: MY88 failure rates at 70,000 miles are 2 to 3 times those of MY93 cars. Therefore, failure rate, rather than average emissions, is mostly responsible for the increase in emissions from failing cars.

Figure 11. Average Car HC Emissions by MY and Mileage
1995 AZ IM240 (n=220,000)

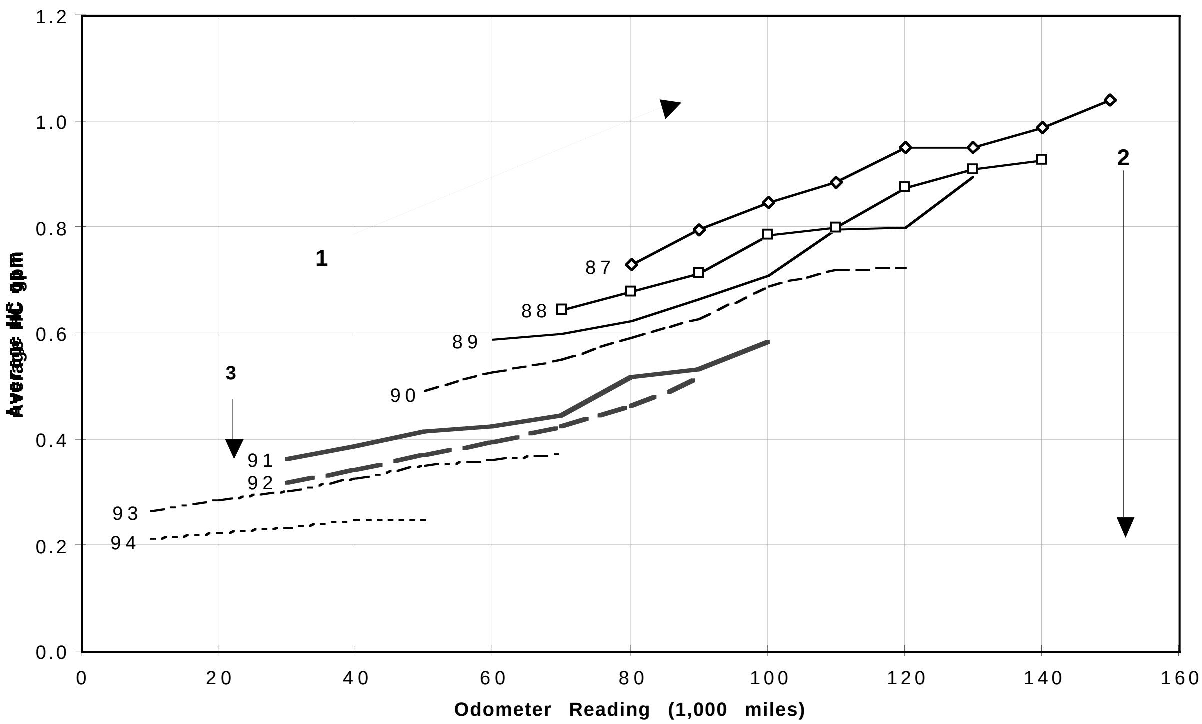


Figure 12. Average Car CO Emissions by MY and Mileage
1995 AZ IM240 (n=220,000)

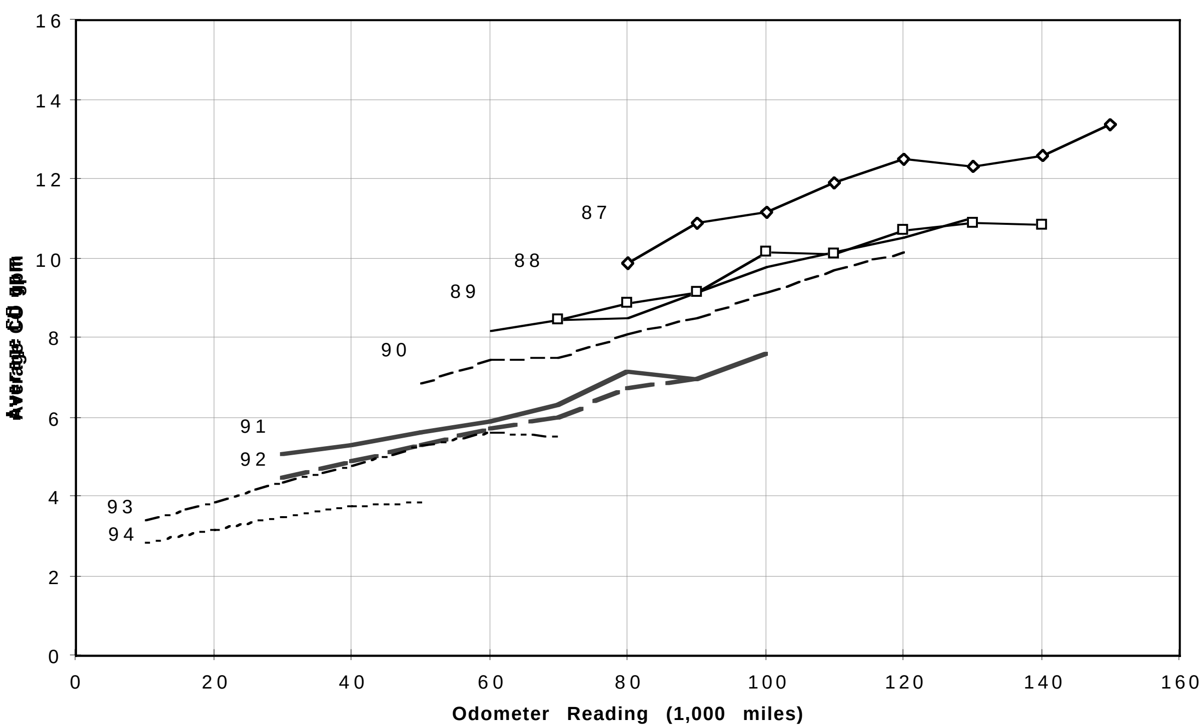


Figure 13. Average Car NOx Emissions by MY and Mileage
1995 AZ IM240 (n=220,000)

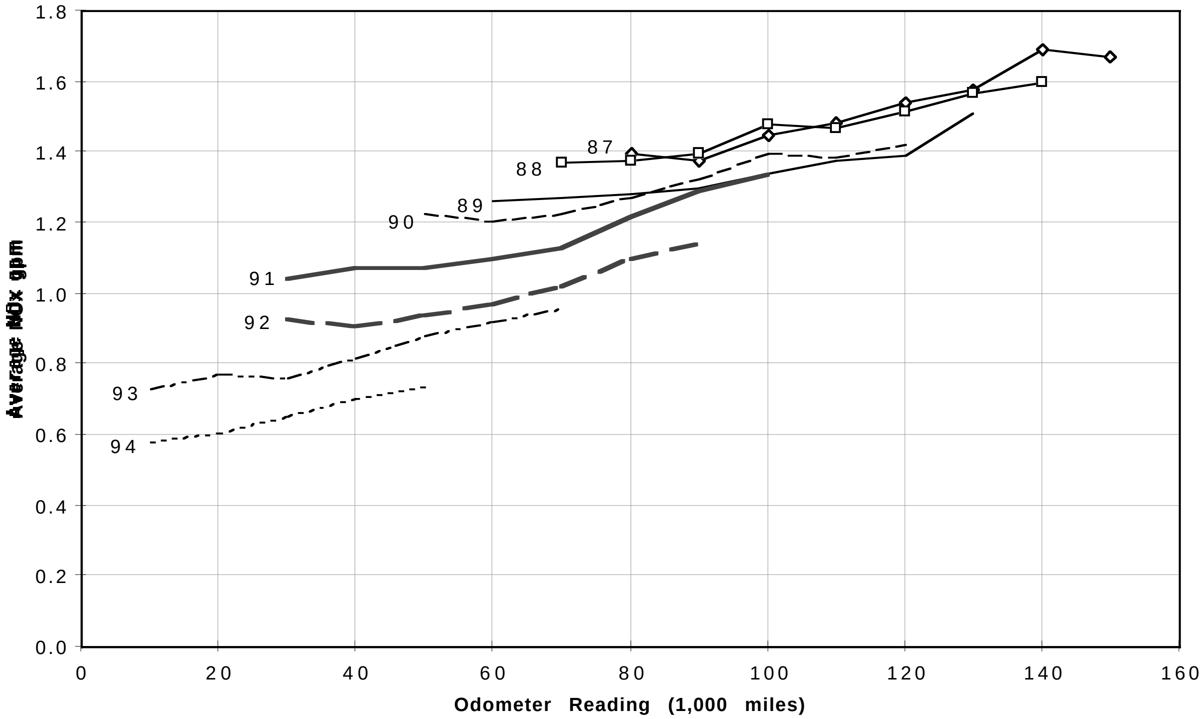


Figure 14. Average Car HC Emissions by MY and Mileage,
1995 vs. 1996 AZ IM240 (n=40,000)

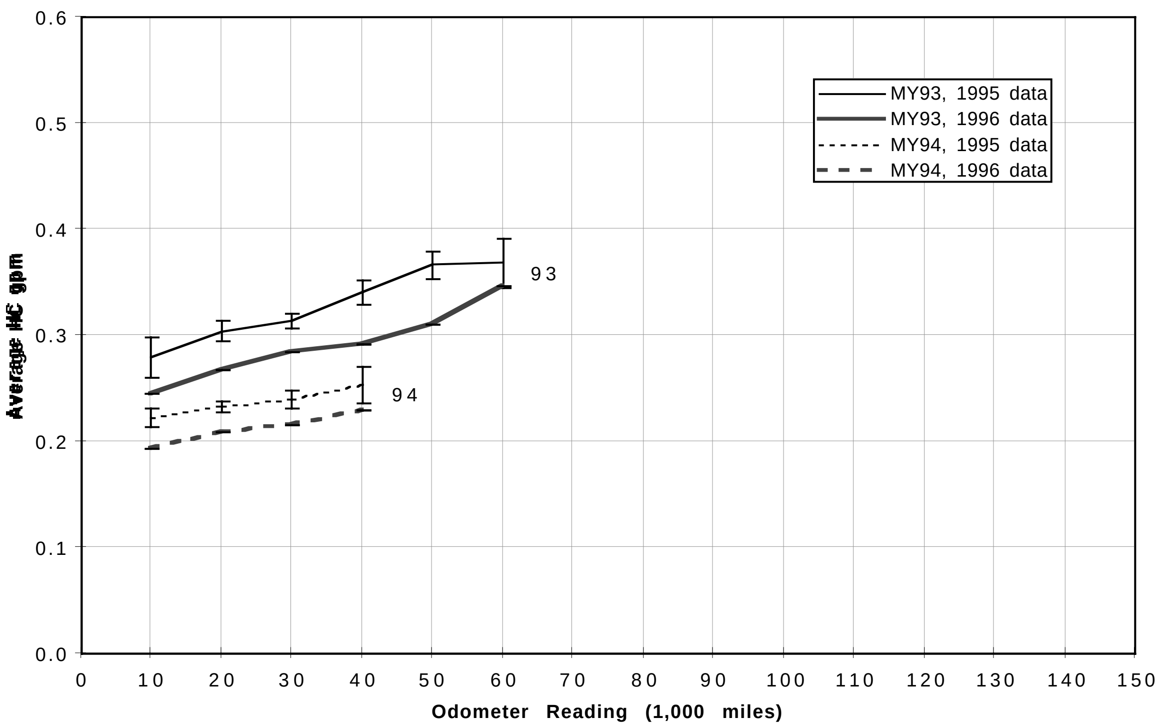


Figure 15. Average Car NOx Emissions by MY and Mileage,
1995 vs. 1996 AZ IM240 (n=40,000)

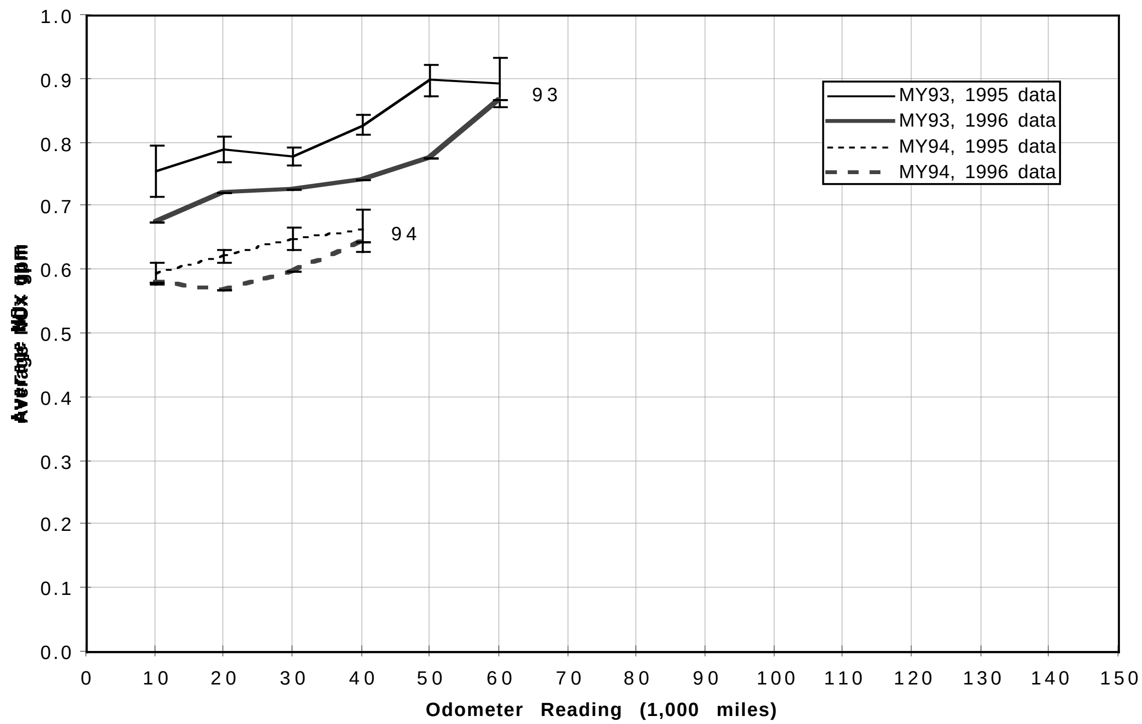


Figure 16. Average HC Emissions by Mileage, for Passing and All Cars,
1995 AZ IM240 (n=57,000)

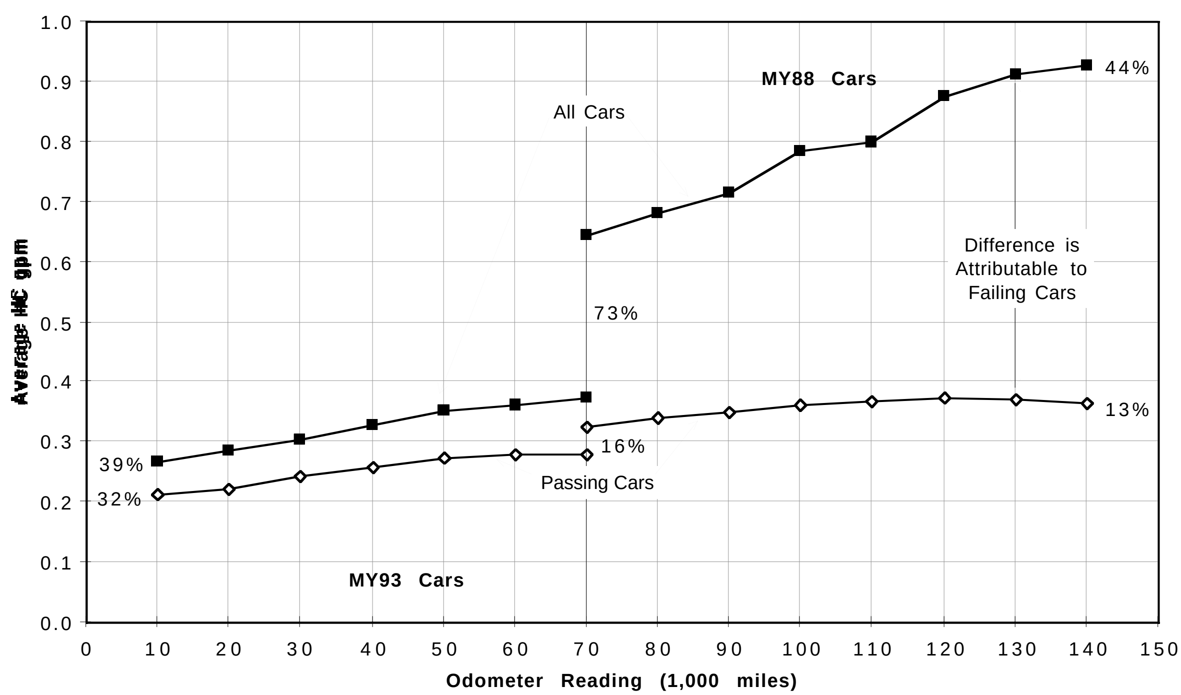


Figure 17. Average CO Emissions by Mileage, for Passing and All Cars, 1995 AZ IM240 (n=57,000)

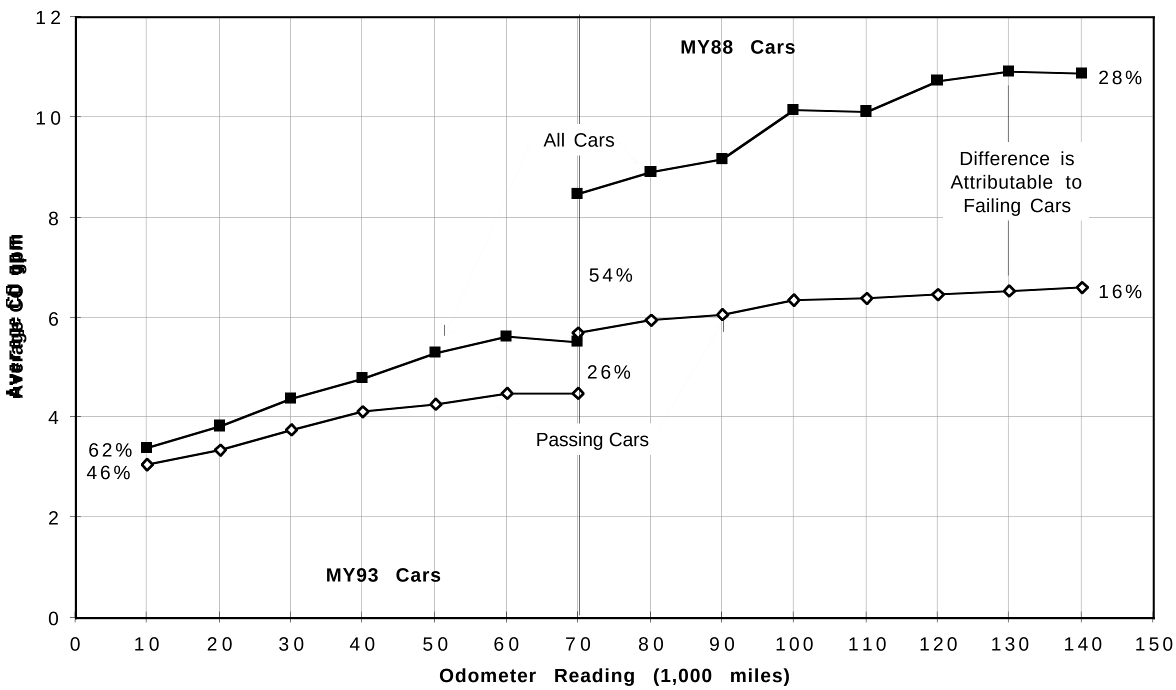


Figure 18. Average NOx Emissions by Mileage for Passing, All Cars 1995 AZ IM240 (n=57,000)

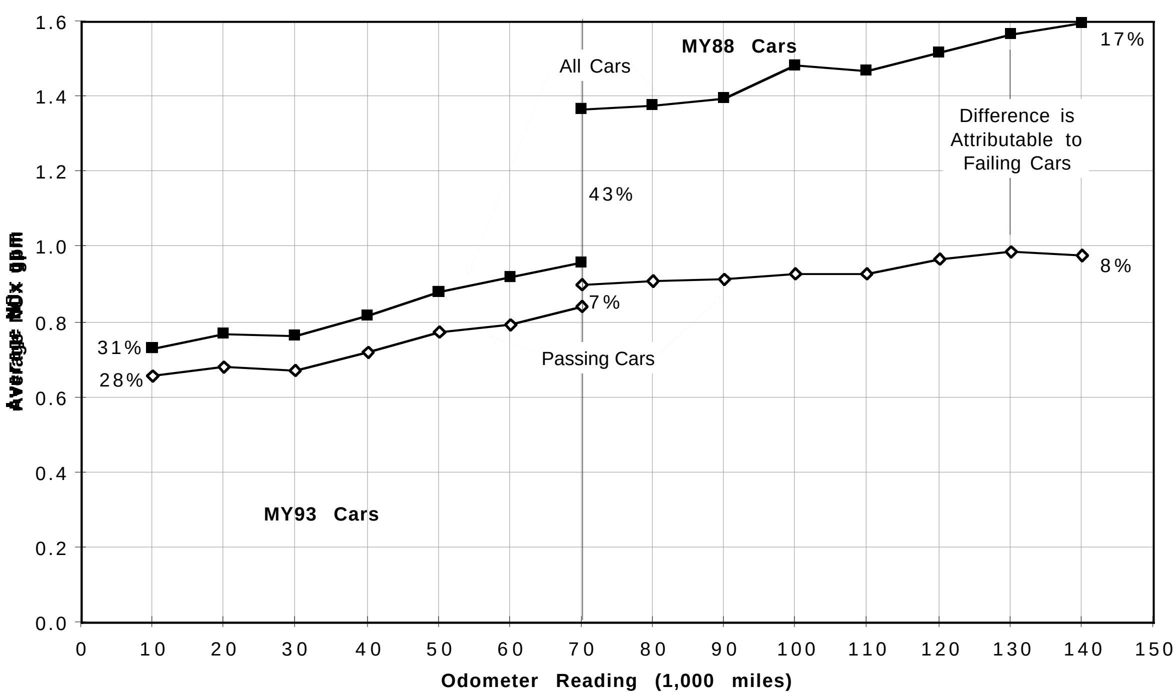


Figure 19. Components of Failing Car Contribution to Average HC by Mileage, 1995 AZ IM240 (n=57,000)

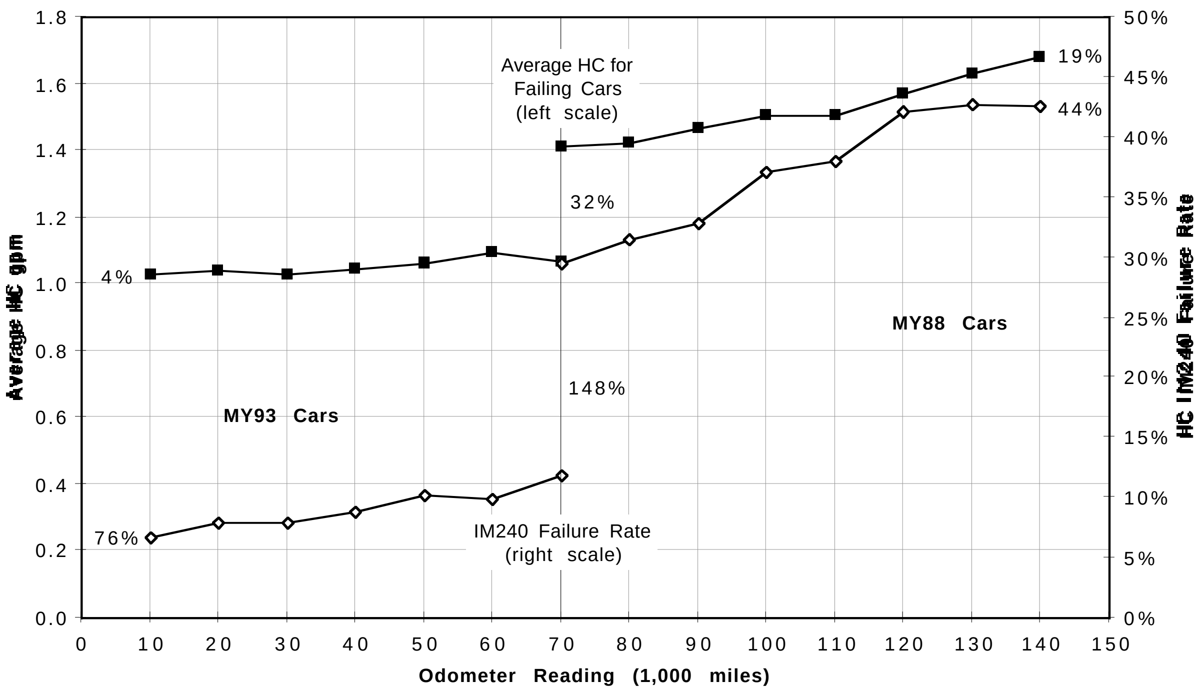


Figure 20. Components of Failing Car Contribution to Average CO by Mileage, 1995 AZ IM240 (n=57,000)

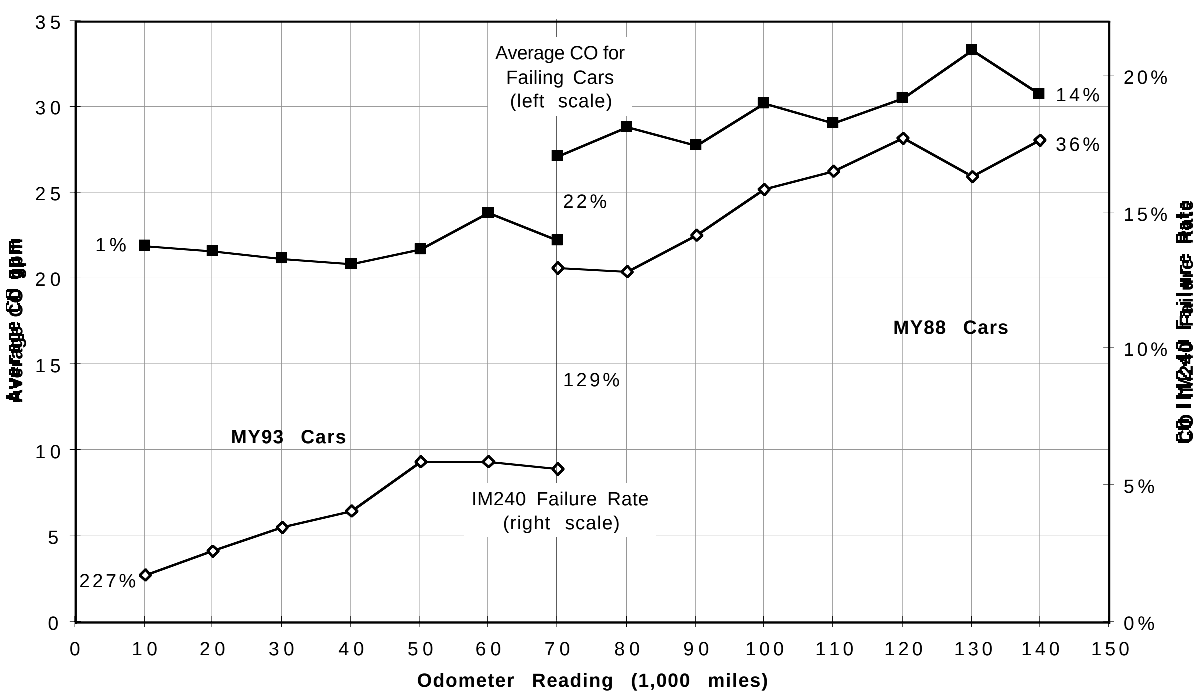
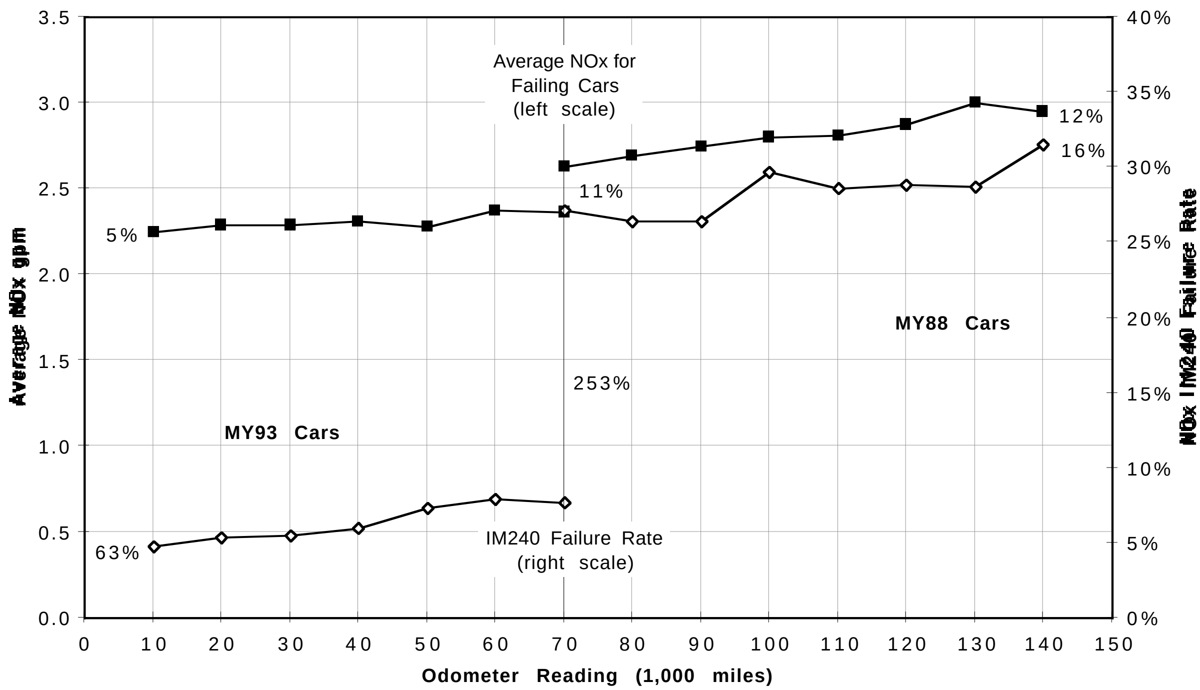


Figure 21. Components of Failing Car Contribution to Average NOx
by Mileage, 1995 AZ IM240 (n=57,000)



Summary

We examined 1995 IM240 data from Arizona to determine the factors that are driving emissions deterioration as in-use vehicles age. For each model year, emissions increase linearly with increasing mileage. Emission rate curves do not kink upward with increasing mileage, as the MOBILE5 model predicts. HC emissions deterioration rates by mileage (i.e. the slopes of the curves) appear to be decreasing slightly with newer vehicle technologies, whereas the slopes of the CO and NOx deterioration curves appear fairly constant over model years.

For each mileage bin, there are large decreases in emissions with increasing model year. Most of this improvement in emissions in new vehicles is likely due to technological improvements. We suspect that vehicle age independent of mileage may be a contributing factor. When we test whether vehicle age affects emissions, we find that older cars of the same model year and mileage have higher emissions than younger cars. There are relatively large reductions in emissions in MY91 and MY94 cars. Possible causes are technological differences between model years, such as a large shift to multi-port fuel injection in MY91 and introduction of Tier 1 standards in MY94. Another possible cause is the stricter IM240 emission cutpoints used for MY91 and newer cars.

We use average emissions from older (i.e. MY87) vehicles to simulate emissions at high mileage. Using these data, it appears that vehicle failure rate, rather than increasing average emissions from passing cars or increasing average emissions from failing cars, has the biggest impact on overall emissions deterioration as vehicles accumulate mileage.

We plan to continue analyzing I/M data from Arizona and other states in several ways to learn more about emissions deterioration. Most importantly, we would like several test years of data to better examine the effect of aging independent of mileage on emissions. We also plan to:

- test the sensitivity of our results to the cutpoints we use (particularly for CO);
- identify early model year cars with legitimate odometer readings, by model year and manufacturer or model, in order to include more early model year/low mileage points in our analysis;
- determine why one year older cars (tested in 1996) had lower emissions than the cars tested in 1995; and
- study deterioration rates by type of fuel system (carbureted vs. throttle body vs. multi-point fuel injection) and by vehicle type (car vs. light duty truck).

References

Heirigs, Philip L. and Jay Gordon. 1996. *Preconditioning Effects on I/M Test Results Using IM240 and ASM Procedures*. SAE Technical Paper Series 962091. October.