Emissions from In-use Motor Vehicles in Los Angeles: A Pilot Study of Remote Sensing and the Inspection and Maintenance Program

Douglas R. Lawson
California Air Resources Board
Sacramento, California

Peter J. Groblicki
General Motors Research Laboratories
Warren, Michigan

Donald H. Stedman, Gary A. Bishop and Paul L. Guenther
University of Denver
Denver, Colorado

As part of a major field study to understand the causes of persistent, elevated carbon monoxide pollution episodes in Los Angeles, we performed a project to understand the emissions of vehicles in use. In this experiment, we assessed the accuracy of a remote sensing instrument designed to measure CO concentrations from vehicles as they were driven on the road. The remote sensor was shown to be accurate within ten percent of the directly measured tailpipe value. We performed a roadside inspection on 60 vehicles and demonstrated that the remote sensor could be used as an effective surveillance tool to identify high CO-emitting vehicles. We also compared the roadside data set to the biennial Smog Check (I/M) tests for the same vehicles, and observed that carbon monoxide and exhaust hydrocarbons from high emitters were much higher than when the vehicles received their routine inspection. Furthermore, for the high-emitting vehicles in this data set, the length of time since the biennial Smog Check had little influence on the cars' emissions in the roadside inspection.

California's air pollution control program has been a dynamic one, serving as a pioneer for both Federal and state regulations. It began with the passage of the Stewart Act in 1947, which allowed counties in the State to create air pollution control districts. In 1967, the Mulford-Carrell Air Resources Act, which was signed into law by Governor Ronald Reagan, created the California Air Resources Board (ARB). As required by law, the ARB has been given the responsibility for the control of emissions from mobile sources.[1] Because of the severity of the air pollution problem in California, the ARB received waivers from the Federal government to establish its own emission standards for motor vehicles, and through the years, has established new car standards and assembly line test procedures for vehicles to be sold in the State. As a result of these regulations, air quality in California has improved in many areas, despite the pressures of growth in population and vehicle miles traveled.

Emission inventories show that mobile sources are responsible for 54, 76 and 97 percent of the reactive hydrocarbons, nitrogen oxides and carbon monoxide, respectively, in the Los Angeles Basin, as compared with 45, 72 and 68 percent for the Statewide inventory.[2] In order to assure the proper maintenance of motor vehicle emission control systems, California inspects pollution control systems on cars through its inspection and maintenance (I/M) program, called Smog Check. The Smog Check program, which began in 1984, is required in most of California's nonattainment areas and is administered and enforced by the State Bureau of Automotive Repair (BAR). The California Smog Check is required every two years, is performed at private garages, and consists of a three-part test: a visual, under-hood examination; a functional check of certain emission control systems; and a computerized tailpipe emissions measurement of exhaust hydrocarbons (HC) and carbon monoxide (CO). If the vehicle passes the Smog Check, the owner is issued a Smog Check certificate, which is required for vehicle registration. If the vehicle fails the inspection, repairs are required as long as costs do not exceed specified limits. Through 1989, the cost limit for all vehicles in California was $50. California's revised Smog Check program, which began January, 1990, increases the repair cost limits in amounts up to $300 depending upon model year. Among other things, the revised program includes new emissions analyzers and improved training and qualification criteria for Smog Check mechanics.

In December, 1989, a major field study sponsored by the ARB, the South Coast Air Quality Management District (SCAQMD), and the General Motors Research Laboratories (GMRL) investigated the reasons for persistent carbon

Reprinted from Journal of the Air & Waste Management Association, *Vol. 40, No. 8,* August 1990

monoxide pollution episodes in the Lynwood area of Los Angeles. As part of this study, we used remote sensing measurements of vehicle tailpipe CO concentrations and roadside inspection surveys to assess the emissions of vehicles in use under "real world" conditions. We were interested in testing the ability of remote sensing to quantify CO emissions from vehicles and to evaluate remote sensing as a possible tool for identifying vehicles with high CO emissions. We also compared the roadside inspection results with previous measurements made on the same vehicle during the required Smog Check program in order to provide additional information about emissions from the highest emitting vehicles.

A simple calculation shows that, for a hypothetical case, a vehicle that continuously emits seven percent CO and averages 10 mpg would emit about 300 g/mi of CO. Under the same conditions, a 0.5 percent CO vehicle averaging 30 mpg would emit about six g/mi. Therefore, using the conditions specified in this calculation, the CO emissions from one seven percent vehicle equal those from about 50 low-emitting 0.5 percent vehicles under the same operating conditions. For this reason, we were particularly interested in studying the characteristics of high CO-emitting vehicles, because previous studies showed that the highest emitting vehicles (about ten percent) accounted for about half of the CO emissions.[3–5]

Experimental

The Remote Sensing System

In this experiment we used an infrared, remote monitoring system to measure tailpipe CO emissions. This system, called the FEAT, for Fuel Efficiency Automobile Test, was developed at the University of Denver[6] with initial support from the Colorado Office of Energy Conservation. The system derives its name from the fact that fuel economy improves if rich-burning (high CO) vehicles are tuned to a stoichiometric (and efficient) air/fuel ratio. The FEAT measures the CO/CO_2 ratio in the exhaust of vehicles passing through an infrared light beam transmitted across a single lane of traffic. The emissions of a single car can be measured in less than one second at vehicle speeds as high as 60 mph.

The infrared source emits a beam of radiation 10 inches above road level, which is split in the receiver into three channels having wavelength-specific detectors for CO, CO_2 and a reference signal. Data from all three channels are fed to a computer, which converts the radiation absorbed by CO and CO_2 into the CO/CO_2 ratio (Q). A lean or stoichiometrically operating engine and emission control system will have a Q near zero, whereas Q greater than zero indicates operation on the fuel-rich side of stoichiometry. By using our knowledge of combustion chemistry, we can determine many parameters of the engine/emissions control system, including the instantaneous air/fuel ratio, grams of CO emitted per gallon of gasoline burned and the volume percent CO which would be read by a tailpipe probe (if the probe readings are corrected for the presence of water and excess air in the emissions). CO concentrations measured by the FEAT are most frequently reported as volume percent CO, since vehicle owners and mechanics are familiar with the tailpipe probe readings carried out in conventional I/M programs.

We performed quality assurance calibrations each day with three certified $CO/CO_2/N_2$ gas mixtures (Linde, Denver, Colorado and Scientific Gas Products, Longmont, Colorado), with CO/CO_2 ratios of 1:12.1, 1:1, and 4.96:1. These values correspond to a low CO-emitting car (~1.3 percent CO), a high-emitting car (8.5 percent CO), and a super-emitting car (17 percent CO). The FEAT responses were fitted to a straight line, the slope of which was used to correct the vehicle exhaust measurements. The correction applied to observed CO/CO_2 ratios was less than ten percent each day.

We recorded images of the front license plates of all the vehicles using a freeze-frame video system incorporated into the FEAT. We used the license plate information to determine make and model year of the vehicles in later analyses and verified the data by visual inspection of the video tape vehicle images.

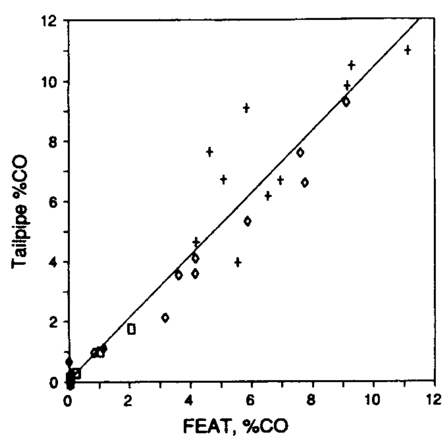

Figure 1. Comparison of tailpipe CO concentrations measured by an on-board analyzer and by remote sensing. □: data of 12/8/89 (n = 6); +: data of 12/11/89 (n = 14); ◇: data of 12/13/89 (n = 14). The equation of the regression line is [Tailpipe %CO] = 1.03[FEAT %CO] + 0.08, with r = 0.97.

Vehicle Instrumentation

In order to assess the accuracy of the FEAT, we used a production model 1989 Pontiac SSE equipped with a 3.8 L "3800" engine with sequential, multiport fuel injection and a three-way catalyst. The Pontiac had been driven about 17,000 miles at the time of the study. We operated the vehicle on unleaded regular gasoline, purchased at local retail outlets.

As part of a larger system designed to measure CO, CO_2, and HC emissions while driving, we equipped the car with a nondispersive infrared (NDIR) analyzer (Horiba MEXA) that measured the CO concentration in the exhaust gas leaving the tailpipe. An Acro-400 datalogger from ACROSYSTEMS Corporation digitized the signal from the NDIR. The datalogger was connected via an RS232 interface to a Toshiba 3200 laptop computer, located on the front passenger seat of the vehicle. A battery bank and inverter, located in the trunk of the car, provided power for the instrumentation.

Recently manufactured GM vehicles are equipped with an "Assembly Line Diagnostic Link" (ALDL) over which vehicle operating parameters can be obtained from the engine control computer. Parameters such as vehicle speed and engine rpm were obtained from the engine control computer over the ALDL and fed into a second serial port of the laptop computer. A program written in Quickbasic controlled the merging of data from the datalogger and the engine control computer. Tables of data were displayed in real time as well as stored on the internal hard disk of the laptop computer.

The ALDL on the Pontiac was a bidirectional link, allowing messages from the laptop computer to change a limited number of parameters in the engine control computer algorithm. Of special usefulness to this study was the capability to cause the engine to run in an open-loop mode at a modified air/fuel ratio. By pressing special function keys on the laptop computer keyboard, we could change the air/fuel ratio and hence the concentration of CO in the exhaust gas of the Pontiac.

We calibrated the on-board NDIR analyzer daily by using CO-free nitrogen and known concentrations of CO in nitrogen. The ARB Mobile Source Division provided quality assurance analysis of the CO standards, and found that the gas concentrations were within 2.3 percent of the nominal cylinder values. We verified the linearity of the CO analyzer by multipoint calibration using a gas divider (Standard Technology, Inc., SGD-78) to dilute the standard gas. In order to compensate for small misadjustments of the on-board CO analyzer, we multiplied the indicated CO reading by the ratio of the expected response of the analyzer to the actual response of the analyzer to the standard gas. Because we used an ice trap to remove most of the water from the exhaust gas sample stream before analysis by the NDIR, the readings of the on-board CO analyzer were expected to correspond directly to the values measured by the FEAT, which are corrected for water in the exhaust.

Comparison of Remote Sensing and On-Board CO Measurements

In order to investigate the accuracy of the FEAT, we drove the Pontiac through the cross-roadway infrared beam on a surface street in the Lynwood area in Los Angeles on December 8 and 11, 1989. An in-car observer from ARB recorded the tailpipe CO concentration measured by the on-board CO analyzer as the car crossed the FEAT infrared beam.[a] The observer then would choose an air/fuel ratio for the next pass while the car was driven back to the starting point for the next pass. Neither the driver nor the FEAT operator knew beforehand what the tailpipe concentrations would be in this double-blind experiment. At the end of the six runs on December 8 and the 14 runs on December 11, the observer obtained the CO concentrations measured by the FEAT for comparison. On December 13 we obtained our most stable operating conditions: the vehicle was operated with cruise control in 14 runs on a freeway on-ramp in the Lynwood area. The December 13th runs were not performed in a strict double-blind mode, since the in-car observer was from the University of Denver research group. Vehicle speeds on the three days ranged from ~15 to 50 mph in these comparisons.

We corrected the FEAT and tailpipe results for each day's calibration factors, and show the values in Figure 1. By regressing the percent tailpipe CO aainst the FEAT percent CO, we obtained the equation:

$$[\text{Tailpipe \%CO}] = 1.03[\text{FEAT \%CO}] + 0.08$$

with a correlation coefficient equal to 0.97 for the sample of 34 data points. This correlation is demonstrated for CO values that ranged from zero to twelve percent on three separate days, illustrating the reproducibility and stability of the two measurement systems. The ratio of means (Tailpipe/FEAT) for all 34 values is 1.05; the ratio of means for values greater than one percent is 1.03 (n = 22). This data set confirms the accuracy of the FEAT in measuring instantaneous CO tailpipe values at different vehicle speeds.

Comparison of FEAT Measurements to Roadside Inspection Data

The ARB Mobile Source Division has the authority and equipment to conduct roadside inspections of in-use vehicle emission control systems. In these inspections, which are equivalent to the I/M test, tailpipe CO and HC and engine rpm measurements are made at slow and fast idle speeds and compared to pass/fail standards which vary depending upon the age and type of vehicle. A visual inspection is also performed to check for obvious tampering with the engine and emission control equipment.

[a] A problem arises because of unavoidable lags in the sample handling system and analyzer and the every two-second sampling rate of the data acquisition system. Constant speed, steady state conditions are desirable so that there is no possibility of ambiguity in matching the gas analyzed by the remote sensing beam with that analyzed on board. Much of the scatter in the data is due to the problem of choosing the right time at which to record the on-board measurement when concentrations are changing rapidly due to non-steady state engine operation. In order to compensate for the lags in the analytical system, the observer would read the concentration of CO in the exhaust from the computer display several seconds after the driver had signaled that the car had crossed the measuring beam.

We combined the ability of the FEAT to provide real-time CO measuremens with the roadside inspection to ask: 1) If the FEAT shows a car to be a low CO emitter, is that finding confirmed by the roadside inspection? 2) If the FEAT shows a car to be a high CO emitter, can the inspection give the reason (e.g., malfunction, deterioration, tampering, misfueling, cold start operation, etc.)?

The Measurement Site

With these questions in mind, we used the FEAT to identify a group of low and high CO-emitting vehicles on La Cienega Boulevard between Pacific Concourse and 120th Street in the Hawthorne area of Los Angeles on December 18 and 19, 1989. La Cienega Blvd. is a divided four-lane, north-south street. We installed the FEAT to monitor the inside lane of southbound La Cienega Blvd. Both southbound lanes remained open during the measurements. Los Angeles County personnel constructed a lane divider to create a small island (about one m wide) between the lanes of traffic within which the infrared source and a small generator could be safely located. We set up the detector unit, video camera, and the FEAT support vehicle within the center median. The site was on a flat section of highway, about 100 m north of a traffic light-controlled intersection. Because of this configuration, deceleration and light cruise were the most often-observed driving modes, with approximate speeds of 20 mph.

Fleet Characteristics at the Measurement Site

Traffic was relatively light during much of the day with 1587 FEAT measurements made between 0920 and 1725 hrs on December 18 and 1184 measurements made between 0830 and 1525 hrs on December 19. Of the total fleet passing by the FEAT on December 18 and 19, the emissions of 79 percent were measured. Twenty-one percent were not counted because they did not meet quality assurance criteria established for the FEAT measurements.[3] The overall mean FEAT percent CO values and standard error of the means were 1.42 ± 0.06 for the 18th and 1.13 ± 0.06 for the 19th. On the 19th, FEAT measurements showed that half the CO in on-road operation was emitted by the 7.8 percent of the vehicles with CO emissions greater than 4.6 percent, averaged on a gm CO per gallon of fuel burned basis. We show the distribution for the CO emissions in Figure 2a, combined for both days.

ARB Roadside Inspection

When a car passed the FEAT, we decided, based upon the CO reading, whether we wanted a roadside test performed on the vehicle. When we observed a candidate vehicle, we radioed the California Highway Patrol, who stopped that vehicle for an inspection. We obtained both a small sample of low CO-emitting cars (ten vehicles with a FEAT measurement of less than two percent CO) and a larger sample of higher CO-emitting vehicles (50 cars with a FEAT value greater than two percent CO, for better characterization of this portion of the vehicle fleet), as shown in Figure 2b. We obtained these samples to study the false positive and false negative rates of low/high FEAT measurements as predictors of passing/failing the roadside inspection. The prediction is a false positive if the FEAT value is high and the vehicle passes the test; it is a false negative if the FEAT value is low and the vehicle fails the test.

Because vehicles operating in a cold start mode could appear high to the FEAT, but normal in the roadside test, the ARB Mobile Source Division staff asked each driver how long and how many miles the vehicle was driven prior to the roadside check. We selected the 60 vehicles without regard to make and model year; the criteria for selection were the CO value measured by the FEAT and the readiness of the roadside inspection group to begin testing another vehicle. Twenty vehicles were sampled on December 18 and 40 vehicles were checked on December 19. These vehicles were not randomly chosen; therefore this small sample of vehicles is not representative of the vehicles passing the sampling point or any larger population of vehicles. Although the 60-car sample does not represent the entire fleet, the sample size is large enough for the purposes of this pilot study.

The 60-Vehicle Roadside Data Set

Table I summarizes the data obtained in the 60 vehicle set. We list the vehicles by model year, separated into three general classes according to emission control technologies. The 1980 and later model year vehicles are primarily three-way catalyst and oxygen sensor-equipped vehicles with closed loop control; the 1975–1979 model years are mostly oxidation catalyst equipped open-loop vehicles; and pre-1975 model years are pre-catalyst vehicles. In this small, non-random data set of 60 vehicles, 45 failed the ARB roadside inspection, with twelve of those 45 having emissions control systems that had been tampered with. The extreme case was a 1984 GMC pickup with a FEAT reading of 8.1 percent, which originally was a diesel vehicle. Its engine had been changed to a 350 CID gasoline engine with no emission components. Because the California Department of Motor Vehicle (DMV) records classify the GMC as a diesel vehicle, it was not subjected to the Smog Check. Another five vehicles' systems were diagnosed as nonconforming, which indicated a system problem which could not be confirmed as deliberately tampered with.

Ten vehicles were inspected which had FEAT CO levels of less than two percent, as shown in Figure 3. Eight of those cars passed the roadside inspection. Of the two vehicles that did not pass, one passed both the CO and HC tests, but failed

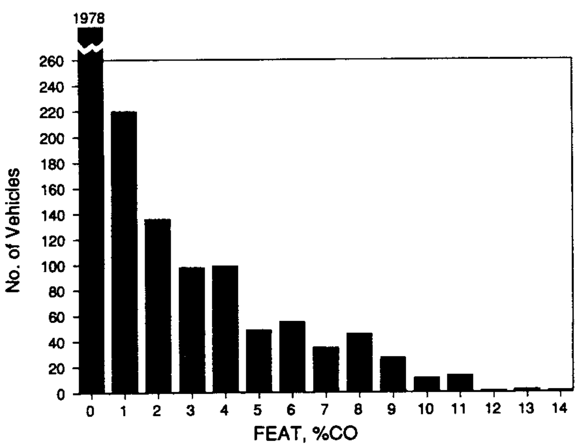

Figure 2a. Distribution of CO concentrations for 2771 vehicles measured with the FEAT on La Cienega Boulevard on December 18–19, 1989. Values in the 0% bar correspond to FEAT readings of 0 to 0.99%; the 1% bar corresponds to FEAT readings of 1.00 to 1.99%, etc.

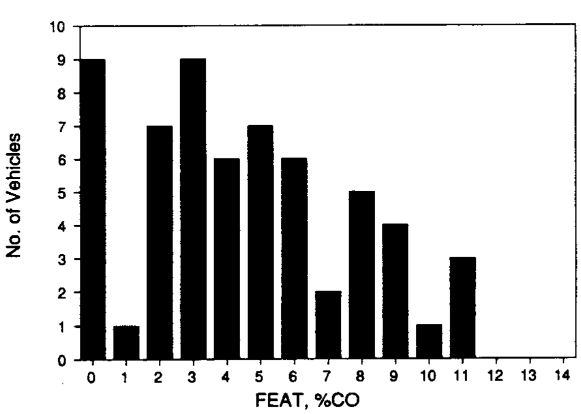

Figure 2b. Distribution of CO concentrations for only the 60 vehicles subjected to the roadside inspection.

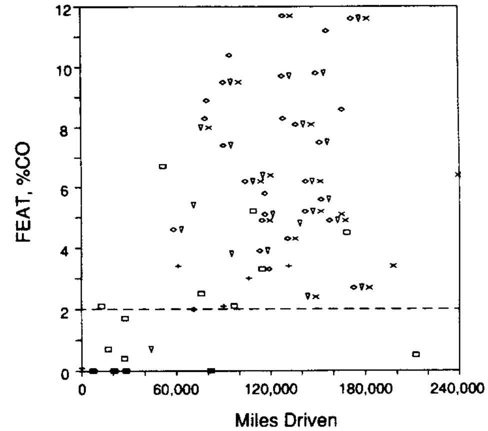

Figure 3. Comparison of the reasons for failure in the roadside inspection to the CO concentration measured by the FEAT, plotted against odometer readings. The coding for the points is: □: Pass; +: Fail, idle only; ◊: Fail, CO; ∇: Fail, HC; and ×: Fail, tampering. the dashed line at 2% CO shows that below 2%, the majority of the vehicles pass the test, whereas above 2% and 80,000 miles driven, the majority fail.

the idle speed requirement (1099 rpm measured vs. 1000 rpm standard). The other vehicle failed the idle HC test (147 ppm vs. 100 ppm standard). Its CO levels were about one-fourth the standard. The FEAT CO measurement with an arbitrary two percent cutoff point had an 80% success rate at predicting pass/fail performance on the complete roadside inspection and a 100 percent success rate at predicting performance on the CO portion of the test. CO readings from the FEAT resulted in no false negatives for the CO portion of the Smog Check. Because of differing control technologies and more lenient standards for older vehicles, it is more difficult to assess the false positive rates for the FEAT CO measurements.

Fifty vehicles were inspected which had FEAT CO measurements greater than two percent. The 50 car subset with FEAT CO greater than two percent is roughly a ten percent sample of the highest emitting vehicles on the two sampling days. Forty-three of those vehicles failed the roadside test. Of the seven vehicles expected to have higher emissions, but which passed the test, it was likely that two were operating in a cold-start mode (two and three minutes' driving time) when the FEAT measurement was made. For an additional two vehicles, responses to the cold start survey questions were not obtained. It also is possible that momentary high CO emissions were present when the vehicles passed through the FEAT beam due to transient engine operating conditions. Every vehicle that had been tampered with had FEAT CO levels above two percent. The FEAT had an 86 percent success rate in identifying vehicles that failed the roadside inspection test.[b]

Having shown that the FEAT provides an accurate measure of CO concentrations being emitted by the vehicles, and also having shown that FEAT measurements with a criterion of two percent CO have a high success rate of predicting pass/fail performance on the roadside inspection, we now investigate the quantitative relationship between CO concentrations measured by the FEAT and by the roadside test. Our expectation is that real-world driving (cold start, accelerations and decelerations) would cause FEAT CO measurements to be higher than those measured on the roadside test. We illustrate the relationship between the CO concentration measured by the FEAT and the higher CO concentration measured in the low or high idle test in Figure 4. By comparing the spread of the data with the 1:1 correspondence line,

b Passing the Smog Check does not necessarily mean the vehicle is a low emitter. It only means the vehicle is performing as well as could be expected for its age and emission control system. For older vehicles, up to seven percent CO at idle is passing.

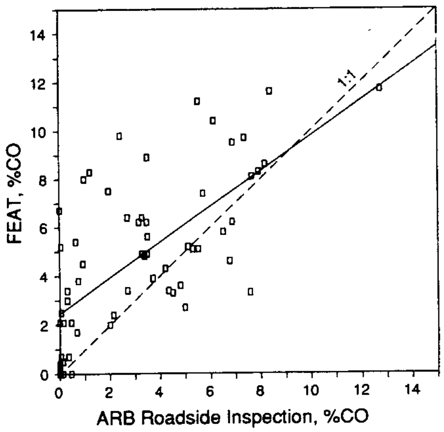

Figure 4. Comparison of the CO concentration from the moving car measured by the FEAT with the CO measured at idle during the roadside Smog Check. Most FEAT measurements are greater than the no-load idle measurements. The regression line corresponds to: [FEAT %CO] = 0.73[Roadside Idle %CO] + 2.51, with r = 0.67.

we see that the majority of the FEAT measurements are higher than the idle measurement, whereas very few are less. Figure 4 also includes the regression line:

$$[\text{FEAT \%CO}] = 0.73[\text{Roadside Idle \%CO}] + 2.51,$$

with the correlation coefficient r equal to 0.67. The regression model, which explains about 48 percent of the variance, is highly significant. Although the FEAT and idle test measurements were made with vehicles in different operating modes, the regression model indicates that, in general, cars that tend to be high emitters in the idle test are also high emitters in use. From Figure 4, we observe that there are several zero or near-zero roadside inspection values which correspond to high values from the FEAT. Apparently the FEAT is sampling emissions from higher-emitting operating modes than the no-load low idle test.

We also calculated the Spearman rank correlation coefficient r_s, which is a nonparametric measure of the association between two separate rankings—in this case, the rankings of the FEAT data and the ARB roadside inspection data. This correlation coefficient is less sensitive to outliers than the Pearson correlation coeficient r. Statistical inference for the Spearman correlation coefficient is not based on any distributional assumptions, whereas inference for the Pearson correlation coefficient is based on a commonly violated assumption that the two variables have a bivariate normal distribution. Testing the Spearman coefficient allows us to determine if, in general, higher FEAT values are significantly associated with higher ranking ARB roadside inspection values. The value of r_s is 0.66. If the null hypothesis of no association between the two rankings were true, a correlation this large would occur in less than 0.01 percent of the samples. We conclude that the hypothesis of no association between the rankings of FEAT data and Smog Check data is extremely improbable.

Factors Affecting CO Emissions

In previous studies[3–5] using remote sensing, statistical data on the tailpipe CO levels were obtained, but there was no opportunity to inquire as to potential causes of the high CO emissions. The availability of the roadside inspection data allows us to study the effect of mileage accumulation and vehicle age on CO emissions. We show four different approaches to examining the CO data in Figure 5. Figures 5a–d identify the vehicles that had been tampered with; many of the highest emitters are tampered with, but a number of those vehicles meet the standard. In Figure 5a we present the maximum CO measured on the low or high idle test (for 1980 and later model years, and the low idle value only for pre-1980 model years) as a function of odometer mileage. Apparently, CO emissions increase with mileage, as would be expected from a fleet in which the highest mileage vehicles have the least sophisticated emission controls. Figure 5b is an attempt to remove the effect of different types of emission control systems, thereby isolating the effects of mileage accumulation. The idle standard varies with the age and sophistication of the vehicle's emission control system. In Figure 5b, we show the maximum ratio of either the low or high idle CO measurement to the corresponding idle standard as a function of mileage. Based on this limited data set which is biased toward high emitters, in the 80,000 to 100,000 mi range, we see a transition from most vehicles meeting the standard to an increasing fraction of the vehicles exceeding the standard.

We present another view of these data in Figure 5c, where percent CO is plotted against model year, and in Figure 5d, where we plot the ratio of the measured CO to the CO standard against model year. Figure 5d shows that most of the cars newer than 1982 meet the idle I/M standards (see Table I for values), and that increasing numbers of older vehicles approach or slightly exceed the standard. This figure also shows a group of not-obviously tampered with vehicles in the 1978 to 1983 model years which exceed the standards by two to six times. Even though these vehicles exceed the idle standard by such a large factor, their absolute CO emissions are no higher than those from vehicles meeting the CO idle standard for 1975 and earlier model years. It is unknown whether these vehicles are high because of malfunction or undetected tampering. However, the majority of these vehicles are models likely to be driven by car enthusiasts (Camaro, Mustang, Cutlass, etc.).

Comparison of Roadside Inspection Data with Smog Check I/M Data

We used the license plate numbers of the 60 vehicles to gain access to the BAR Smog Check records to retrieve the results of the last Smog Check on each vehicle. We also obtained the vehicles' registration status from the DMV data base. This search showed that seven of the vehicles (twelve percent) were not currently registered, as compared with about six percent unregistered vehicles in an informal survey we conducted in the area.

With considerable assistance from DMV and BAR personnel, we were able to retrieve Smog Check data for 34 of the 60 vehicles in the set. These data are included in Table IIB, along with comments from the ARB roadside visual inspection conducted during this test (Table IA). Eight of the 60 vehicles were too new to have required an I/M check, and five vehicles (pre-1968 model years) were too old and exempt from the Smog Check program. Two other vehicles, the 1977 Ford 800 (a heavy duty gasoline vehicle) and the 1984 GMC, were also exempt from the I/M program. Therefore, we were able to obtain data on 34 out of 45 vehicles (76 percent) eligible for the I/M program. For five of the vehicles, we could find only data indicating that they had failed the Smog Check. However, because all of those five were current in their registration, they had received their Smog Check within the past two years. Only one of the 45 eligible vehicles (1980 Chevy Caprice) received an "FR" exemption, given when the repair cost limit was exceeded and emission standards were still violated. Although seven of the cars were not currently registered, two had passed the Smog Check. DMV records showed that the checks written for registration of those two cars apparently had bounced. At least 41 vehicles had passed the Smog Check within the last two years because they were currently registered or had received a Smog Check certificate.

We now compare the ARB roadside data with the most recent data for the 34 cars from the BAR Smog Check data set in Figure 6. This figure compares the low idle CO from

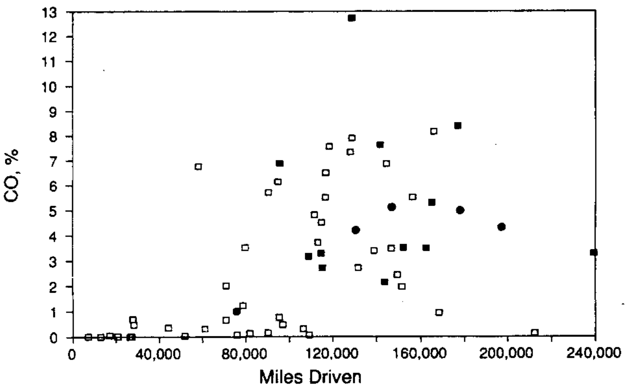

Figure 5a. The effect of mileage accumulation on idle CO concentration measured in the roadside inspection. Open squares represent vehicles that passed the visual inspection. Solid squares denote cars having emission control systems that had been tampered with; solid circles indicate nonconforming control systems (see text for explanation).

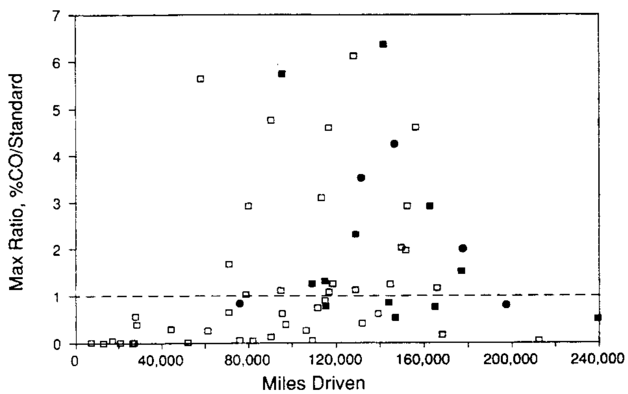

Figure 5b. The effect of mileage accumulation on the maximum ratio of the CO concentration measured in either the low idle or fast idle test to the CO standard for each vehicle.

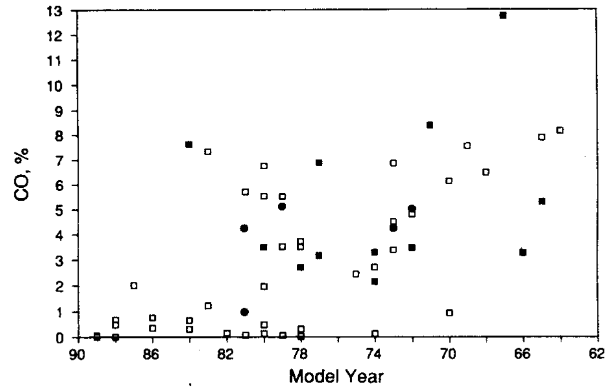

Figure 5c. The effect of model year on idle CO concentration measured in the roadside inspection.

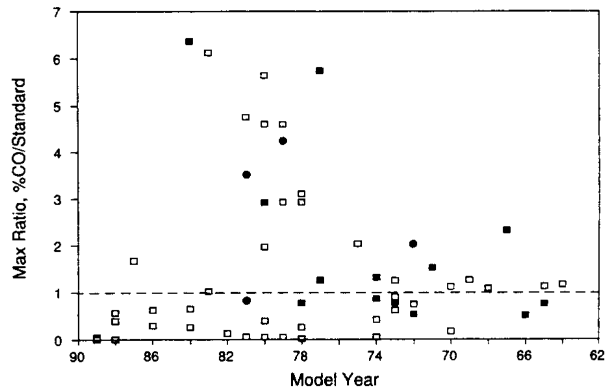

Figure 5d. The effect of model year on the maximum ratio of the CO concentration measured in either the low idle or fast idle test to the CO standard for each vehicle.

the two tests, and shows that for vehicles exceeding one percent (the low idle standard for many 1980 and later model years), 20 out of 23 vehicles showed higher current CO emissions than they had in the required, biennial I/M program. Moreover, as the figure shows, the number of months since the Smog Check was performed had little influence on how the cars performed on the roadside inspection. In fact, eight of the thirteen cars which received a Smog Check less than eleven months prior to the roadside check failed the emissions portion of the test. Five of nine cars failed the roadside inspection within six months after their regularly scheduled Smog Check. We also have labelled only the data points for which the vehicle was driven five minutes or less before ARB carried out the roadside inspection. Because the majority of these twenty cars had been driven five minutes or longer, they were not in a cold-start mode.

We carried out a similar comparison for the 34 vehicles on the low idle HC emissions. As shown in Figure 7, for the 24 vehicles exceeding the 150 ppm value (a typical low idle HC standard for early 1980 model years), 21 vehicles showed higher HC emissions in the roadside inspection than in the required Smog Check. Cars which had received the Smog Check in the six months before the roadside inspection did not seem to be any cleaner than those inspected earlier.

This comparison indicates that high CO-emitting cars identified by the FEAT are significantly higher emitters of CO and HC when measured on the road than when measured during the previously scheduled Smog Check. Possible reasons incude mechanical adjustments, illegal or improper Smog Checks, tampering with emissions control equipment and deterioration of the vehicles after the regularly scheduled Smog Check. The presence of so many cars that had been tampered with in our set of 60 vehicles suggests that either the required I/M test is not identifying tampering properly or that an appreciable fraction of the high CO-emitting cars have been tampered with after passing the Smog Check. According to studies in Arizona[6] a common practice is mechanical adjustment of vehicles to "pass the test" followed by immediate mechanical return to the normal operating mode.

Conclusions

By providing independent quality assurance and by utilizing on-board exhaust CO measurements from a specially equipped vehicle, we have show in blind and double-blind tests that remote sensing by the FEAT can measure on-road CO emissions with an accuracy of ±10 percent. We also have demonstrated that the FEAT can be used as an effective surveillance tool to identify high CO-emitting vehicles.

Our data show that for the 2771 vehicles measured by remote sensing on La Cienega Blvd., ten percent of the fleet (FEAT CO values greater than four percent) was responsible for about 55 percent of the total CO emissions, averaged on a gm CO per gallon of fuel burned basis (Figure 2a). The CO measurements made by the FEAT at this location show that the fleet characteristics are similar to those from other parts of the country.

In this pilot study, where we examined a small and intentionally biased set of 60 vehicles, we observed that for the high CO-emitting vehicles (by either the instantaneous FEAT measurement or the low or high idle value), nearly all of the eligible vehicles had passed the required biennial I/M test. However, most of the vehicles having FEAT CO readings greater than two percent failed the roadside inspection. For the cars emitting greater than one percent CO on the

Table I. Description of the vehicles in the 60 car data set, the remote-sensing CO values, and the ARB roadside inspection results. An underscored value denotes an exceedance of the standard in the roadside inspection.

Model Year	Make	Model	Odometer (miles)	Travel time	Distance traveled (miles)	University of Denver FEAT % CO	Visual inspection	ARB Roadside Inspection (measurement/standard): RPM	Low idle CO (%)	Low idle HC (ppm)	High idle CO (%)	High idle HC (ppm)	Pass/fail
89	Honda	Civic	27,216	15 min	10	0.4	Pass	/1000	0.01/1.0	20/100	—	—	P
89	Plymouth	Reliant	16,983	5 min		0.7	Pass	858/1000	0.05/1.0	2/100	0.04/1.2	1/220	P
89	Toyota	Camry	7,121	30 min	20	0.0	Pass	689/1000	0.01/1.0	11/100	0/1.2	10/220	P
89	Toyota	Corolla	12,942	5 min	2	2.1	Pass	805/1000	0/1.0	15/100	0/1.2	10/220	P
88	Honda	Accord	26,381	5 min	3	0.1	Pass	<u>1099</u>/1000	0/1.0	16/100	0/1.2	21/220	F
88	Honda	Civic	28,215	8 min	2	0.0	Pass	794/1000	0.01/1.0	5/100	0.47/1.2	29/220	P
88	Honda	Civic	27,726	20 min		1.7	Pass	780/1000	0.02/1.0	0/100	0.68/1.2	6/220	P
88	Mazda	626	20,677	3 min	2 blks	0.0	Pass	789/1000	0/1.0	19/100	0.01/1.2	16/220	P
87	Hyundai	Excel	71,039	4 hr	>20	2.0	?	/1000	0.03/1.0	5/100	<u>2.01</u>/1.2	45/220	F
86	Chevrolet	Sprint	95,350	25 min		3.8	Pass	<u>1233</u>/1000	0.04/1.0	38/100	0.75/1.2	<u>340</u>/220	F
86	Toyota	MR-2	44,210	5 min		0.7	Pass	936/1000	0.28/1.0	<u>147</u>/100	0.35/1.2	82/220	F
84	GMC	1500	141,565	8 min		8.1	Tamp	930/1000	<u>6.98</u>/2.5	<u>864</u>/150	<u>7.64</u>/1.2	<u>396</u>/220	F
84	Renault	Alliance	70,954	10 min	10	5.4	Pass	808/1000	0.65/1.0	<u>260</u>/100	0.60/1.2	184/220	F
84	Toyota	Pickup	61,211	5 min	1	3.4	Pass	<u>1002</u>/1000	0.03/1.0	28/100	0.31/1.2	43/220	F
83	Chevrolet	Camaro	127,934			9.7	Pass	719/1000	<u>2.43</u>/1.0	<u>202</u>/100	<u>7.35</u>/1.2	<u>233</u>/220	F
83	Dodge	Ram 50	78,780	all day		8.3	Pass	789/1000	0.02/1.0	27/100	<u>1.23</u>/1.2	62/220	F
82	Nissan	200SX	90,175	2 min	4 blks	2.1	Pass	<u>1033</u>/1000	0.13/1.0	57/100	0.15/1.2	37/220	F
81	Buick	Regal	130,963	30 min	6	4.3	Non	<u>1408</u>/1000	0.72/1.5	9/100	<u>4.22</u>/1.2	166/220	F
81	Chevrolet	Camaro	90,348	10 min	2	7.4	Pass	877/1000	<u>2.64</u>/1.0	<u>386</u>/100	<u>5.71</u>/1.2	108/220	F
81	Chevrolet	Malibu	75,956	6 min	2	2.5	Pass	689/1000	0.01/1.0	46/100	0.07/1.2	8/220	P
81	Dodge	Omni	76,306	3 min	3 blks	8.0	Non	890/1000	0.04/1.2	<u>439</u>/150	0.99/1.2	96/220	F
80	Chevrolet	Caprice	162,509	20 min	3	4.9	Tamp	/1000	0.30/2.5	72/150	<u>3.50</u>/1.2	<u>274</u>/220	F
80	Chevrolet	Monza	96,923			2.1	Pass	879/1000	0.07/1.2	78/150	0.47/1.2	75/220	P
80	Datsun	510	156,222			11.2	Pass	<u>1267</u>/1000	0.08/2.5	44/150	<u>5.53</u>/1.2	118/220	F
80	Dodge	200 Van	81,865	25 min		0.0	Pass	778/1000	0.13/2.5	0/150	0.02/1.2	1/220	P
80	Mercury	Capri	58,182	5 min	1	4.6	Pass	<u>1112</u>/1000	<u>5.64</u>/1.2	<u>314</u>/150	<u>6.77</u>/1.2	192/220	F
80	Olds	Cutlass	151,565	7 min	2	7.5	Pass	994/1000	<u>1.97</u>/1.0	<u>103</u>/100	<u>1.78</u>/1.2	47/220	F
79	Buick	Century Wgn	147,087	20 min	8	5.2	Non	931/1100	<u>5.12</u>/1.2	<u>1918</u>/150	0.40	1386	F
79	Ford	Mustang	109,105	10 min	5	5.2	Pass	997/1100	0.06/1.2	109/150	0.95	235	P
79	Ford	Mustang	116,458	5 min	2	5.1	Pass	971/1100	<u>5.52</u>/1.2	<u>217</u>/150	6.22	197	F
79	Olds	Cutlass	79,945	15 min	4	8.9	Pass	<u>1255</u>/1100	<u>3.51</u>/1.2	89/150	2.23	51	F
78	Chevrolet	Malibu	152,195			5.6	Pass	<u>1170</u>/1100	<u>3.51</u>/1.2	<u>1017</u>/150	1.23	333	F
78	Dodge	Omni	106,245	15 min	2	3.0	Pass	<u>2286</u>/1100	0.31/1.2	34/150			F
78	Ford	Mustang	113,205	15 min	5	3.9	Pass	1098/1100	<u>3.72</u>/1.2	<u>155</u>/150	4.13	206	F
78	Ford	T-Bird	51,916			6.7	Pass	818/1100	0.02/1.2	149/150	0.10	634	P
78	Olds	Omega	115,294	35 min	12	6.4	Tamp	779/1100	2.71/3.5	<u>1733</u>/250	0.22	676	F
77	AMC	Hornet	95,416	25 min	10	9.5	Tamp	601/1100	<u>6.89</u>/1.2	<u>641</u>/150	4.05	234	F
76	Ford	800	108,900	15 min	5	6.2	Tamp	1063/1100	<u>3.73</u>/2.5	<u>284</u>/220	1.54	26	F
	(Dual exhaust)							1065/1100	<u>2.59</u>/2.5	<u>1244</u>/220	0.66	42	
75	Chevrolet	10	149,497	3 min	1	9.8	Pass	557/1100	<u>2.44</u>/1.2	<u>455</u>/150	0.06	23	F
74	Chevrolet	Malibu	212,275	8 min	2	0.5	Pass	1021/1100	0.13/2.5	53/300	0.09	14	P
74	Chevrolet	Nova	143,816	20 min	8	2.4	Tamp	766/1100	2.27/2.5	<u>1378</u>/300	0.49	>2000	F
	(Dual exhaust)								2.04/2.5	96/300	0.20	126	
74	Ford	Mustang	114,611	5 min	1	4.9	Tamp	943/1100	<u>3.29</u>/2.5	172/300	1.07	85	F
74	Honda	Civic	131,720	5 min	1	3.4	Pass	<u>1263</u>/1100	2.71/6.5	193/350	0.52	73	F
73	Chevrolet	Nova	197,781	2 min	1	3.4	Non	911/1100	4.34/5.5	219/400	5.45	408	F
73	Ford	Courier	114,728	5 hr		3.3	Pass	987/1100	4.51/5.0	314/350	3.93	175	P
73	Olds	Cutlass	144,423	10 min	5	6.2	Pass	543/1100	<u>6.87</u>/5.5	281/400	3.12	103	F
73	Plymouth	Roadrnnr.	138,880	10 min	2	4.8	Pass	957/1100	3.39/5.5	<u>572</u>/400	1.32	58	F
72	Datsun	B510	146,856	5 hr	300	6.2	Tamp	914/1100	3.48/6.5	<u>439</u>/350	4.43	211	F
72	GMC	Vandura	177,867			2.7	Non	/1100	<u>4.99</u>/2.5	<u>1664</u>/300			F
72	VW	Bug	111,435	10 min	2	3.6	Pass	<u>1627</u>/1100	4.82/6.5	174/350	4.18	132	F
70	Ford	Maverick	176,843	15 min	5	11.6	Tamp	1037/1100	<u>8.39</u>/5.5	<u>1620</u>/400			F
70	Ford	Van	94,640	15 min		10.4	?	/1100	<u>6.15</u>/5.5	275/500			F
70	Plymouth	Valiant	168,315	50 min	40	4.5	Pass	811/1100	0.94/5.5	98/500	0.94	55	P
69	VW	Sq. back	118,215	3 min	1	3.3	Pass	<u>1114</u>/1100	<u>7.57</u>/6.0	423/700	8.92	467	F
68	VW	Bug	116,559			5.8	Pass	986/1100	<u>6.51</u>/6.0	643/700	5.42	340	F
67	Ford	Mustang	128,685			11.7	Tamp	653/1100	<u>12.74</u>/5.5	452/500			F
66	VW	Bug	239,338	5 min	5	6.4	Tamp	<u>1226</u>/1100	3.29/6.5	1059/1200	3.27	1065	F
65	Ford	Mustang	164,977	20 min	12	5.1	Tamp	957/1100	5.31/7.0	314/800	3.73	>2000	F
65	Ford	Mustang	128,565	10 min	2	8.3	Pass	912/1100	<u>7.91</u>/7.0	289/800			F
64	Ford	Falcon	165,810	10 min	5	8.6	Pass	<u>1217</u>/1100	<u>8.17</u>/7.0	329/800	3.49	143	F

Table IIA. Comments from the ARB roadside inspection.

Model year	Make	Model	Comments from roadside visual inspection
89	Honda	Civic	
89	Plymouth	Reliant	
89	Toyota	Camry	
89	Toyota	Corolla	
88	Honda	Accord	
88	Honda	Civic	
88	Honda	Civic	
88	Mazda	626	
87	Hyundai	Excel	Wrecked; hood could not be opened.
86	Chevrolet	Sprint	
86	Toyota	MR-2	
84	GMC	1500	Engine change from 6.2 L diesel to 350 CID gas; all emission components missing.
84	Renault	Alliance	
84	Toyota	Pickup	
83	Chevrolet	Camaro	
83	Dodge	Ram 50	
82	Nissan	200SX	
81	Buick	Regal	Fuel cap missing.
81	Chevrolet	Camaro	
81	Chevrolet	Malibu	
81	Dodge	Omni	Air injection—belt missing; temp. contr. air cleaner—hot air tube missing.
80	Chevrolet	Caprice	Engine change; air injection, EGR and ox. cat. removed; evap. control—hoses plugged; PCV—breather missing.
80	Chevrolet	Monza	
80	Datsun	510	
80	Dodge	200 Van	
80	Mercury	Capri	
80	Olds	Cutlass	Engine change; current engine has only 20,000 miles on it.
79	Buick	Century Wgn	Temp. contr. air cleaner—hot air tube missing.
79	Ford	Mustang	
79	Ford	Mustang	
79	Olds	Cutlass	
78	Chevrolet	Malibu	
78	Dodge	Omni	Idle excessive; no 2500 rpm test.
78	Ford	Mustang	
78	Ford	T-Bird	
78	Olds	Omega	Temp. contr. air cleaner—hot air tube missing; fuel restrictor—gouged out.
77	AMC	Hornet	Air Cleaner removed; TCAC/PCV removed; catalyst removed; air guard system removed; broken exhaust manifold.
77	Ford (Dual exhaust)	800	Air injection, EGR hoses, and air cleaner heat stove/hot air tube removed; Purge hose dangling.
75	Chevrolet	10	
74	Chevrolet	Malibu	
74	Chevrolet (Dual exhaust)	Nova	Temp. contr. air cleaner—heat stove/hot air tube removed.
74	Ford	Mustang	PCV-breather hose missing; temp. contr. air cleaner—vac. hoses removed; heat stove removed.
74	Honda	Civic	
73	Chevrolet	Nova	Air injection—belt missing.
73	Ford	Courier	
73	Olds	Cutlass	EGR—inoperative.
73	Plymouth	Roadrunner	
72	Datsun	B510	Temp. contr. air cleaner—removed; Non OEM carburetor.
72	GMC	Vandura	Temp. contr. air cleaner—hot air tube missing.
72	VW	Bug	
71	Ford	Maverick	Temp. contr. air cleaner removed.
70	Ford	Van	Small hood opening; parts inaccessible.
70	Plymouth	Valiant	
69	VW	Squareback	
68	VW	Bug	
67	Ford	Mustang	Air injection—removed; temp. contr. air cleaner—heat stove removed. (Idle only—belt almost coming off.)
66	VW	Bug	Distributor advance vac. system—009 race distributor; carb. throttle positioner removed.
65	Ford	Mustang	Temp. contr. air cleaner and PCV breather missing.
65	Ford	Mustang	Low idle only—coolant leak.
64	Ford	Falcon	

Table IIB. Previous measurements from the required biennial Smog Check program and comments from the biennial Smog Check records. Vehicles from 1988 and newer model years and 1967 and older model years were exempt from the program.

				Bureau of Automotive Repair Biennial Smog Check Data						
				Last		Low idle		High idle		
Model year	Make	Model	Regis. status	test mo/yr	Pass/ fail	CO (%)	HC (ppm)	CO (%)	HC (ppm)	Comments & reasons for failure
89	Honda	Civic								
89	Plymouth	Reliant								
89	Toyota	Camry								
89	Toyota	Corolla								
88	Honda	Accord								
88	Honda	Civic								
88	Honda	Civic	EXPIRED							
88	Mazda	626								
87	Hyundai	Excel		8/89	P	0.05	17	0.36	148	
86	Chevrolet	Sprint								
86	Toyota	MR-2		10/88	F	0.53	212	0.58	97	Low RPM HC
84	GMC	1500		EXEMPT—Originally had diesel engine; changed to gasoline engine						
84	Renault	Alliance		1/87	P	0.01	79	0.10	100	
84	Toyota	Pickup	EXPIRED							
83	Chevrolet	Camaro	EXPIRED							
83	Dodge	Ram 50								DMV says it's an '86 model
82	Nissan	200SX		6/88	P	0.09	23	0.08	15	
81	Buick	Regal		1/89	F	1.63	66	>10.0	607	Low & high RPM CO; high RPM HC
81	Chevrolet	Camaro		2/88	P	0.38	85	0.17	9	Recorded by Smog check test operator as a Honda
81	Chevrolet	Malibu		8/89	P	0.00	22	0.08	0	
81	Dodge	Omni		6/89	P	0.00	0	0.00	0	Recorded by Smog check test operator as '82 model
80	Chevrolet	Caprice		8/88	FR	0.58	226	0.66	57	2nd try; low RPM HC
80	Chevrolet	Monza								
80	Datsun	510								
80	Dodge	200 Van		9/88	P	0.00	11	0.00	9	
80	Mercury	Capri		10/89	P	0.02	19	0.07	19	
80	Olds	Cutlass								
79	Buick	Cent. Wgn.	EXPIRED	11/89	P	0.15	37	0.09	59	
79	Ford	Mustang		7/89	P	0.01	35	0.01	71	2nd try
79	Ford	Mustang		12/88	P	0.00	25	0.00	98	2nd try
79	Olds	Cutlass		4/88	P	0.68	68	0.05	36	
78	Chevrolet	Malibu		4/88	P	0.00	30	0.03	67	
78	Dodge	Omni		5/87	P	0.07	33	1.53	73	
78	Ford	Mustang		8/88	P	0.85	113	1.85	121	
78	Ford	T-Bird		1/89	F	0.01	15	0.01	6	2nd try—EGR, Spark adv, others dismantled
78	Olds	Omega		8/88	P	0.09	37	0.06	22	
77	AMC	Hornet	EXPIRED	9/88	P	0.00	19	0.00	26	
77	Ford (Dual exhaust)	800		EXEMPT—Heavy Duty Gas Vehicle						ARB says it's a '77; DMV says it's a '76
75	Chevrolet	10		12/88	P	0.35	34	0.70	9	
74	Chevrolet	Malibu								
74	Chevrolet (Dual exhaust)	Nova								
74	Ford	Mustang	EXPIRED							
74	Honda	Civic		6/89	P	0.06	118	1.96	167	
73	Chevrolet	Nova		8/89	P	0.66	100	0.32	353	
73	Ford	Courier		11/88	P	1.96	244	3.30	84	
73	Olds	Cutlass		10/87	P	2.94	156	0.40	13	
73	Plymouth	Roadrunner		10/87	P	2.07	205	0.97	182	2nd try
72	Datsun	B510		4/88	P	4.36	265	0.85	124	2nd try
72	GMC	Vandura		11/88	P	0.04	57	0.04	175	
72	VW	Bug								
71	Ford	Maverick		1/88	P	1.75	202	1.62	120	ARB & BAR says it's a '71; DMV says it's a 70
70	Ford	Van		10/87	F	5.34	238	8.69	265	Air cleaner missing; low RPM CO
70	Plymouth	Valiant		3/89	P	1.41	97	0.61	44	2nd try
69	VW	Squareback		2/89	F	6.80	>2000	>10.0	1927	Low RPM CO & HC
68	VW	Bug		11/89	P	3.31	112	1.72	50	
67	Ford	Mustang								
66	VW	Bug								
65	Ford	Mustang	EXPIRED							
65	Ford	Mustang								
64	Ford	Falcon								

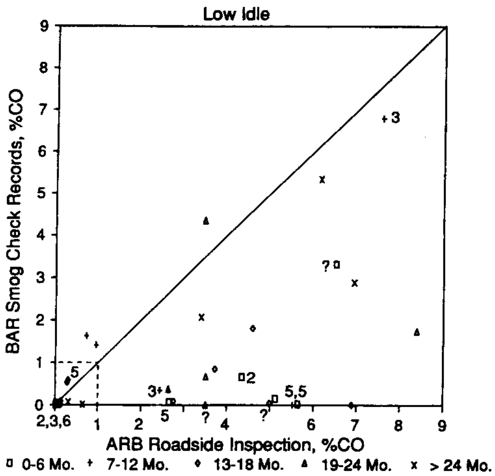

Figure 6. Comparison of the CO concentration at idle measured in the roadside inspection and in the routine biennial Smog Check. The points are coded to show the number of months since the biennial Smog Check. The number near the point is the number of minutes the vehicle had been driven before being inspected for only those cars driven 5 minutes or less. The dashed lines at 1.0% CO represent the low idle standard for several 1980 and later model years.

roadside inspection, 20 were emitting higher CO than when the required Smog Check took place: only three were not. We observed the same general features with the HC emissions in this data set. For the cars that had received their Smog Check less than six months prior to the roadside inspection, more than half the vehicles failed the emissions portion of the roadside test. These data show the need for understanding the reasons why these vehicles become high emitters in a relatively short time period following the Smog Check.

Acknowledgments

We gratefully acknowledge the support of the California Air Resources Board and General Motors Research Laboratories in conducting this work. Financial assistance was provided to the University of Denver through ARB contract A832-135. We also thank Tom Cackette and John R. Holmes of the ARB for their support and Bart Croes, Eric Fujita and John Moore of the ARB Research Division for their assistance in this analysis. We are grateful to the ARB Mobile Source Division for conducting the roadside inspections and the quality assurance for the study. We also thank the California Highway Patrol for their assistance in this project. We especially acknowledge the assistance of Phil Wilson of the BAR and Betty Stanfield of the DMV in helping us acquire vehicle inspection and registration data.

The statements and conclusions in this paper are not necessarily those of the California Air Resources Board. The mention of commercial products, their source or their use in connection with material reported is not to be construed as either an actual or implied endorsement of such products.

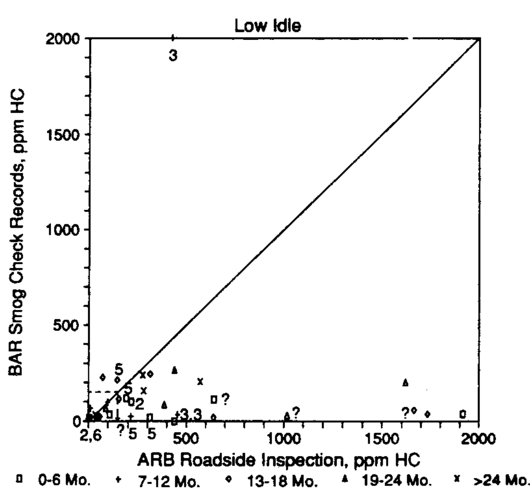

Figure 7. Similar to Figure 6, but for exhaust hydrocarbons. The dashed lines at 150 ppm HC represent the low idle standard for several 1980 and later model years.

References

1. California Health and Safety Code, Division 26, Part 1, Chapter 1, section 39002, 1990.
2. 1987 Emission Inventory, California Air Resources Board, Technical Support Division, 1990.
3. D. H. Stedman, G. A. Bishop, "An Analysis of On-Road Remote Sensing as a Tool for Automobile Emissions Control," final report to the Illinois Department of Energy and Natural Resources, ILENR/RE-AQ-90/05 (1990).
4. R. D. Stephens, S. H. Cadle, "Remote Sensing Measurements of Carbon Monoxide Emissions from On-Road Vehicles," General Motors Research Laboratories Publication GMR-7030, 1990.
5. G. A. Bishop, D. H. Stedman, "On-road carbon monoxide emission measurement comparisons for the 1988–1989 Colorado oxy-fuels program," *Environ. Sci. Technol.* **24:** 843 (1990).
6. G. A. Bishop, J. R. Starkey, A. Ihlenfeldt, W. J. Williams, D. H. Stedman, "IR long path photometry: a remote sensing tool for automobile emissions," *Anal. Chem.* **61:** 671A (1989).
7. Arizona Auditor General, "Performance Audit: Department of Environmental Quality, Vehicle Emissions Inspection and Maintenance Program," report to the Arizona Legislature, 1988.

Dr. Lawson is with the Research Division of the California Air Resources Board, P.O. Box 2815, Sacramento, California 95812. Dr. Groblicki is with the Environmental Science Department of General Motors Research Laboratories, Warren, Michigan 48090. Dr. Stedman is Brainerd Phillipson Professor of Chemistry, Dr. Bishop is Research Scientist, and Mr. Guenther is Graduate Research Assistant in the Department of Chemistry, University of Denver, Denver, Colorado 80208.

This paper was submitted for peer review on April 27, 1990. The revised manuscript was received June 18, 1990.