On-Road Remote Sensing of Automobile Emissions in the La Brea Area: Year 3, October 2003

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EXECUTIVE SUMMARY

The University of Denver conducted a five-day remote sensing study in the La Brea, California area in October of 2003. The remote sensor used in this study measures the ratios of CO, HC, and NO to CO_2 in motor vehicle exhaust. From these ratios, we calculate the percent concentrations of CO, CO_2, HC and NO in the exhaust that would be observed by a tailpipe probe, corrected for water and any excess oxygen not involved in combustion. Mass emissions per mass or volume of fuel can also be determined. The system used in this study was configured to determine the speed and acceleration of the vehicle, and was accompanied by a video system to record the license plate of the vehicle.

Five days of fieldwork, October 27-31, 2003, were conducted as vehicles entered I-10 eastbound frontage road from La Brea Blvd. in west Lost Angles basin. A database was compiled containing 25,847 records. Of these records, the State of California provided make and model year information on 20,191 which contained valid measurements for at least CO and CO_2, and most contained valid measurements for HC and NO as well. The database, as well as others compiled by the University of Denver, can be found at www.feat.biochem.du.edu.

The mean percent CO, HC, and NO were determined to be 0.34%, 0.012%, and 0.032%, respectively. The emissions measurements in this study exhibit a gamma distribution, with the dirtiest 10% of the measurements responsible for 72.2%, 60.3%, and 59.3% of the CO, HC, and NO emissions, respectively. The HC readings contain a 35 ppm offset, which has been used to reduce all of the measured HC values for comparisons.

Vehicle emissions as a function of vehicle specific power revealed that NO emissions show a flat dependence on specific power when speed and acceleration are measured after emissions. This is quite possibly a result of increased CO emissions in the same VSP range. HC emissions show a negative dependence on specific power – the expected trend. CO emissions show a positive dependence on specific power in the range from 5 to 30 kW/tonne.

Using vehicle specific power, the emissions from the vehicle fleet measured in 2003 were adjusted to match the vehicle driving patterns of the fleet measured in 1999. After doing so, it was seen that the emissions measured in the current year are lower than those measured during 1999. Model year adjustments gave equivocal results.

A new analysis looked at vehicle emission levels as a function of the type of transmission the vehicle uses. It suggests that when comparing emissions between E-23 sites one may need to consider transmission type in addition to age and vsp. Since, even after age adjustments are made, manual transmission equipped vehicles at La Brea had more than twice the average CO, 40% higher HC and 20% higher NO emissions.

An analysis of high emitting vehicles showed that there is considerable overlap of CO and HC high emitters, for instance 3.7% of the measurements contribute 36% of the total CO and 35% of the total HC. The noise levels in the CO, HC and NO measurement channels were determined to be within acceptable limits that were minimal when compared to the standard error of the mean of the measurements.

INTRODUCTION

Many cities in the United States are in violation of the air quality standards established by the Environmental Protection Agency (EPA). Carbon monoxide (CO) levels become elevated primarily due to direct emission of the gas, and ground-level ozone, a major component of urban smog, is produced by the photochemical reaction of nitrogen oxides (NO_x) and hydrocarbons (HC). As of 1998, on-road vehicles were estimated to be the single largest source for the major atmospheric pollutants, contributing 60% of the CO, 44% of the HC, and 31% of the NO_x to the national emission inventory.[1]

For a description of the internal combustion engine and causes of pollutants in the exhaust see Heywood.[2] Properly operating modern vehicles with three-way catalysts are capable of partially (or completely) converting engine-out CO, HC and NO emissions to carbon dioxide (CO_2), water and nitrogen.

Control measures to decrease mobile source emissions in non-attainment areas include inspection and maintenance (I/M) programs, reformulated and oxygenated fuel mandates, and transportation control measures, but the effectiveness of these measures remains questionable. Many areas remain in non-attainment, and with the new 8 hour ozone standards introduced by the EPA in 1997, many locations still violating the standard may have great difficulty reaching attainment.[3]

The remote sensor used in this study was developed at the University of Denver for measuring the pollutants in motor vehicle exhaust, and has previously been described in the literature.[4,5] The instrument consists of a non-dispersive infrared (NDIR) component for detecting CO, CO_2, and HC, and a dispersive ultraviolet (UV) spectrometer for measuring nitric oxide (NO). The source and detector units are positioned on opposite sides of the road in a bi-static arrangement. Colinear beams of infrared (IR) and UV light are passed across the roadway into the IR detection unit, and are then focused onto a dichroic beam splitter, which serves to separate the beams into their IR and UV components. The IR light is then passed onto a spinning polygon mirror, which spreads the light across the four infrared detectors: CO, CO_2, HC and reference.

The UV light is reflected off the surface of the beam splitter and is focused into the end of a quartz fiber-optic cable, which transmits the light to a UV spectrometer. The UV unit is then capable of quantifying NO by measuring an absorbance band at 226.5 nm in the UV spectrum and comparing it to a calibration spectrum in the same region.

The exhaust plume path length and density of the observed plume are highly variable from vehicle to vehicle, and are dependent upon, among other things, the height of the vehicle's exhaust pipe, wind, and turbulence behind the vehicle. For these reasons, the remote sensor only directly measures ratios of CO, HC or NO to CO_2. The ratios of CO, HC, or NO to CO_2, termed Q, Q' and Q'' respectively, are constant for a given exhaust plume, and on their own are useful parameters for describing a hydrocarbon combustion system. This study reports measured emissions as %CO, %HC and %NO in the exhaust gas, corrected for water and excess oxygen not used in combustion. The %HC measurement is a factor of two smaller than an equivalent measurement by a flame ionization detector (FID).[6] Thus, in order to calculate mass emissions as described below, the %HC values reported will first be multiplied by 2.0 as shown below, assuming that the fuel used is regular gasoline. These percent emissions can be directly converted into mass emissions by the equations shown below.

$$\text{gm CO/gallon} = 5506 \bullet \%\text{CO}/(15 + 0.285 \bullet \%\text{CO} + 2(2.87 \bullet \%\text{HC}))$$
$$\text{gm HC/gallon} = 2(8644 \bullet \%\text{HC})/(15 + 0.285 \bullet \%\text{CO} + 2(2.87 \bullet \%\text{HC}))$$
$$\text{gm NO/gallon} = 5900 \bullet \%\text{NO}/(15 + 0.285 \bullet \%\text{CO} + 2(2.87 \bullet \%\text{HC}))$$

These equations indicate that the relationship between concentrations of emissions to mass of emissions is linear, especially for CO and NO and at low concentrations for HC. Thus, the percent difference in emissions calculated from the concentrations of pollutants reported here is equivalent to a difference calculated from masses.

Another useful conversion is from percent emissions to grams pollutant per kilogram (g/kg) of fuel. This conversion is achieved directly by first converting the pollutant ratio readings to moles of pollutant per mole of carbon in the exhaust using the following equation:

$$\frac{\text{moles pollutant}}{\text{moles C}} = \frac{\text{pollutant}}{CO + CO_2 + 6HC} = \frac{(\text{pollutant}/CO_2)}{(CO/CO_2) + 1 + 6(HC/CO_2)} = \frac{(Q, 2Q', Q'')}{Q+1+6Q'}$$

Next, moles of pollutant are converted to grams by multiplying by molecular weight (e.g., 44 g/mole for HC since propane is measured), and the moles of carbon in the exhaust are converted to kilograms by multiplying (the denominator) by 0.014 kg of fuel per mole of carbon in fuel, assuming gasoline is stoichiometrically CH_2. Again, the HC/CO_2 ratio must use two times the reported HC (as above) because the equation depends upon carbon mass balance and the NDIR HC reading is about half a total carbon FID reading.[6]

$$\text{gm CO/kg} = (28Q/(1 + Q + 6Q'))/0.014$$
$$\text{gm HC/kg} = (2(44Q')/(1 + Q + 6Q'))/0.014$$
$$\text{gm NO/kg} = (30Q''/(1 + Q + 6Q'))/0.014$$

Quality assurance calibrations are performed twice daily in the field unless observed voltage readings or meteorological changes are judged to warrant additional calibrations. A puff of gas containing certified amounts of CO, CO_2, propane and NO is released into the instrument's path, and the measured ratios from the instrument are then compared to those certified by the cylinder manufacturer (Praxair). These calibrations account for day-to-day variations in instrument sensitivity and variations in ambient CO_2 levels caused by local sources, atmospheric pressure and instrument path length. Since propane is used to calibrate the instrument, all hydrocarbon measurements reported by the remote sensor are as propane equivalents.

Studies sponsored by the California Air Resources Board and General Motors Research Laboratories have shown that the remote sensor is capable of CO measurements that are correct to within ±5% of the values reported by an on-board gas analyzer, and within ±15% for HC.[7,8]

The NO channel used in this study has been extensively tested by the University of Denver, but we are still awaiting the opportunity to participate in an extensive blind study and instrument intercomparison to have it independently validated. Tests involving a late-model low-emitting vehicle indicate a detection limit (3σ) of 25 ppm for NO, with an error measurement of ±5% of the reading at higher concentrations. Appendix A gives a list of criteria for valid or invalid data.

The remote sensor is accompanied by a video system to record a freeze-frame image of the license plate of each vehicle measured. The emissions information for the vehicle, as well as a time and date stamp, are also recorded on the video image. The images are stored on videotape, so that license plate information may be incorporated into the emissions database during post-processing. A device to measure the speed and acceleration of vehicles driving past the remote sensor was also used in this study. The system consists of a pair of infrared emitters and detectors (Banner Industries) which generate a pair of infrared beams passing across the road, six feet apart and approximately two feet above the surface. Vehicle speed is calculated from the time that passes between the front of the vehicle blocking the first and the second beam. To measure vehicle acceleration, a second speed is determined from the time that passes between the rear of the vehicle unblocking the first and the second beam. From these two speeds, and the time difference between the two speed measurements, acceleration is calculated, and reported in mph/s. Appendix B defines the database format used for the data set.

The purpose of this report is to describe the remote sensing measurements made in the La Brea area in the fall of 2003, under CRC Contract No. E-23-4. Measurements were made on five consecutive weekdays, from Monday, October 27, to Friday, October 31, between the hours of 6:00 and 18:00 on the uphill ramp. This intersection is just west of the location where La Brea Blvd. passes under I-10. The instrument was located as far up the ramp as possible, the same location as was used during the IMRC measurements in 1999 and the E-23 measurements in 2001. A map of the measurement location is shown in Figure 1 and a photograph of the ramp is shown in Figure 2. The uphill grade at the measurement location is 2°. Appendix C gives temperature and humidity data for the 1999, 2001 and 2003 studies from Los Angeles International Airport, approximately ten miles southwest of the measurement site. This is the sixth year (3 years in Riverside, CA and 3 years in La Brea) of a study to characterize motor vehicle emissions and deterioration in the Los Angeles area.

RESULTS AND DISCUSSION

Following the five days of data collection in October of 2003, the videotapes were read for license plate identification. Plates that appeared to be in state and readable were sent to the State of California to have the vehicle make and model year determined. The resulting database contained 20,191 records with make and model year information and valid measurements for at least CO and CO_2. The database and all previous databases compiled for CRC E-23-4 campaigns can be found at www.feat.biochem.du.edu. Most of these records also contain valid measurements for HC and NO as well. The validity of the attempted measurements is summarized in Table 1. The table describes the data reduction process beginning with the

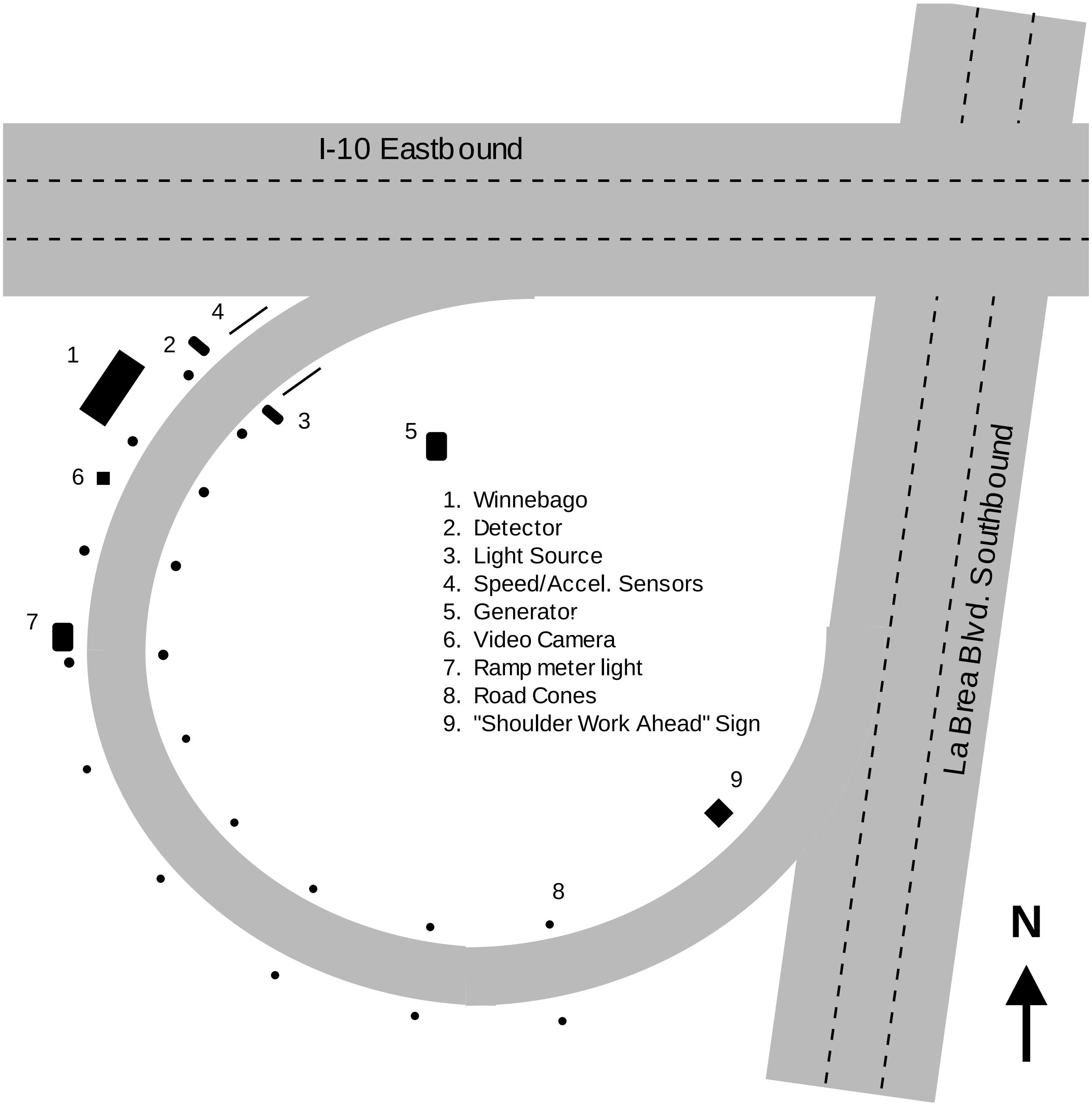

Figure 1. A schematic drawing of the on-ramp from southbound La Brea Blvd. to eastbound I-10. The location and safety equipment configuration was for all five days of measurements.

number of attempted measurements and ending with the number of records containing both valid emissions measurements and vehicle registration information. An attempted measurement is defined as a beam block followed by a half second of data collection. If the data collection period is interrupted by another beam block from a close following vehicle, the measurement attempt is aborted and an attempt is made at measuring the second vehicle. In this case, the beam block from the first vehicle is not recorded as an attempted measurement. Invalid measurement attempts arise when the vehicle plume is highly diluted, or the reported error in the ratio of the pollutant to CO_2 exceeds a preset limit (see Appendix A). The greatest loss of data in this process occurs during the plate reading process, when out-of-state vehicles and vehicles with unreadable plates (obscured, missing, dealer, out of camera field of view) are omitted from the database.

Figure 2. La Brea monitoring site with the measurement beam located at the end of the guardrail, to the right of the motor home. The vehicle stopped at the light is 84ft. from the measurement location.

Table 1. Validity Summary.

	CO	HC	NO
Attempted Measurements	25,847		
Valid Measurements	24,643	24,566	24,624
Percent of Attempts	95.3%	95.0%	95.3%
Submitted Plates	20,988	20,940	20,973
Percent of Attempts	81.2%	81.0%	81.1%
Percent of Valid Measurements	85.2%	85.2%	85.2%
Matched Plates	20,191	20,147	20,176
Percent of Attempts	78.1%	77.9%	78.1%
Percent of Valid Measurements	81.9%	82.0%	81.9%
Percent of Submitted Plates	96.2%	96.2%	96.2%

The percent validity of the 2003 measurements is similar to the validity seen in the previous two years, with approximately 78% of attempted measurements being valid and plate matched.

Table 2 provides an analysis of the number of vehicles that were measured repeatedly, and the number of times they were measured. Of the 20,191 records used in this fleet analysis, 11,783 (58.4%) were contributed by vehicles measured once, and the remaining 8,408 (41.6%) records were from vehicles measured at least twice. A look at the distribution of measurements for vehicles measured five or more times showed that low or negligible emitters had more normally distributed emission measurements, while higher emitters had more skewed distributions of measurement values. For example, of the 137 vehicles that had five or more valid CO measurements, twelve had mean %CO>1. The means varied from 1.06 to 7.64. These twelve vehicles' calculated variances in their measurements were 0.2, 2.2, 3.9, 4.3, 9.7, 3.6, 0.4, 3.9, 1.9, 6.7, 1.1 and 1.1, while the average variance in the measurements of the other 125 vehicles was 0.08. This observation is expected in view of the known large variability in the emissions of high emitting vehicles regardless of the emission testing method.[9]

Table 2. Number of measurements of repeat vehicles.

Number of Times Measured	Number of Vehicles
1	11,783
2	1,643
3	815
4	486
5	109
6	16
7	6
>7	6

Table 3 is the data summary; included are summaries of previous remote sensing databases collected by the University of Denver at the La Brea site. These other measurements were conducted in November of 1999 and 2001. Some of the values for the 1999 data have changed slightly since the last report due to the availability of a database where the HC and NO data have not been rounded to the nearest 100ppm value.

Mean fleet emissions are decreasing at the La Brea site in much the same manner as they are at the other E-23 sites. The mean model year in La Brea has kept pace with the measurement schedule. The percentage of emissions from the dirtiest 10% of the measurements increased again for the NO distribution but remained steady for CO and HC.

The average HC values here have been adjusted to remove an artificial offset in the measurements. This offset, restricted to the HC channel, has been reported in earlier CRC E-23-4 reports. Calculation of the offset is accomplished by computing the mode and means of the newest model year vehicles, and assuming that these vehicles emit negligible levels of hydrocarbons, using the lowest of either of these values as the offset. The offset adjustment subtracts this value from all of the hydrocarbon data. Since we assume the cleanest vehicles to emit little hydrocarbons, such an approximation will only err slightly towards clean because the

Table 3. Data summary.

Study Year	1999	2001	2003
Mean CO (%) (g/kg of fuel)	0.58 (70.3)	0.44 (56.2)	0.34 (42.4)
Median CO (%)	0.09	0.06	0.06
Percent of Total CO from Dirtiest 10% of the Fleet	67.4%	72.4%	72.2%
Mean HC (ppm)* (g/kg of fuel)* Offset (ppm)	195 (7.0) 60	125 (4.6) 21	121 (4.5) 35
Median HC (ppm)*	70	39	45
Percent of Total HC from Dirtiest 10% of the Fleet	57%	61.6%	60.3%
Mean NO (ppm) (g/kg of fuel)	477 (6.6)	411 (5.6)	323 (4.5)
Median NO (ppm)	116	72	48
Percent of Total NO from Dirtiest 10% of the Fleet	51.6%	54.9%	59.3%
Mean Model Year	1992.4	1994.4	1996.5
Mean Speed (mph)	17.6	18.3	17.0
Mean Acceleration (mph/s)	1.4	1.4	1.9
Mean VSP (kw/tonne) Slope (degrees)	9.0 2.0°	10.3 2.0°	11.6 2.0°
*Indicates values that have been HC offset adjusted as described in text.			

true offset will be a value somewhat less than the average of the cleanest model year and make. This adjustment facilitates comparisons with the other E-23 sites and/or different collection years for the same site. The offset subtraction (35ppm) has been performed where indicated in the analyses in this report, but has not been applied to the archived database.

Figure 3 shows the distribution of CO, HC and NO emissions by percent or ppm category from the data collected in La Brea in 2003. The black bars show the percentage of the fleet in a given emission category, and the shaded bars show the percentage of the total emissions contributed in that category. This figure illustrates the skewed nature of automobile emissions, showing that the lowest emission category is occupied by no less than 78% of the fleet (for HC) and as much as 92% of the fleet (for CO). The fact that the cleanest 92% of the fleet are responsible for only 32% of the CO emissions further demonstrates how the emissions picture can be dominated by a small number of high-emitting vehicles. The skewed distribution was also seen during the other years of the study in La Brea and is represented by the consistent high values of percent of total emissions from the dirtiest 10% of the fleet (see Table 3).

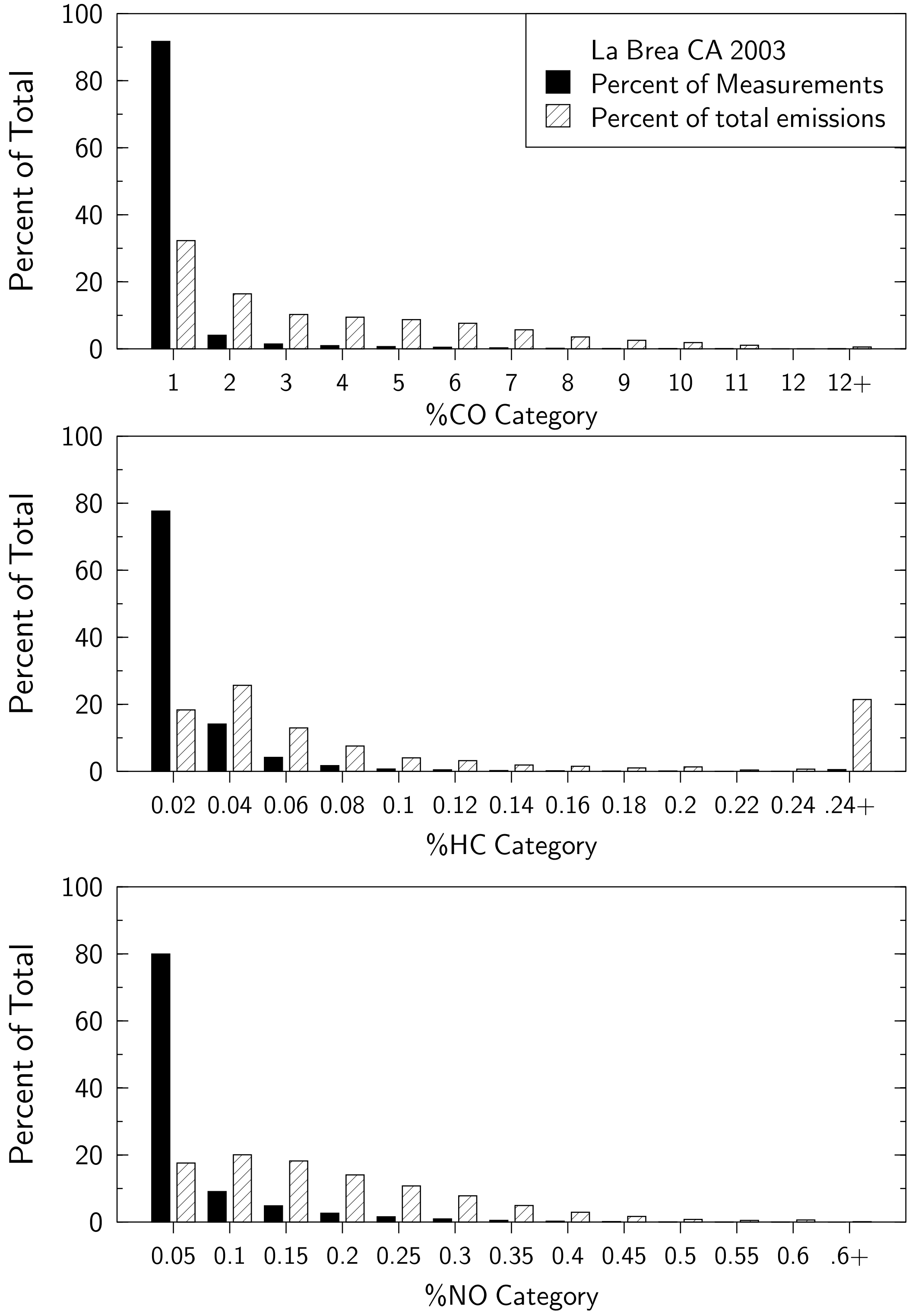

Figure 3. Emissions distribution showing the percentage of the measurements in a given emission category (black bars) and the percentage of the total emissions contributed by the category (shaded bars).

The inverse relationship between vehicle emissions and model year is shown in Figure 4, for data collected during each of the three years. The HC data have been offset adjusted here for comparison. Unlike the CO and HC plots NO emissions vs. model year rises for about fourteen years and then appears to level out in model years prior to 1989. This “leveling out” phenomenon has been observed previously,[5,10] and it has been proposed that the tendency for older vehicles to lose compression and operate under fuel-rich conditions negates the tendency for poor maintenance and catalyst deterioration to result in continually increasing NO emissions with age. Unlike data collected in Chicago from 1997-1999, the La Brea measurements do not show a pronounced tendency for the mean and median emissions to increase significantly for the newest model year.[11] The absence is most likely due to license plates remaining with the vehicle in California, as opposed to license plates moving with the owner, as is the case in Illinois.

As originally shown by Ashbaugh et al.,[12] vehicle emissions by model year, with each model year divided into emission quintiles, were plotted for data collected in 2003. This resulted in the plots shown in Figure 5. The bars represent the mean emissions for each quintile, and do not account for the number of vehicles in each model year. This figure illustrates that the cleanest 40% of the vehicles, regardless of model year, make an essentially negligible contribution to the total fleet emissions. The large accumulations of negative emissions in the first two quintiles are the result of ever decreasing emission levels. Our instrument is designed such that when measuring a true zero emission plume, half of the readings will be negative and half will be positive. As the lowest emitting segments of the fleets continue to dive toward zero emissions, the negative emission readings will continue to grow toward half of the measurements.

Figure 5 can also be used to get a picture of federal compliance standards. The on-road data are measured as mass emissions per kg of fuel. It is not possible to determine mass emissions per mile for each vehicle because the instantaneous gasoline consumption (kg/mile) is not known. An approximate comparison with the fleet average emissions shown in Figure 5 can, however, be carried out. To make this comparison, we assume a fuel density of 0.75 kg/L and an average gas mileage for all model years of 23mpg. The Tier 1, 100,000 mile standards for CO, HC, and NO are 4.2, 0.31, and 0.6 gm/mi, respectively. With the above assumptions, these correspond to 34, 2.5, and 4.9 gm/kg, respectively. Inspection of Figure 5 shows that significant fractions, especially of the newer vehicles, are measured with on-road emissions well below these standards.

An equation for determining the instantaneous power of an on-road vehicle has been proposed by Jimenez,[13] which takes the form

$$\mathrm{VSP} = 4.39\bullet\sin(slope)\bullet v + 0.22\bullet v\bullet a + 0.0954\bullet v + 0.0000272\bullet v^3$$

where VSP is the vehicle specific power in kW/metric tonne, *slope* is the slope of the roadway (in degrees), v is vehicle speed in mph, and a is vehicle acceleration in mph/s. Derived from dynamometer studies, and necessarily an approximation, the first term represents the work required to climb the gradient, the second term is the $f = ma$ work to accelerate the vehicle, the

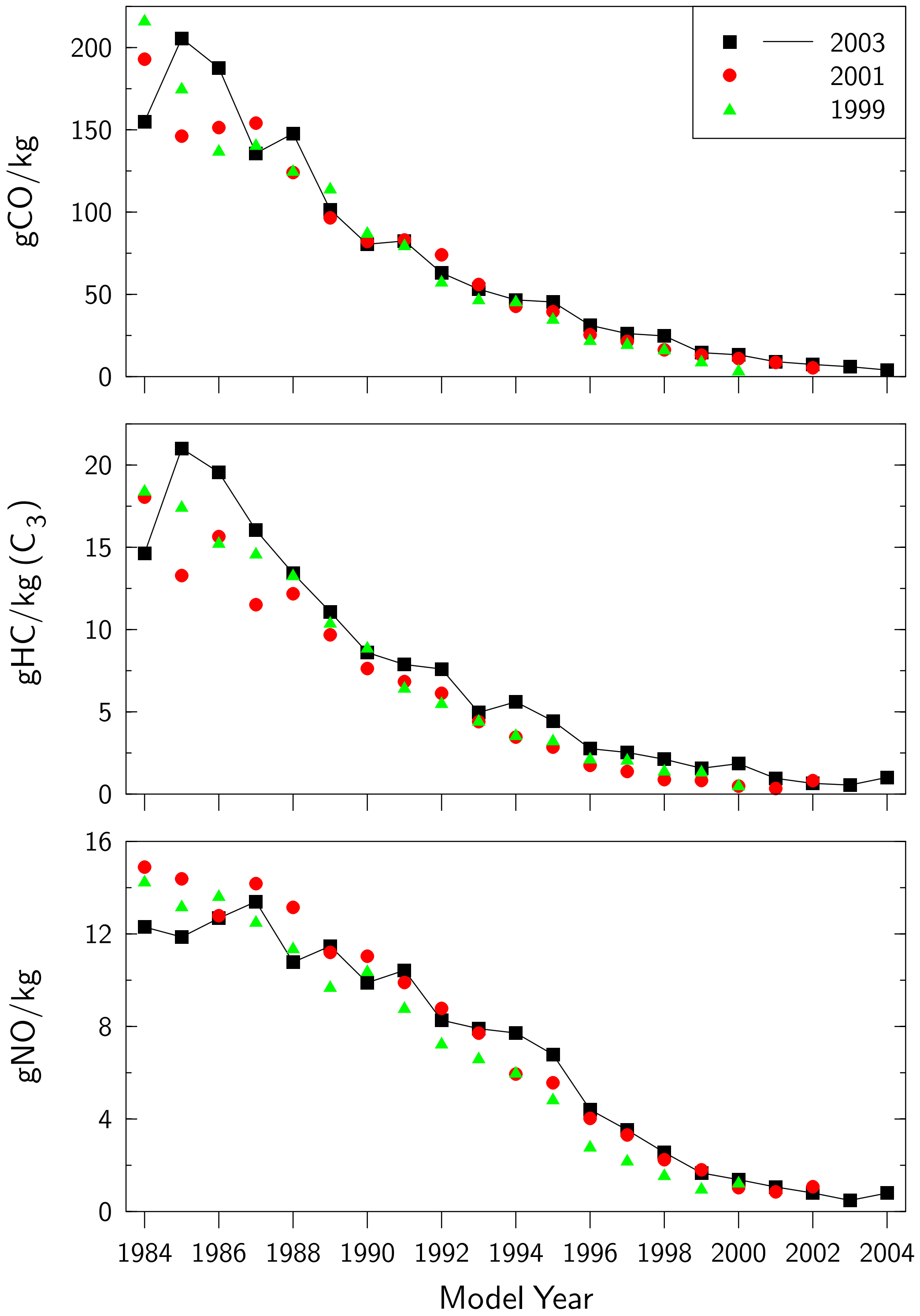

Figure 4. Mean vehicle emissions illustrated as a function of model year. HC data have been offset adjusted as described in the text.

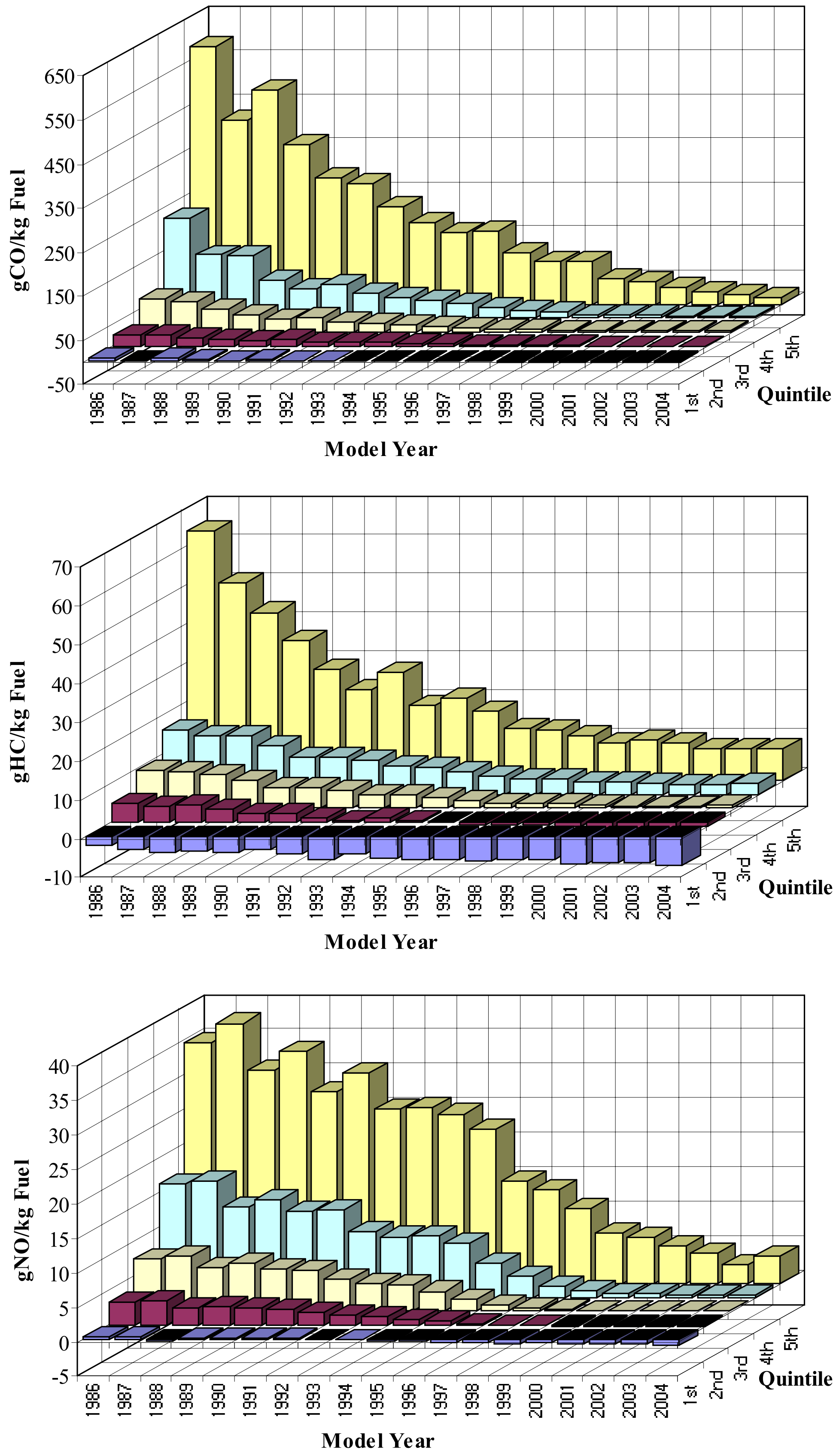

Figure 5. Vehicle emissions by model year, divided into quintiles.

third is an estimated friction term, and the fourth term represents aerodynamic resistance. Using this equation, VSP was calculated for all measurements in each of the four years' databases. This equation, in common with all dynamometer studies, does not include any load effects arising from road curvature. The emissions data were binned according to vehicle specific power, and illustrated in Figure 6. All of the specific power bins contain at least 100 measurements except for VSPs of 30 in 1999 and 2001 which contain 77 and 69 measurements, respectively. The HC data have been offset adjusted for this comparison.

CO emissions show a positive dependence on specific power and while the data are similar to the previous years, there is a noticeable downward trend in all three emissions. The HC emissions show a negative dependence on specific power and the NO shows little dependence on VSP at this site. The lack of VSP influence on NO may be a result of the fact that this is a traffic light controlled on ramp and the rising CO emissions with VSP (implying enrichment) blunts the NO emissions. The error bars included in the plot are standard errors of the mean calculated from the daily averages. These uncertainties were generated for these γ-distributed data sets by applying the central limit theorem. Each day's average emissions for a given VSP bin were assumed an independent measurement of the emissions at that VSP. Normal statistics were then applied to these daily averages.

Using VSP, it is possible to eliminate the influence of driving behavior from the mean vehicle emissions. Table 4 shows the mean emissions from all vehicles in the 1999, 2001 and 2003 databases with specific powers between –5 and 20 kw/tonne. Note that these emissions do not vary considerably from the mean emissions for the entire databases, as shown in Table 3. Also shown in Table 4 are the mean emissions for the 1999, 2001 and 2003 databases, adjusted for specific power to the 1999 VSP distribution.

This correction is accomplished by applying the mean vehicle emissions for each VSP bin (between –5 and 20 kw/tonne) from a certain year's measurements to the vehicle distribution, by specific power, for each bin from 1999. A sample calculation, for the specific power adjusted mean NO emissions, is shown in Appendix D.

Table 4. Vehicle specific power adjusted fleet emissions (-5 to 20 kw/tonne only) with standard error of the means calculated using daily averages.

	1999 measured (adjusted)	2001 measured (adjusted)	2003 measured (adjusted)
Mean gCO/kg	68.1 ± 2.1 (68.1 ± 2.1)	52.5 ± 2.5 (52.9 ± 2.6)	40.3 ± 1.0 (43.7 ± 1.0)
Mean gHC/kg[a]	9.1 ± 0.7 (6.7 ± 0.7)	5.2 ± 0.2 (4.5 ± 0.2)	5.7 ± 0.3 (4.9 ± 0.3)
Mean gNO/kg	6.4 ± 0.5 (6.4 ± 0.5)	5.6 ± 0.3 (5.5 ± 0.3)	4.3 ± 0.2 (4.2 ± 0.2)

[a] HC emissions are offset adjusted for all of the years' adjusted data.

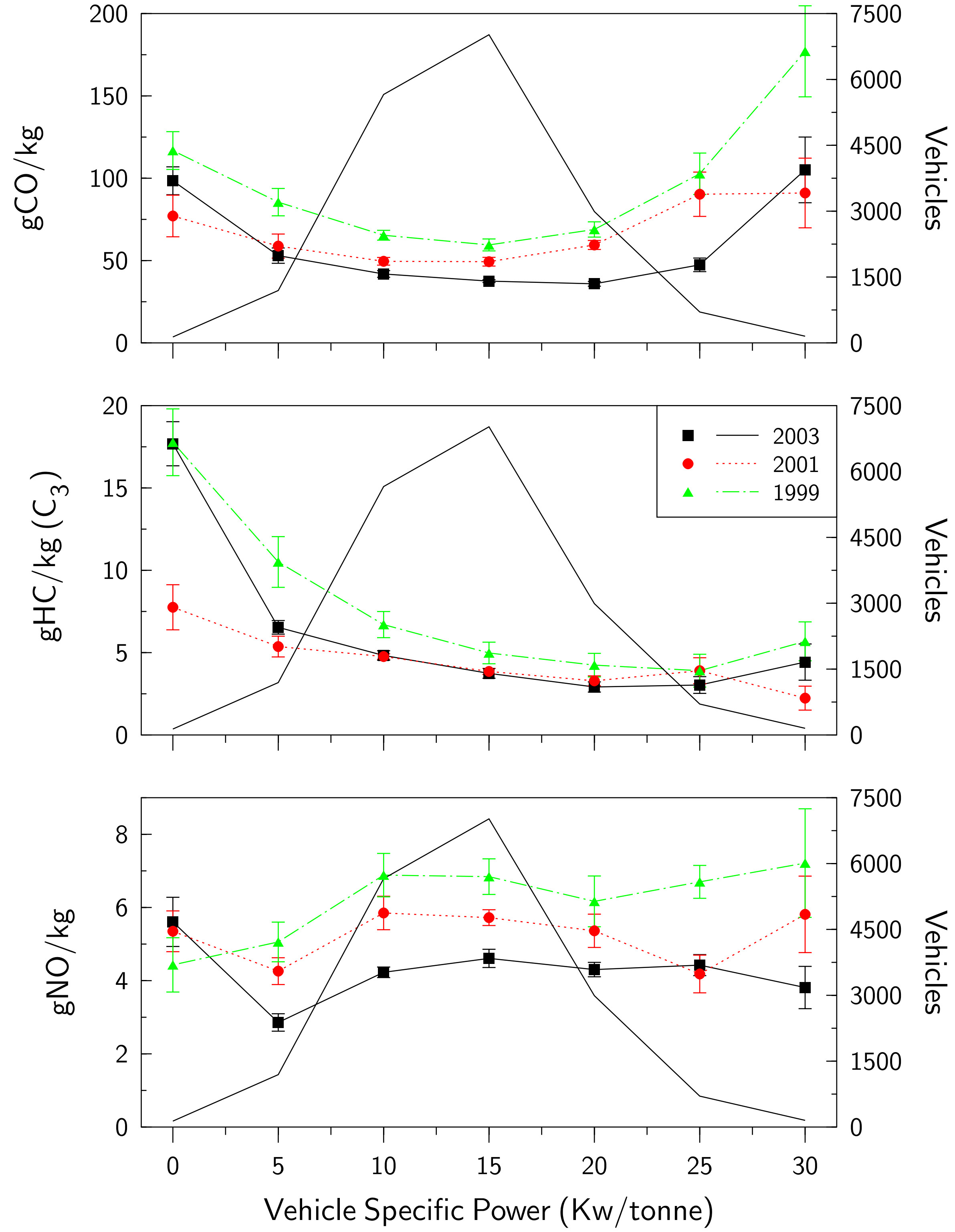

Figure 6. Vehicle emissions as a function of vehicle specific power for all of the La Brea E-23 data sets. Error bars are standard errors of the mean calculated from daily samples. The solid line without markers is the vehicle count profile for the 2003 data set.

In the case of CO and NO, the decrease in average emissions with time is more pronounced with these adjusted values. The HC emissions in 2003 show increased emissions at the low VSP levels (see Figure 6) raising the adjusted emissions. Because all VSP data are adjusted to the 1999 vehicle distribution by VSP bin, the 1999 adjusted column is the same as the measured column except for the HC data that include the offset adjustment in the adjusted column.

A similar correction can be applied to a fleet of specific model year vehicles to track deterioration, provided we use as a baseline only the model years measured in 1999. A sample calculation, for the model year adjusted mean NO emissions, is shown in Appendix E. Table 5 shows the mean emissions for all vehicles from model year 1984 to 2000, as measured in each of the three years of the study. Applying the vehicle frequency distribution by model year from 1999 to the mean emissions by model year from the later studies yields the model year adjusted fleet emissions. The calculation indicates that, although some of the measured decrease in fleet average emissions is due to fleet turnover, the emissions of even the older model years (1984-2000) measured previously has not increased significantly. The lack of emissions deterioration could be caused by the imposition of reformulated fuels, as discussed in previous CRC reports, and as observed on-road by Kirchstetter et al.[14] Note that the fleet of 1984 – 2000 model year vehicles has shrunk about 23% from 1999 and the values presented here include not only vehicle emission deterioration, but all the mechanisms which result in vehicles being permanently removed from the fleet. The slowly increasing emissions suggest that vehicle retirement is positively correlated with higher emissions.

Table 5. Model year adjusted fleet emissions (MY 1984-2000 only). Errors are standard error of the means calculated from the daily means.

	1999 measured (adjusted)	2001 measured (adjusted)	2003 measured (adjusted)
Mean gCO/kg	60.6 ± 2.0 (60.6 ± 2.0)	52.1 ± 2.3 (61.1 ± 2.7)	51.8 ± 1.6 (65.6 ± 2.0)
Mean gHC/kg[a]	8.3 ± 0.6 (5.9 ± 0.6)	5.2 ± 0.2 (5.2 ± 0.2)	6.8 ± 0.3 (6.7 ± 0.3)
Mean gNO/kg	6.2 ± 0.4 (6.2 ± 0.4)	6.1 ± 0.4 (7.0 ± 0.4)	5.8 ± 0.2 (7.0 ± 0.3)
Number of Vehicles[b]	17,903/17,798	17,304/17,194	13,827/13,786

[a] HC emissions are offset adjusted for all of the years adjusted data.

[b] Number of vehicles in the CO mean / number of vehicles in the HC and NO means.

Vehicle deterioration is also illustrated in Figure 7, which shows the mean emissions of the 1984 to 2000 model year fleet as a function of vehicle age. The first point for most model years was measured in 1999, the second point in 2001, etc. The HC offsets have been subtracted here for comparison. Vehicle age was determined by the difference between the year of measurement and the vehicle model year. Two features of this analysis stand out. The first is the gap between the

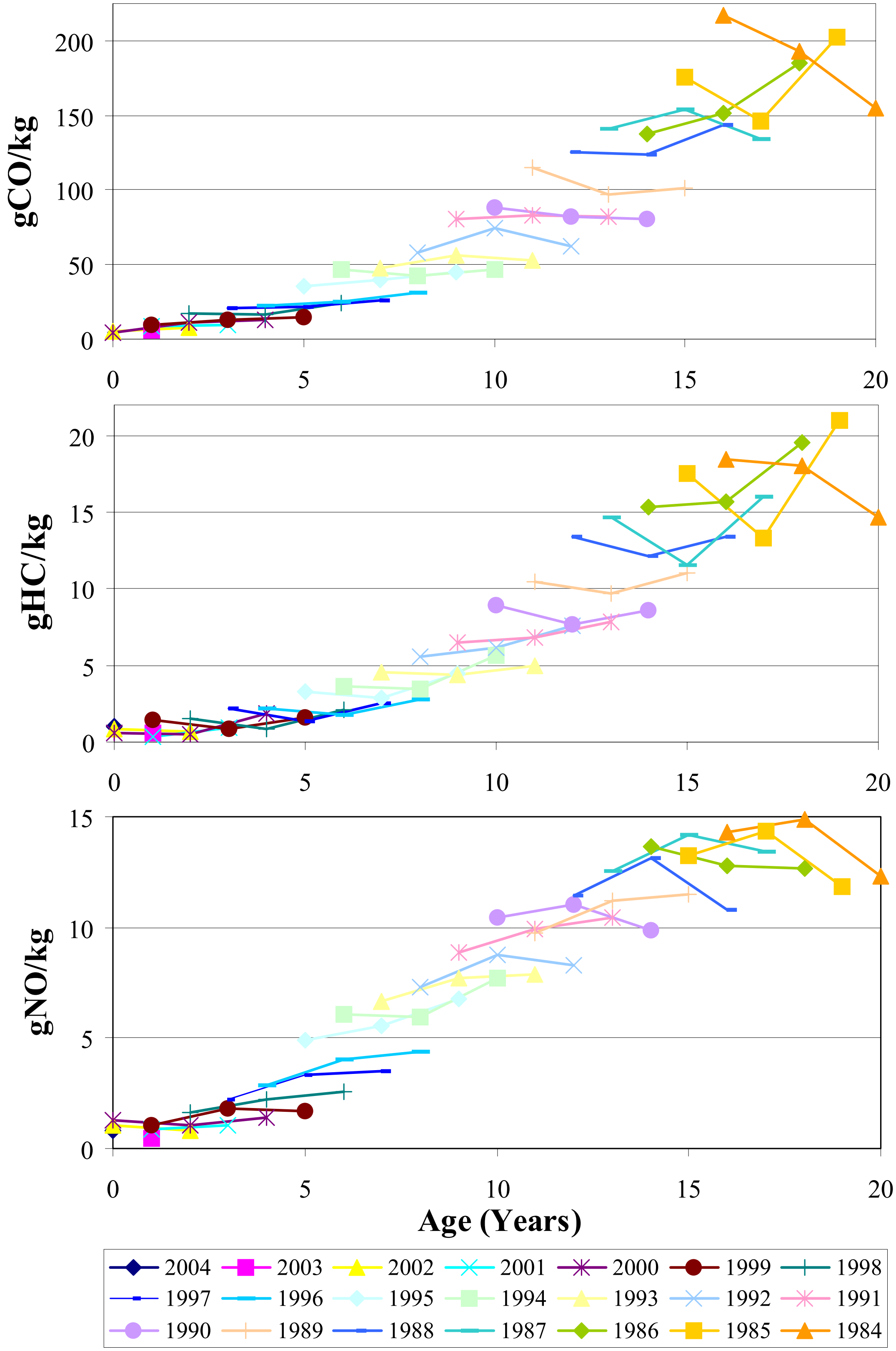

Figure 7. Mean vehicle emissions as a function of age, shown by model year.

1996 and newer model year vehicles and the older fleets. There were significant changes in the motor vehicle emissions regulations for the 1996 model year. These seem to be reflected in a noticeable gap between 1995 and older vehicles and 1996 and newer vehicles shown in Figure 6. The second feature, common to much of the E-23 data, is that each model year shows very little deterioration with age, but each model year has higher emissions than its newer neighbor.

The various analyses of the data presented up to this point suggest small increases in emissions from the previous years even when model year adjustment is conducted, in order to remove effects of fleet turnover. The lack of larger deterioration rates also shows up clearly in Figure 7. We can imagine several programs and processes which could have suppressed the fleet emissions: improvements in California's I/M program, the use of reformulated gasoline[14] and the "natural" loss of the least well maintained vehicles as fleets age. The enhanced Smog Check II I/M program was phased in during 1998.[15] The fact that the same phenomenon is seen in the newest model years that are not subject to I/M until their fifth model year indicates that I/M effectiveness cannot be the whole story. The E-23 supplemental study in Omaha and Tulsa is designed partly to answer this question, but only one on-road measurement campaign has been made so far.

Since the ramp in La Brea is metered, we decided to look into what if any effect that manual transmission shifting, which should be more common at La Brea than the other E-23 sites, might have on emissions. With the help of the *Passenger Vehicle Identification Manuals* from the National Insurance Crime Bureau, it is possible to decode some VINs for transmission type.[16] Makes with transmission information in the VIN are Jaguar, Honda, Land Rover, Subaru and Saab since 1981, Acura since their inception, some models of Chyrsler and Jeep since 2000, one model of Daewoo (1998-2002), Daihatsu (1987-1992), Saturn since 2000 and Sterling (1987-1991). It is possible to add a few additional makes (Volvo and Lexus, for example) for which only the automatics are identified. However, this query of makes and models has been limited to only those manufacturers that explicitly define both their automatic and manual transmission vehicles.

Table 6 provides a summary of emissions by make and transmission type for the 2,266 automatics and 636 manuals identified for this analysis. Honda and Acura account for almost 88% of the total. For all three pollutants, the manual transmission vehicles show higher on-road average emissions than automatic. Some of this difference is related to the age of the vehicles being compared. When the manuals are artificially aged (an example of this process is given in Appendix E) to match the automatics, the emission differences are still quite large for CO and HC, while the NO difference appears largely to be accounted for. When data are paired by model year, in every case $CO_{manuals} > CO_{automatics}$ and for model years newer than 1997 the $HC_{manuals} > HC_{automatics}$. When this analysis is carried out on the 2001 database, the age and emission differences are similar to those presented for the 2003 data.

If shifting increases the observed fleet emissions, then comparisons with other E-23 sites can be affected based on the amount of shifting that is observed at each site. Table 7 provides a summary of the emission differences at the E-23 sites in Phoenix and Chicago from data

Table 6. Data summary by transmission type for the La Brea database.

Make	Automatics (Manuals)	Mean Model Year	Mean gCO/kg	Mean gHC/kg[a]	Mean gNO/kg
Acura	295 (102)	1994.9 (1993)	48.1 (115)	2.5 (10.8)	3.8 (8.0)
Daewoo	23	2000.3	3.1	5.4	0.2
Honda	1684 (464)	1997.2 (1994.5)	32.1 (116)	3.0 (8.1)	3.2 (6.4)
Jaguar	66 (2)	1998.5 (2003)	15.0 (2.6)	3.0 (1.5)	2.5 (0)
Jeep	(22)	(2002.2)	(2.5)	(-0.4)	(0.2)
Land Rover	91 (2)	1998.9 (1994.5)	10.6 (377)	0 (11.4)	2.5 (0.4)
Saab	29 (17)	1999.4 (1993.5)	9.4 (49.3)	1.7 (7.0)	0.6 (4.9)
Sterling	(1)	(1988)	(6.6)	(6.4)	(1.4)
Saturn	48 (6)	2001.6 (2001.2)	2.6 (4.2)	1.8 (0.2)	0.6 (3.0)
Subaru	30 (20)	1998.2 (1996.1)	34.2 (84.2)	1.8 (6.4)	2.5 (2.9)
Totals	2266 (636)	1997.2 (1994.6)	31.6 (108)	2.8 (8.1)	3.1 (6.2)
Manuals Age Corrected to Automatics	(636)	(1997.2)	(81.7)	(4.8)	(3.8)

[a] HC data are offset adjusted

collected in the fall of 2002. Each site's emissions data are restricted to model years 1986 and newer to age match the fleets and the driving modes for the two transmission types are similar at each site. Both Phoenix and Chicago show differences in emissions between transmissions types, however, the differences are less than observed at La Brea. When age corrections are applied only the emissions difference observed for CO in Chicago is reconciled. The remaining emissions differences indicate that transmission type effects vehicle emissions in ways that cannot be corrected for by age or driving mode alone and may contribute to emission differences between sites.

Another use of the on-road remote sensing data is to predict the effectiveness with which high emitter identification for one pollutant actually predicts high emissions for another pollutant. One can look at the high CO emitters (as defined as the top emissions decile) and calculate that a percentage of these are also high emitting for HC, for example. This type of analysis would allow a calculation of the maximum HC emission benefits resulting from fixing all high CO emitters. To this extent, we have analyzed our data to determine what percent of the top decile of

Table 7. E-23 site comparisons by transmission type for 1986 and newer vehicles.

	La Brea 2003	Phoenix 2002	Chicago 2002
Automatics (Manuals / Age Adjusted)	2266 (636)	1387 (551)	1824 (411)
Mean Model Year	1997.2 (1994.6)	1998.2 (1996.1)	1998.1 (1996.2)
Mean gCO/kg	31.6 (108 / 81.7)	22.2 (50.7 / 41.6)	31.9 (41.4 / 32.1)
Mean gHC/kg[a]	2.8 (8.1 / 4.8)	2.0 (3.5 / 3.0)	2.8 (5.5 / 4.4)
Mean gNO/kg	3.1 (6.2 / 3.8)	2.4 (4.9 / 3.0)	2.3 (4.8 / 3.4)
Mean Speed	17.4 (16.6)	34.7 (36.0)	24.3 (24.1)
Mean Accel	2.0 (2.1)	2.4 (3.0)	-0.5 (-0.4)
Mean Vsp	12.4 (12.0)	26.4 (32.6)	-9.1 (-9.4)

[a] HC data are offset adjusted

measurements of one pollutant is also in the top decile for another pollutant. These data are in Table 8; included in the analysis are only those readings that have valid readings for all three pollutants. The column heading is the pollutant whose top decile is being analyzed, and the values indicate the percentage of the fleet that is also in the top decile for the pollutants in the row headings. The values where the column and row headings are the same indicate the percentage that is in the top decile for that pollutant only. The "All" row gives the percentage of the readings that are in the top decile for all three pollutants. Thus, 3.7% of the measurements are in the top decile for both HC and CO; 0.8% of the measurements are in the top decile for CO and NO; 4.6% of the measurements are only in the top CO decile.

Table 8. Percent of vehicle overlap in the top decile (highest emissions) by exhaust species.

Top 10% Decile	CO	HC	NO
CO	4.6%	3.7%	0.8%
HC	3.7%	3.9%	1.5%
NO	0.8%	1.5%	6.8%
All	0.9%		

The preceding analysis gives the percent of vehicle overlap but does not directly give emissions overlap. In order to assess the overlap, one must convert the Table 8 values to percent of emissions. This number is a maximum because the normal variability of emissions readings, particularly from high emitters[9], has not been included in this analysis. Table 9 shows that

Table 9. Percent of total g/kg emissions from the top decile (highest emissions) vehicles.

Top 10% Decile	CO Emissions	HC[a] Emissions	NO Emissions
CO	27.3%	35.3%	15.7%
HC	35.5%	21.2%	9.8%
NO	3.2%	8.4%	40.2%
All	4.3%	6.4%	5.2%

[a] HC data used has been offset adjusted.

identification of the 4.6% of the measurements that are in the top CO decile only would identify an overall 27.3% of total measured on-road CO. More efficiently, identification of the 3.7% of the measurements that are in the top decile for both CO and HC accounts for 35.5% of the total CO and 35.3% of the total HC from these data.

Most vehicles are low emitting and show little emissions variability when measured more than once. Vehicles that have one high reading often have other readings that vary widely.[9] This effect has also been observed from multiple FTP and IM240 tests. The evidence from pullover studies in California is that even one high reading identifies vehicles that have a >90% probability of failing an alternative I/M test if performed immediately. These vehicles also have a high probability of showing evidence of tampered or defective emission control equipment.[7,17] Because of this variability in the emissions of broken cars, the emissions distribution obtained from any snapshot of fleet emissions (remote sensing or annual I/M testing) is bound to be more skewed than were we able to monitor the emissions of all vehicles at all times. This phenomenon does not affect the means measured by these snapshots, but it does imply that the overlap and high emitter fractions in the tables above would show less skewness were we able to fully characterize all vehicles and their variability.

As an independent means of testing the sensitivity/noise of our speed and acceleration measurements, an alternate measure of vehicle acceleration (actually the recent acceleration history) can be obtained by virtue of the nature of the La Brea site. From 6:00 am onwards throughout the day, the lane is metered by a traffic light. This forces all vehicles to come to a stop about 84 ft. from the location at which their exhaust emissions and their speed are measured. Making the simplest assumption that acceleration has been uniform from the stop, the average acceleration is given as $a = v^2/2d$. If one measures v in mph, and d in ft and a in mph/s then $a = 0.682*v^2/d$.

Figure 8 plots the measured instantaneous acceleration data versus measured instantaneous speed (binned into 1mph bins) and the theoretical line assuming the vehicles are under constant acceleration. Vehicles traveling with speed above 10mph show mean values similar to, but with less curvature than would be expected if the acceleration were constant. If the acceleration were increasing, the curvature would be even higher. If the acceleration were decreasing, or part of the trip was at constant speed, the curvature would be less than the solid line, as is observed.

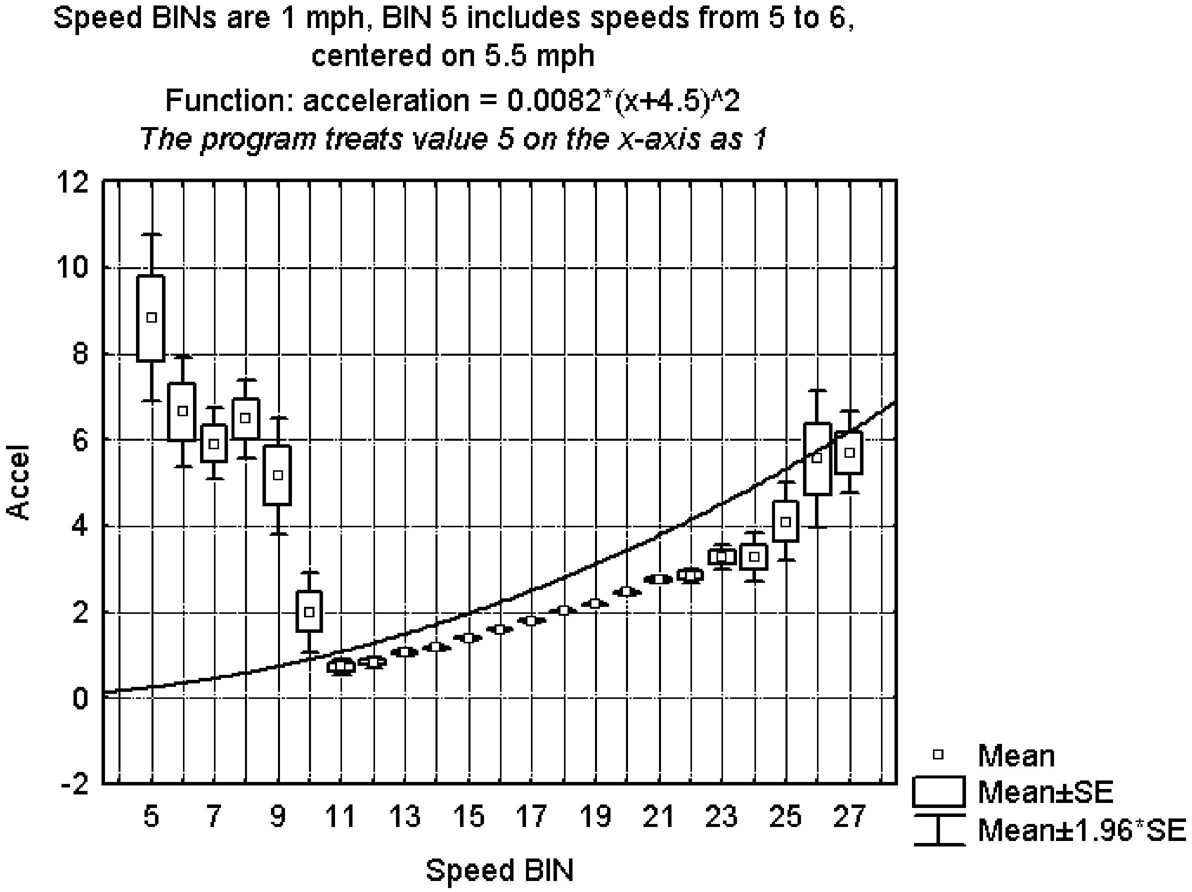

Figure 8. A graph of acceleration as a function of speed binned into 1 mph speed bins. also shows the function represented by equation (3) as a solid line. . The higher standard errors on the extreme values of speed reflect the fewer numbers of vehicles driving at these speeds. Figure prepared by R. Slott 2004.

When we remove vehicle records with speeds lower than 11 and higher than 23 mph, this eliminates the few periods of very slow total congestion and the fastest few. Upon analysis of the remainder, we see a scatter diagram in which the average acceleration history and the measured acceleration are correlated. This is expected since slower/faster drivers/vehicles will appear slower/faster on both measures. Figure 9 shows these data and the binned means for each 0.5 mph/s of average acceleration history, determined as described above and the least squares fit to the binned means. The correlation is excellent ($r^2 = 0.99$) and the line passes close to the origin (as expected). The slope of 0.7 indicates that on average vehicles are accelerating faster from a full stop over 84 ft. approaching a freeway than they are when their instantaneous acceleration is measured at the 84 ft. distance. This conclusion was also apparent in the analysis of Figure 8. When the data in the individual bins are interrogated for distribution, 50% of the measured instantaneous accelerations are within 0.5 mph/s of the mean for that bin. This is a conservative measure of the noise in our instantaneous acceleration measurements, and indicates that VSP bins of 5 kw/tonne can reasonably be distinguished in our data.

In the manner described in the Phoenix, Year 2 report,[18] instrument noise was measured using the slope of the negative portion of a plot of the natural log of the binned emission measurement

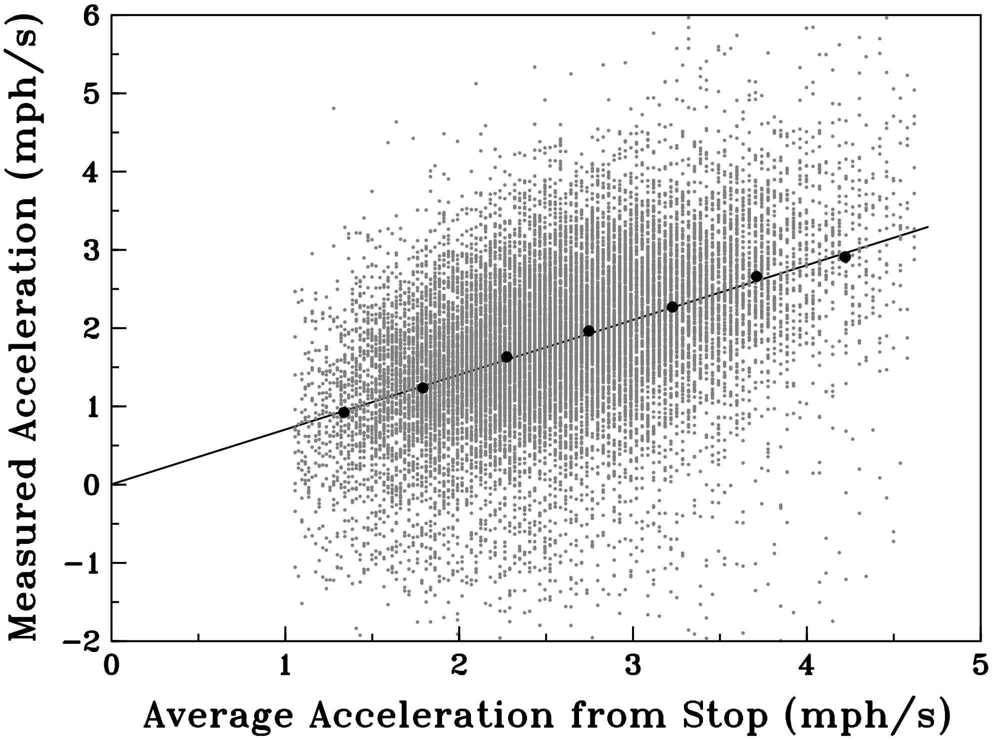

Figure 9. A plot of measured acceleration versus calculated average uniform acceleration from stop for vehicles with speeds between 11 and 23 mph. The filled circles are the mean accelerations for 0.5mph bins of data from 1 to 4.5 mph/s and the line the least squares fit to those points. The equation for the line is $y = 0.7x + 0.0047$ and the $r^2 = 0.99$.

frequency versus the emission level. Such plots were constructed for the three pollutants. Linear regression gave best fit lines whose slopes correspond to the inverse of the Laplace factor, which describes the noise present in the measurements. This factor must be viewed in relation to the average measurement for the particular pollutant to obtain a description of noise. The Laplace factors were 4.3, 4.0, and 0.3 for CO, HC and NO, respectively. These values indicate standard deviations of 6.0 g/kg (0.05%), 5.7 g/kg (134 ppm) and 0.5 g/kg (39 ppm) for individual measurements of CO, HC and NO, respectively. These levels are consistent with the low noise level as discussed in a previous Phoenix report.[18] In terms of uncertainty in average values reported here, the numbers are reduced by a factor of the square root of the number of measurements. For example, with averages of 100 measurements, which is the low limit for number of measurements per bin, the uncertainty reduces by a factor of 10. Thus, the uncertainties in the averages of 100 measurements reduce to 0.6 g/kg, 0.6 g/kg, and 0.05 g/kg, respectively.

CONCLUSIONS

The University of Denver has completed the third year of a multi-year remote sensing study of motor vehicle emissions and deterioration in the La Brea area, with measurements made in 1999, 2001 and in 2003. A database was compiled containing 20,191 records for which the State of California provided registration information. All of these records contained valid measurements for at least CO and CO_2, and 20,135 records contained valid measurements for HC and NO as well.

The mean CO, HC and NO emissions for the fleet measured in this study was 0.34%, 121 ppm and 323 ppm, respectively. The fleet emissions observed at the site exhibited a skewed distribution, with most of the total emissions contributed by a relatively small percentage of the measurements. Emission levels for all three species continue to decline. The CO emissions show the largest dependence on VSP and, consequently, the NO emissions appear to be suppressed.

With the collection of the third data set over a four-year period at the same time and location, it is possible to show the “deterioration” of specific model year fleets from one year to the next. Note that the fleets measured from year to year are not all the same vehicles. More recent model year fleets were seen to have lower emissions independent of age over this time span. The 1984 - 2000 model year vehicles had rather constant emissions with age, counter to the expected, and previously observed, deterioration of these model year vehicles. The factors influencing this observation could be an improved I/M program,[15] reformulated gasoline program[14] or fleet retirement patterns (almost a quarter of the fleet has retired by now) which favors the less well maintained members of the fleet. Continuing studies at the same site and at non I/M, non special fuels sites should allow further insight to be gained as to the extent I/M programs and special fuels contribute to reducing motor vehicle fleet emissions deterioration. Data are available at www.feat.biochem.du.edu for the three years of measurements in La Brea and for other measurement campaigns undertaken by the University of Denver.

Using vehicle specific power, the emissions of the vehicle fleet measured in 2003 was adjusted to match the vehicle driving patterns of the fleet in 1999. After doing so, it was seen that the emissions measured in the current year are lower than those measured during 1999. Model year adjustments gave equivocal results.

A new analysis looked at vehicle emission levels as a function of the type of transmission the vehicle uses. It suggests that when comparing emissions between E-23 sites one may need to consider transmission type in addition to age and vsp. Since, even after age adjustments are made, manual transmission equipped vehicles at La Brea had more than twice the average CO, 40% higher HC and 20% higher NO emissions.

An analysis of high emitting vehicles showed that there is considerable overlap of CO and HC high emitters, for instance 3.7% of the measurements contribute 36% of the total CO and 35% of the total HC. The noise levels in the CO, HC and NO measurement channels were determined to be within acceptable limits that were minimal when compared to the standard error of the mean of the measurements.

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ACRONYMS

CH_2 – Generic formula for gasoline
CO – Carbon monoxide
CO_2 – Carbon dioxide
CRC – Coordinating Research Council
EPA – Environmental Protection Agency
FEAT – Fuel Efficiency Automobile Test
FID – Flame Ionization Detector
HC – Hydrocarbons
I/M – Inspection and Maintenance
IMRC – California Inspection and Maintenance Review Committee
IR – Infrared
MY– Model Year
NDIR – Non-Dispersive Infrared
NO – Nitric Oxide
NO_x – Nitrogen oxides
ppm – Parts per million
UV – Ultraviolet
VIN – Vehicle Identification Number
VSP – Vehicle Specific Power

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APPENDIX A: FEAT criteria to render a reading "invalid" or not measured.

Not measured:

1) Beam block and unblock and then block again with less than 0.5 seconds clear to the rear. Often caused by elevated pickups and trailers causing a "restart" and renewed attempt to measure exhaust. The restart number appears in the database.

2) Vehicle which drives completely through during the 0.4 seconds "thinking" time (relatively rare).

Invalid :

1) Insufficient plume to rear of vehicle relative to cleanest air observed in front or in the rear; at least five, 10ms averages >0.25% CO_2 in 8 cm path length. Often heavy-duty diesel trucks, bicycles.

2) Too much error on CO/CO_2 slope, equivalent to ±20% for %CO. >1.0, 0.2%CO for %CO<1.0.

3) Reported %CO , <-1% or >21%. All gases invalid in these cases.

4) Too much error on HC/CO_2 slope, equivalent to ±20% for HC >2500ppm propane, 500ppm propane for HC <2500ppm.

5) Reported HC <-1000ppm propane or >40,000ppm. HC "invalid".

6) Too much error on NO/CO_2 slope, equivalent to ±20% for NO>1500ppm, 300ppm for NO<1500ppm.

7) Reported NO<-700ppm or >7000ppm. NO "invalid".

Speed/Acceleration valid only if at least two blocks and two unblocks in the time buffer and all blocks occur before all unblocks on each sensor and the number of blocks and unblocks is equal on each sensor and 100mph>speed>5mph and 14mph/s>accel>-13mph/s and there are no restarts, or there is one restart and exactly two blocks and unblocks in the time buffer.

APPENDIX B: Explanation of the La Brea03.dbf database.

The La Brea03.dbf is a Microsoft FoxPro database file, and can be opened by any version of MS FoxPro. The file can be read by a number of other database management programs as well, and is available on CD-ROM or FTP. The following is an explanation of the data fields found in this database:

License	California license plate.
Date	Date of measurement, in standard format.
Time	Time of measurement, in standard format.
Percent_CO	Carbon monoxide concentration, in percent.
CO_err	Standard error of the carbon monoxide measurement.
Percent_HC	Hydrocarbon concentration (propane equivalents), in percent.
HC_err	Standard error of the hydrocarbon measurement.
Percent_NO	Nitric oxide concentration, in percent.
NO_err	Standard error of the nitric oxide measurement.
Percent_CO2	Carbon dioxide concentration, in percent.
CO2_err	Standard error of the carbon dioxide measurement.
Opacity	Opacity measurement, in percent.
Opac_err	Standard error of the opacity measurement.
Restart	Number of times data collection is interrupted and restarted by a close-following vehicle, or the rear wheels of tractor trailer.
HC_flag	Indicates a valid hydrocarbon measurement by a "V", invalid by an "X".
NO_flag	Indicates a valid nitric oxide measurement by a "V", invalid by an "X".
Opac_flag	Indicates a valid opacity measurement by a "V", invalid by an "X".
Max_CO2	Reports the highest absolute concentration of carbon dioxide measured by the remote sensor over an 8 cm path; indicates plume strength.
Speed_flag	Indicates a valid speed measurement by a "V", an invalid by an "X", and slow speed (excluded from the data analysis) by an "S".
Speed	Measured speed of the vehicle, in mph.
Accel	Measured acceleration of the vehicle, in mph/s.
Ref_factor	Measurements background reference voltage value.
CO2_factor	Measurements background CO_2 voltage value.
Vin	Vehicle identification number.
Make	Manufacturer of the vehicle.
Year	Model year.

Exp_date	License expiration date.
Body_style	California designated body style
Zip	Registrant's mailing zip code.
First_sold	Year of first vehicle entry in California records.
County	California county number vehicle is registered in.
Fuel	Fuel type G (gasoline), D (diesel), N (natural gas) and Q (hybrid).
GVW	Gross vehicle weight.
Smog_due	Date next Smog Check is due.

APPENDIX C: Temperature and Humidity Data as Recorded at Los Angles International Airport

La Brea 1999 Temperature and Humidity Data

Time	11/09 °F	11/09 %RH	11/10 °F	11/10 %RH	11/11 °F	11/11 %RH	11/12 °F	11/12 %RH	11/13 °F	11/13 %RH
5:50	54	87	53	93	52	89	58	93	56	100
6:50	55	80	55	83	57	75	57	100	57	100
7:50	57	78	57	81	60	70	59	96	58	100
8:50	60	72	61	70	63	65	59	90	59	93
9:50	63	68	64	63	67	59	62	84	61	84
10:50	66	61	65	66	68	59	61	87	61	84
11:50	68	55	65	70	68	61	62	84	61	84
12:50	67	66	64	75	68	63	61	84	62	81
13:50	64	73	64	75	69	57	62	81	62	81
14:50	64	75	64	70	67	66	62	84	62	81
15:50	62	81	64	68	65	76	61	87	62	81
16:50	61	84	63	73	63	81	61	90	61	87

La Brea 2001 Temperature and Humidity Data

Time	10/15 °F	10/15 %RH	10/16 °F	10/16 %RH	10/17 °F	10/17 %RH	10/18 °F	10/18 %RH	10/19 °F	10/19 %RH
8:03	64	90	66	90	61	90	62	93	64	84
9:03	67	87	66	81	63	87	65	78	67	76
10:03	68	79	69	73	65	78	70	64	69	73
11:03	71	73	70	71	67	73	69	73	68	76
12:03	68	68	67	79	67	73	70	68	66	78
13:03	69	76	69	73	66	75	69	70	66	78
14:03	69	76	68	76	67	76	70	66	63	84
15:03	67	76	68	76	66	78	68	70	64	84
16:03	65	84	66	81	65	81	67	79	63	87
17:03	63	87	64	90	63	87	64	87	63	87
18:03	63	93	63	90	62	90	63	90	62	90

La Brea 2003 Temperature and Humidity Data										
Time	10/27 °F	10/27 %RH	10/28 °F	10/28 %RH	10/29 °F	10/29 %RH	10/30 °F	10/30 %RH	10/31 °F	10/31 %RH
7:50	71	31	69	41	64	87	64	73	57	78
8:50	78	24	75	33	66	81	64	73	58	72
9:50	84	21	79	30	68	73	65	70	61	56
10:50	87	24	81	29	69	70	67	66	62	56
11:50	84	29	80	41	67	81	66	59	62	58
12:50	82	27	75	58	69	76	65	59	63	52
13:50	83	24	77	54	67	81	63	63	62	56
14:50	82	26	77	50	66	81	64	54	61	58
15:50	79	32	75	54	64	87	62	52	61	60
16:50	74	54	70	76	63	90	60	62	61	63
17:50	72	60	70	82	64	87	60	62	61	60
18:50	73	62	67	97	63	87	60	62	60	62

APPENDIX D: Example Calculation of Vehicle Specific Power Adjusted Vehicle Emissions

1997 (Measured)	VSP Bin	Mean NO (ppm)	No. of Measurements	Total Emissions
	-5	236	225	53200
	0	224	1609	360090
	5	307	4985	1531000
	10	431	6146	2648020
	15	548	2624	1438060
	20	590	456	269180
			16045	6299550
			Mean NO (ppm)	**393**

1998 (Measured)	VSP Bin	Mean NO (ppm)	No. of Measurements	Total Emissions
	-5	233	137	31951
	0	239	784	187394
	5	265	3613	956613
	10	385	6685	2576433
	15	475	6012	2856195
	20	483	2392	1156320
			19623	7764906
			Mean NO (ppm)	**396**

1998 (Adjusted)	VSP Bin	‘98 Mean NO (ppm)	‘97 No. of Meas.	Total Emissions
	-5	233	225	52474
	0	239	1609	384588
	5	265	4985	1319877
	10	385	6146	2368700
	15	475	2624	1246616
	20	483	456	220436
			16045	5592691
			Mean NO (ppm)	**349**

Note that the Mean NO readings listed here have been rounded to the nearest ppm values which results in the Total Emissions column appearing to not be a direct multiplication product. The -5 to 20 kw/tonne bins are chosen to preclude any “off-cycle” emissions.

The object of this adjustment is to have the 1998 fleet’s emissions calculated as if they drove (VSP wise) like the 1997 fleet. This is accomplished by first binning and averaging the 1997 and 1998 data (the top two tables). We then combine the mean NO values from the 1998 fleet with the numerical VSP bin distribution from the 1997 fleet in the bottom table. The product of these two columns is summed and the sum total emissions are divided by the number of 1997 vehicles to produce the 1998 adjusted mean NO average. For this example, it shows that the 1998 fleet when driven like the 1997 fleet has lower NO emissions than the 1997 fleet.

APPENDIX E: Example Calculation of Model Year Adjusted Fleet Emissions

1997 (Measured)	Model Year	Mean NO (ppm)	No. of Measurements	Total Emissions
	83	690	398	274620
	84	720	223	160560
	85	680	340	231200
	86	670	513	343710
	87	690	588	405720
	88	650	734	477100
	89	610	963	587430
	90	540	962	519480
	91	500	1133	566500
	92	450	1294	582300
	93	460	1533	705180
	94	370	1883	696710
	95	340	2400	816000
	96	230	2275	523250
	97	150	2509	376350
			17748	7266110
			Mean NO (ppm)	**409**
1998 (Measured)	Model Year	Mean NO (ppm)	No. of Measurements	Total Emissions
	83	740	371	274540
	84	741	191	141531
	85	746	331	246926
	86	724	472	341728
	87	775	557	431675
	88	754	835	629590
	89	687	1036	711732
	90	687	1136	780432
	91	611	1266	773526
	92	538	1541	829058
	93	543	1816	986088
	94	418	2154	900372
	95	343	2679	918897
	96	220	2620	576400
	97	177	3166	560382
			20171	9102877
			Mean NO (ppm)	**451**
1998 (Adjusted)	Model Year	'98 Mean NO (ppm)	'97 No. of Meas.	Total Emissions
	83	740	398	294520
	84	741	223	165243
	85	746	340	253640
	86	724	513	371412
	87	775	588	455700
	88	754	734	553436
	89	687	963	661581
	90	687	962	660894
	91	611	1133	692263
	92	538	1294	696172
	93	543	1533	832419
	94	418	1883	787094
	95	343	2400	823200
	96	220	2275	500500
	97	177	2509	444093
			17748	8192167
			Mean NO (ppm)	**462**

APPENDIX F: Field Calibration Record.

2001 (FEAT 3002)				
Date	Time	CO Cal Factor	HC Cal Factor	NO Cal Factor
10/15	8:00	1.56	1.40	2.01
10/15	13:00	1.22	1.05	1.26
10/16	7:00	1.47	1.25	1.85
10/16	15:30	1.23	1.02	1.39
10/17	7:00	1.47	1.50	2.30
10/17	12:50	1.39	1.12	1.53
10/18	8:30	2.17	1.87	2.67
10/18	10:55	1.63	1.46	2.02
10/19	7:55	1.68	1.39	1.42
10/19	10:09	1.50	1.26	1.31

2003 (FEAT 3002)				
Date	Time	CO Cal Factor	HC Cal Factor	NO Cal Factor
10/27	12:30	1.228	1.27	2.14
10/27	17:20	1.333	1.19	1.7
10/28	8:00	3.14	2.91	7.2
10/28	9:45	2.22	2.2	4.87
10/28	11:23	1.6	1.5	2.53
10/29	7:50	1.666	1.47	1.89
10/29	11:30	1.31	1.15	1.42
10/29	14;20	1.31	1.14	1.228
10/29	17:30	1.41	1.28	1.62
10/30	6:05	1.48	1.35	2.53
10/30	9:30	1.41	1.29	2.03
10/30	14:30	1.42	1.28	1.73
10/31	5:50	1.55	1.35	2.85
10/31	10:35	1.34	1.19	1.79