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On-Road Remote Sensing of CO Emissions in the Los Angeles Basin

Donald H. Stedman
University of Denver

Gary A. Bishop
University of Denver, gabishop10@yahoo.com

James E. Peterson
University of Denver

Paul L. Guenther
University of Denver

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On-Road CO Remote Sensing in the Los Angeles Basin

State of California
AIR RESOURCES BOARD
Research Division

ON-ROAD REMOTE SENSING OF CO EMISSIONS IN THE LOS ANGELES BASIN

Donald H. Stedman, Gary A. Bishop,
James E. Peterson and Paul L. Guenther

University of Denver
Chemistry Department
Denver CO, 80208

Final report to the California Air Resources Board,
under Contract Number A932-189

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EXECUTIVE SUMMARY

The University of Denver remote sensor for on-road motor vehicle carbon monoxide emissions was used for eleven days in the Los Angeles Basin in December, 1989. The remote sensor has been incorporated into the 1990 Clean Air Act Amendments as "on-road emissions testing". The device measures the CO/CO_2 ratio for one-half second behind each vehicle, from which the exhaust %CO is calculated. Vehicles were measured in a mix of many driving modes and speeds ranging from deceleration coming up to a red traffic light through idling in heavy congestion up to accelerations and cruises entering a freeway ramp at highway speeds. The results have been validated by both EPA and CARB blind comparisons. The calculated %CO is analogous to that which would have been measured had the vehicle been equipped with a tailpipe probe. The mass emissions in grams CO per gallon of gasoline used can also be derived. Eight of the days monitored normal urban street driving; three monitored freeway ramps. Over 27,000 valid CO emission measurements were made. When the videotapes had been read and returned to California authorities for matching the license plates, the total number of vehicles both measured and matched with the license plate database was over 16,000. Because of the poor contrast of older California license plates and the sun angles, more plates were readable when the front of the vehicles were imaged. With this arrangement a significant number of vehicles without front plates could not be identified. The license plate matched fleet was 0.15 %CO cleaner (~3/4 of year on average newer) than the total fleet. This probably arises because older vehicles have older style plates which are both intrinsically harder to read (lower contrast), and often in poorer condition.

Overall for the driving modes and vehicles tested more than fifty percent of the CO was emitted by eleven percent of the vehicles with %CO equal to or greater than five (gross polluters). New vehicles were so clean (gross polluters were less than 1% for the 1989 and 90 model years) that their emissions were almost negligible. The percentage of gross polluters rises from 4% (328 vehicles) of the 83-90 model year vehicles through 17% for the 75-80 model year vehicles to 30% (504 vehicles) of the 1974 and older fleet. If the whole measured fleet could maintain the 1989 and 1990 measured emissions then the total on-road pollution from the 16,000 vehicles measured would decrease more than fivefold. Despite the fact that the new vehicles are on average clean, the dirtiest 20% of the one year old fleet was dirtier than the cleanest 20% of any model years regardless of age. Because old vehicles are not numerous, and most new vehicles are low emitters, most of the carbon monoxide came from emissions of the dirtiest 20% of the vehicles with model years between 1976 and 1988.

An analysis of the data indicates that a conservative upper limit of fifteen percent of the measured CO emissions arises from vehicles in either a cold start or an off-cycle acceleration mode. Forty three percent of the fleet of 77 vehicles measured four or more times were always in the clean (<1 %CO) category. These emit 4% of the total CO from all 77 vehicles. One quarter of the fleet of 77 showed emissions consistently between one and five percent CO. These vehicles emitted 18% of the CO An additional 25% of the fleet were over the five percent CO cut point at least twice. These vehicles emitted 70% of the emissions. Only a small fraction (5 vehicles, 7% of the fleet of 77 vehicles) jumped into the high category only once. The emissions variability observed in this data set is similar to the emissions variability observed when vehicles are repetitively subjected to conventional I/M testing. These results imply that an inspection and maintenance program incorporating remote sensing, which targets gross polluters with multiple violations, has the potential to identify a significant fraction of the CO emissions while inconveniencing only a small fraction of the vehicle owners. Our analysis concludes that on-road remote sensing as a **component** of an I/M program has the advantages of being representative of the on-road emissions of the vehicle in question, being an emissions test which is almost impossible to circumvent, and incorporates a "fairness factor" such that the more a vehicle is driven, the more frequently it will be tested. When age related factors are eliminated the findings in California are essentially identical to findings from on-road CO studies of large fleets of vehicles in Denver, Chicago and Toronto.

Forty-seven vehicles out of a fleet of 387 vehicles registered as diesels show emissions greater than 2%CO. Of these vehicles, thirty-nine are 1975-84 General Motors vehicles. The vehicles are such high emitters that the only sub-fleet found to be dirtier are 1955-1970 vehicles. Three lines of evidence point to the conclusion that more than half of the vehicles listed in this category are not diesel powered and are incorrectly registered thereby avoiding the California Smog-Check program.

There were differences in average CO emissions between the sites measured, and to a lesser extent between different days at the same sites. To aid in understanding this phenomenon, all remote sensing data available at the University of Denver from a variety of US cities with altitudes lower than 7,000 ft were analyzed in terms of hourly average CO emissions compared to hourly average fleet age. From this analysis a linear model was developed which demonstrated that almost all of the observed differences could be accounted for by differences in average age. This results because of the previously shown influence of the gross polluters which increases with fleet age. Smaller, load induced average emission increases between an uphill but slow cruise-mode freeway off-ramp and a flat but high speed acceleration on-ramp were discernable after the age differences had been eliminated. The linear model predicts average %CO for all fleets measured in the USA to better than 0.5 %CO with a knowledge of only the average fleet age.

The important conclusions are that a few vehicles (gross polluters) emit most of the CO A few vehicles are always measured in the gross polluter category, a few are frequently in that category, and most are never gross polluters. The fraction of gross polluters increases from one in one hundred new vehicles up to one in three old ones. Although new vehicle standards and technology changed from the early seventies to the early eighties, no sharp breaks are observed for the transition model years. The evidence suggests that on-road CO emissions increase linearly with average age of the fleet, and that the linear increase is dominated by the steady increase in the fraction of gross polluters with age. This increase with age appears to be caused in large part by improper (in some cases illegal) maintenance practices.

INTRODUCTION

Urban air quality does not meet the federal standards in many states. Violations of the ozone standard are believed to arise from photochemical transformation of oxides of nitrogen (NOx) and hydrocarbons (HC). Carbon monoxide (CO) standards are primarily violated as a result of direct emissions of the gas. Mobile sources are a major factor in urban emissions inventories for oxides of nitrogen, hydrocarbons and carbon monoxide.

Additional air pollution control measures beyond the Federal New Vehicle Emissions standards taken to mitigate mobile source emissions in non-attainment areas include inspection and maintenance (I/M) programs, oxygenated fuels mandates and transportation control measures. Nonetheless many areas of non-attainment remained after the 1987 deadline, and some are projected to remain in non-attainment for several more years despite the measures currently undertaken. The remote sensing techniques discussed in this report may have the potential to contribute to further control measures in non-compliance areas. The 1990 US Clean Air Act amendments require non-attainment areas to "include on-road emissions monitoring" in their post-1990 I/M programs. This amendment, the "Barton Clean Air Smog Trap Amendment" was included based on literature and demonstrations of on-road remote sensing to the US Congress by the University of Denver.

With initial support from the Colorado Office of Energy Conservation in 1987, the University of Denver (DU) developed an infra-red (IR) remote monitoring system for automobile carbon monoxide exhaust emissions. Significant fuel economy improvements result if rich-burning (high CO emissions) or misfiring (high HC emissions) vehicles are tuned to a more stoichiometric and more efficient air/fuel (A/F) ratio. Therefore, the University of Denver CO remote sensor is named **F**uel **E**fficiency **A**utomobile **T**est (FEAT). Figure 1 shows a schematic diagram of the basic instrument.

The basic instrument measures in under one second per vehicle the carbon monoxide to carbon dioxide ratio (CO/CO_2) in the exhaust of any vehicle passing through the IR light beam. With support from the American Petroleum Institute an additional channel to measure hydrocarbon emissions has been successfully tested and has monitored over 50,000 on-road vehicle HC emissions.

The IR source sends a horizontal beam of radiation across a single traffic lane, approximately 10 inches above the road. This radiation is picked up by the detector on the opposite side and split into three wavelength channels, CO, CO_2, and reference. Data from all channels are fed to a computer for analysis. The calibration gases (mixtures of CO and CO_2 in nitrogen) are used as a daily quality assurance (Q/A) check on the system.

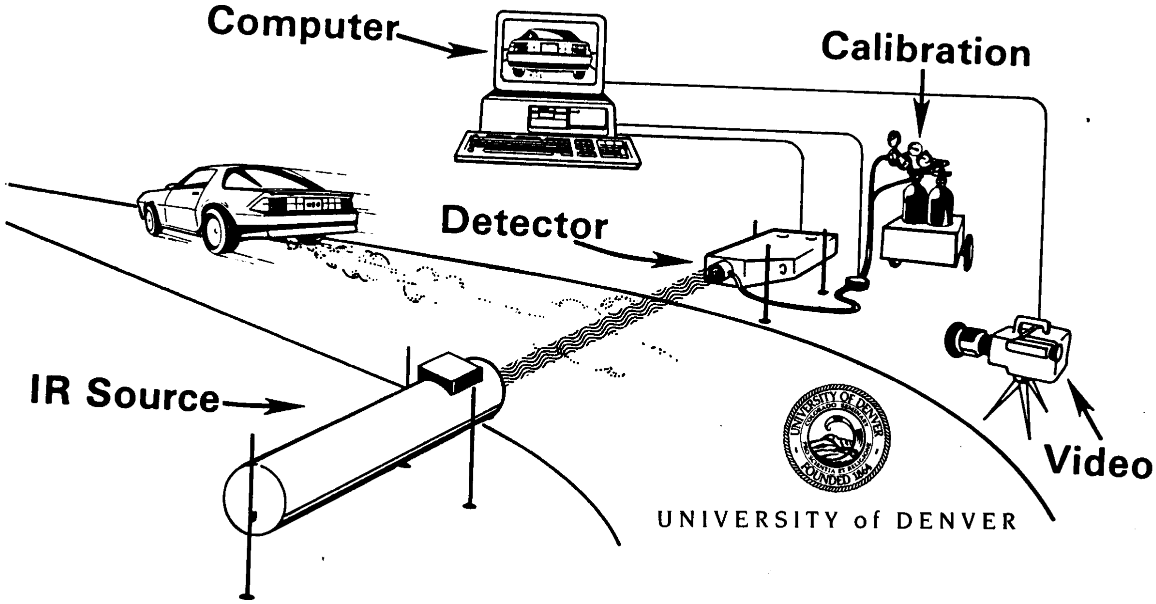

Figure 1. A schematic diagram of the University of Denver on-road emissions monitor. It is capable of monitoring emissions at vehicle speeds between 2.5 and 65 mph in under one second per vehicle.

The determination of the CO/CO_2 ratio is itself a useful parameter to describe the emission status of a combustion system. Most vehicles show ratios close to zero (low emitters). When CO/CO_2 ratios greater than zero are observed the engine must be operating with a fuel rich air/fuel ratio, and the emissions control system must not be fully operational. Emissions systems are not fully operational when the system is missing or has been tampered with. They are also not fully operational when the catalyst is cold (as in cold start operation), or under conditions of extreme acceleration when the manufacturers intentionally allow the vehicle to operate at a much higher emission level than under normal driving conditions. These so called "off cycle" emissions have been described in detail by Austin et al. of Sierra Research (1988).

With a fundamental knowledge of combustion chemistry, many parameters of the vehicle and its emissions system can be determined, including the instantaneous air/fuel ratio, grams of CO emitted per gallon of gasoline and the percentage of CO which would be measured by a tailpipe probe. The mechanism by which FEAT measures a ratio is explained in Bishop et al. (1989). The ratios can be determined by remote sensing, independent of wind, temperature, and turbulence in 0.8 seconds per passing vehicle. Other peer-reviewed publications describing remote sensing are listed in the References.

The FEAT remote sensor is accompanied by a video system when license plate information is required. The video camera is coupled directly into the data analysis computer so that the image of each passing vehicle is frozen onto the video screen. The computer writes the date, time and the CO and CO_2 concentrations at the bottom of the image. These images are then stored on videotape.

FEAT can measure the CO emissions in all vehicles, including gasoline and diesel-powered vehicles, as long as the exhaust plume exits the vehicle within a few feet of the ground. Due to the height of the sensing beam, FEAT will not register emissions from exhausts which exit from the top of vehicles such as heavy duty diesel vehicles in the USA. Carbon monoxide and hydrocarbon emissions from diesel vehicles are in any case usually negligible. FEAT is effective across traffic lanes of up to 40 feet in width. However, if one wishes to positively identify and video each vehicle with its exhaust it can only be used across a single lane of traffic. FEAT operates most effectively on dry pavement. Rain, snow, and vehicle spray from very wet pavement cause interferences with the IR beam. These interferences cause the frequency of invalid readings to increase, ultimately to the point that all data are rejected as being contaminated by too much "noise". At suitable locations exhaust can be monitored from over one thousand vehicles per hour. FEAT has been used to measure the emissions of more than 450,000 vehicles in Denver, Chicago, the Los Angeles Basin, Toronto, the United Kingdom, and Mexico City.

FEAT has been shown to give accurate readings for CO by means of double-blind studies of vehicles both on the road and on dynamometers (Lawson et al.. 1990; Stedman and Bishop, 1990a). EPA has shown that the readings are closely comparable to laboratory readings from a vehicle on a dynamometer (Stedman and Bishop, 1990a). Lawson et al., 1990 used a vehicle with variable emissions under passenger control to show the correctness of the on-road readings. Figure 2 shows the comparison obtained, and described in more detail by Lawson et al.. There are studies underway to attempt to correlate the remote sensing measurements with other tests, particularly the Federal Test Procedure (FTP). Bishop et al., 1989, and unpublished data from EPA Ann Arbor (E. Glover presentation to CARB Mobile Source Division, March 1991) both show that remote sensing measurements are better correlated to the FTP than are the idle/ no-load emissions used for I/M testing.

It is most important to point out that on-road emissions (both evaporative and tailpipe) are the parameter which all mobile source control agencies are constituted to control. The fact that a remote sensor can be used to directly measure the tailpipe component is of considerable advantage over other tests, particularly if there are ways that individuals or manufacturers can circumvent the other tests, thus rendering the results unrepresentative of the on-road fleet. When an NO channel becomes available then on-road CO, HC and NO emissions will be simultaneously measurable.

The purpose of this report is to present the carbon monoxide measurements made by means of remote sensing in the Los Angeles basin in December of 1989 and compare the results with those from other locations. Throughout this report, we use the term

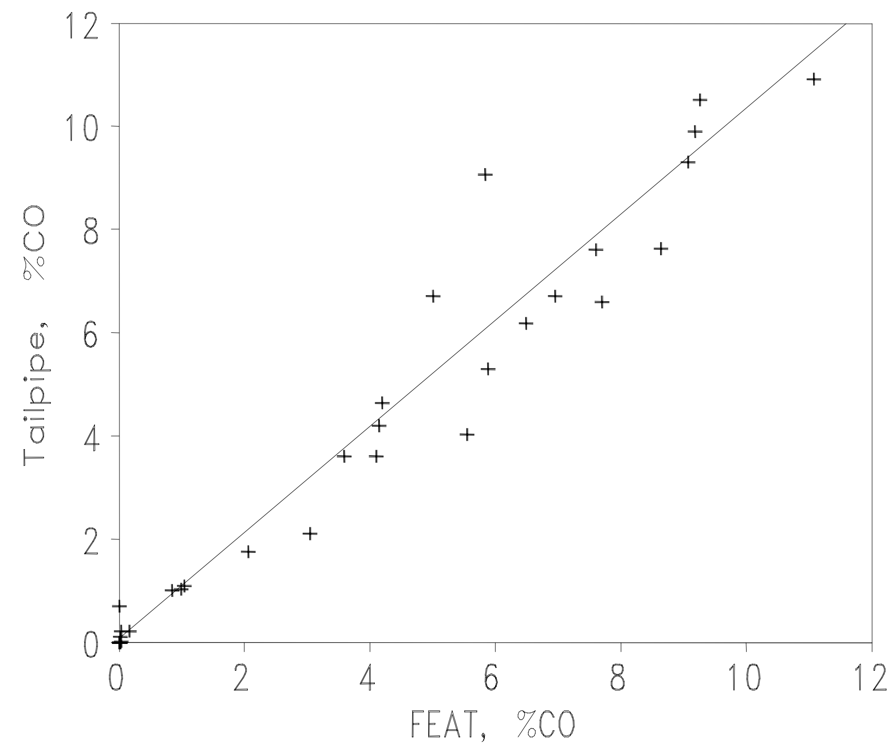

Figure 2. Comparison of tailpipe %CO measured by an on-board analyzer and by remote sensing. Data collected 12/8/89, 12/11/89 and 12/13/89 (n = 34). The equation of the regression line is [Tail pipe %CO] = 1.03[FEAT %CO] + 0.08, with r = 0.97.

"on-road CO emissions" to describe the measurements obtained by the remote sensor, and in the sense of "on-road" intended by the US congress in the 1990 Clean Air Act Amendments. The term "fleet", unless otherwise stated is used to mean those vehicles monitored by on-road remote sensing. When fleet data are analyzed as a whole we find that half the CO is emitted by a small fraction of the vehicles. These vehicles are termed "gross polluters" throughout this text. The cut point for the gross polluter category varies somewhat from fleet to fleet depending mainly on the average age of the vehicles. We also use as a working definition a "clean car" to refer to a vehicle whose on-road CO reading is less than 1 %CO.

Each measurement is a snapshot of the on-road CO emissions at the instant the vehicle passed the FEAT beam, and monitors whatever stable or transient mode the vehicle was in at the time of measurement. In this study vehicles were monitored in a mix of all operating modes. At the freeway on-ramps fast cruise and acceleration were common. At the off ramp the vehicles were travelling uphill, but sometimes the road congested to a point at which very low speed accelerations and decelerations were observed as well as cruise mode driving. On the urban streets all modes of driving common to urban streets were observed including low speed cruise, idle emissions as vehicles moved by in congested traffic, decelerations and accelerations associated with traffic control signals at the end of the block on which the measurements were made.

RESULTS AND DISCUSSION

The FEAT instrument described by Bishop et al., 1989 was set up at several sites in the Los Angeles basin in December, 1989 and three scientific programs were carried out. The three programs were a blind comparison of the FEAT data to emissions from a vehicle of known emissions in order to validate the measurements, a short pilot program in which the FEAT readings were used in real time to direct vehicles to a roadside emissions monitoring test, and a major study of the on-road emissions of a large number of vehicles at several locations chosen by scientists from the California Air Resources Board. The first two programs were very successful and the results have been published (Lawson et al.. 1990). A copy is included as Appendix 1. This report describes the third and final aspect of the study.

Measurements were carried out for eleven days at the six sites listed below. The total number of beam blocks was 33,618. Each beam block starts a search for vehicle exhaust. Error checking routines in the FEAT computer eliminate invalid data caused by pedestrians, bicyclists, etc. The number of measurements with valid emissions data was 27,766. The video tapes were read for license plate identification and the plates which appeared to be in-state and readable were forwarded to the ARB to insert make and model year information. Of the 18,836 emissions readings with readable plates, the ARB returned information on 16,511 from 15,953 unique vehicles. Unless otherwise stated the data analysis uses the data base with 16,511 entries.

Measurement locations

Data on disk will be made available upon publication of this report through Dr. Lowell l. Ashbaugh of the ARB Research Division, P.O. Box 2815, Sacramento CA, 95812, phone (916) 323-1507. The file structure of the data contains headers indicating the site locations. The text below for each site lists the file headers and describes the site in more detail. Figure 3 is a schematic map of the Los Angeles area showing the approximate locations of the sites each indicated by their file header designations.

LONGB06 / Long Beach Boulevard - Dec. 6, 1989

> The first site was used for monitoring vehicles southbound on Long Beach Boulevard in Lynwood one block north of the junction of Long Beach Boulevard and Norton on a typical straight and level city block. Although the Boulevard has two lanes southbound, the left lane was already blocked by gas company operations. The FEAT system was set up within the lane blocked off by the gas company, and the source set up half on the sidewalk and half in the gutter.

Except during the last hour of operation the traffic signals did not block the traffic as far back as the monitoring site. At other times the speeds averaged between 10 and 25 mph.

IMPER07 / Imperial Highway - Dec. 7, 1989

The second site was used for monitoring the right lane of westbound Imperial Highway about 100m west of the junction with Long Beach Boulevard in Lynwood. Both westbound lanes were open, a row of cones and a "pass either side" sign allowed traffic to flow in both lanes around a small island created to shield the FEAT light source and generator. The detector and support vehicle occupied the parking lane. This site was also straight and level driving but since the junction was traffic light controlled the speeds and traffic density depended on the timing of the signal lights. The maximum speeds were 30 mph with mild acceleration when the first few vehicles from the front of the packs came through.

LONGB08 / Long Beach Boulevard - Dec. 8, 1989

This site was approximately 75m south of the first site on the same road, and made use of the same gas company lane closure. This site was nearer to the traffic signals and the traffic regularly backed up to a stop in front of the FEAT beam.

LONGB11 / Long Beach Boulevard - Dec. 11, 1989
LONGB12 / Long Beach Boulevard - Dec. 12, 1989
LONGB15 / Long Beach Boulevard - Dec. 15, 1989

These sites were approximately 100m north of the site LONGB08. The additional move was an attempt to decrease the time that the traffic was backed up in front of the machine by the traffic light at Norton. This was not a complete success, but it was an improvement.

IMPER13 / Imperial Highway - Dec. 13, 1989

This site was used for monitoring vehicles at the south end of the single lane on-ramp from Imperial Highway to Southbound I-710. The same ramp carries through traffic on I-710 which was travelling in the exit lane but chose to carry on under the bridge without taking the optional exit. The lane was flat and the vehicles accelerating and fast moving.

IMPER14 / Imperial Highway - Dec. 14, 1989

This site was pictured on the front cover of the Journal of the Air and Waste Management Association issue of August 1990 in a photograph taken by Dr. Gary Bishop. The measurements were taken near the top of the tightly curved, single lane, uphill ramp from northbound I-710 to westbound Imperial Highway. The vehicles were travelling up a 3% grade in a direction about 45° away from their final westerly direction on Imperial Highway. This was the lone site in which vehicles were not measured on a level grade and was also subject to frequent backups.

WILLO16 / Willow/Katella - Dec. 16, 1989

The on-ramp from Willow/Katella to south bound I-605 freeway was monitored for one day on Saturday December 16th. This location, chosen for a socioeconomic contrast to the Lynwood sites, observed the newest (and cleanest) fleet in this study.

LACN18 / La Cienega - Dec. 18, 1989
LACN19 / La Cienega - Dec. 19, 1989

The La Cienega site monitored the left lane only of southbound La Cienega Blvd. about 600 yds north of the intersection with 120th. Traffic was divided as before (IMPER07) with a "pass either side" island for the light source. This location is also described by Lawson et al.. 1990.

Overall results

Figure 4a shows the distribution of CO emissions (solid bars) by percent CO category from the set of 16,511 vehicles measured at all locations in the Los Angeles area in 1989. The open bars show the overall CO emissions for each category. Not only are more than 10,000 (63%) out of 16,511 vehicles very low emitters, the skewed nature of the distribution is such that more than half the emissions come from only the 10.6 percent of the vehicles with emissions equal to or greater than 4.98% CO or 2,000 gm CO per gallon of gasoline. Very similar rsults have been published by Ashbaugh et el. based on I/M pullover studies. We use the term "gross polluters" for those vehicles identified in this category. Figure 4b and 4c show that the Los Angeles data have a very similar distribution to that from Denver (4,909 vehicles) and Chicago (11,818 vehicles). The overall results from three major studies with fleets matched to license plates are listed in Table I.

Figure 4 is not indicative of a normal (Gaussian) statistical distribution with vehicle numbers spread equally about the mean, and the mean and median equal. Motor vehicle emissions turn out empirically to be distributed according to a gamma

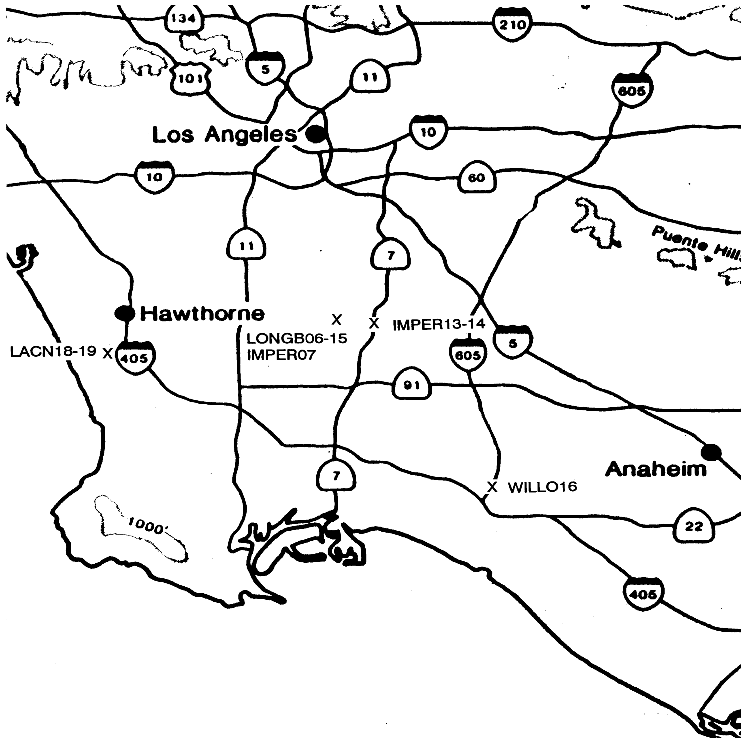

Figure 3. Map of the Los Angeles Basin indicating the approximate locations of the sampling sites.

Table I. Summary of relevant statistics for the three major US cities in which FEAT data have been collected.

Location / Year	Mean %CO	Median %CO	Mean Model Year
Los Angeles / 1989	1.56 0.04	0.37	81.8
Denver / 1989	1.03 0.03	0.15	83.1
Chicago / 1989	1.17 0.05	0.22	83.5

distribution, which is quite different from the more familiar normal or bell shaped distribution. An additional example of this type of distribution is the age distribution of a population with a constant birth rate and an exponentially increasing death rate (for example the human population). Two consequences of gamma distributions are, 1) "outliers" cannot be estimated or eliminated based on classical statistics (i.e. 3 standard deviations) and 2) robust analysis of emissions data requires large N

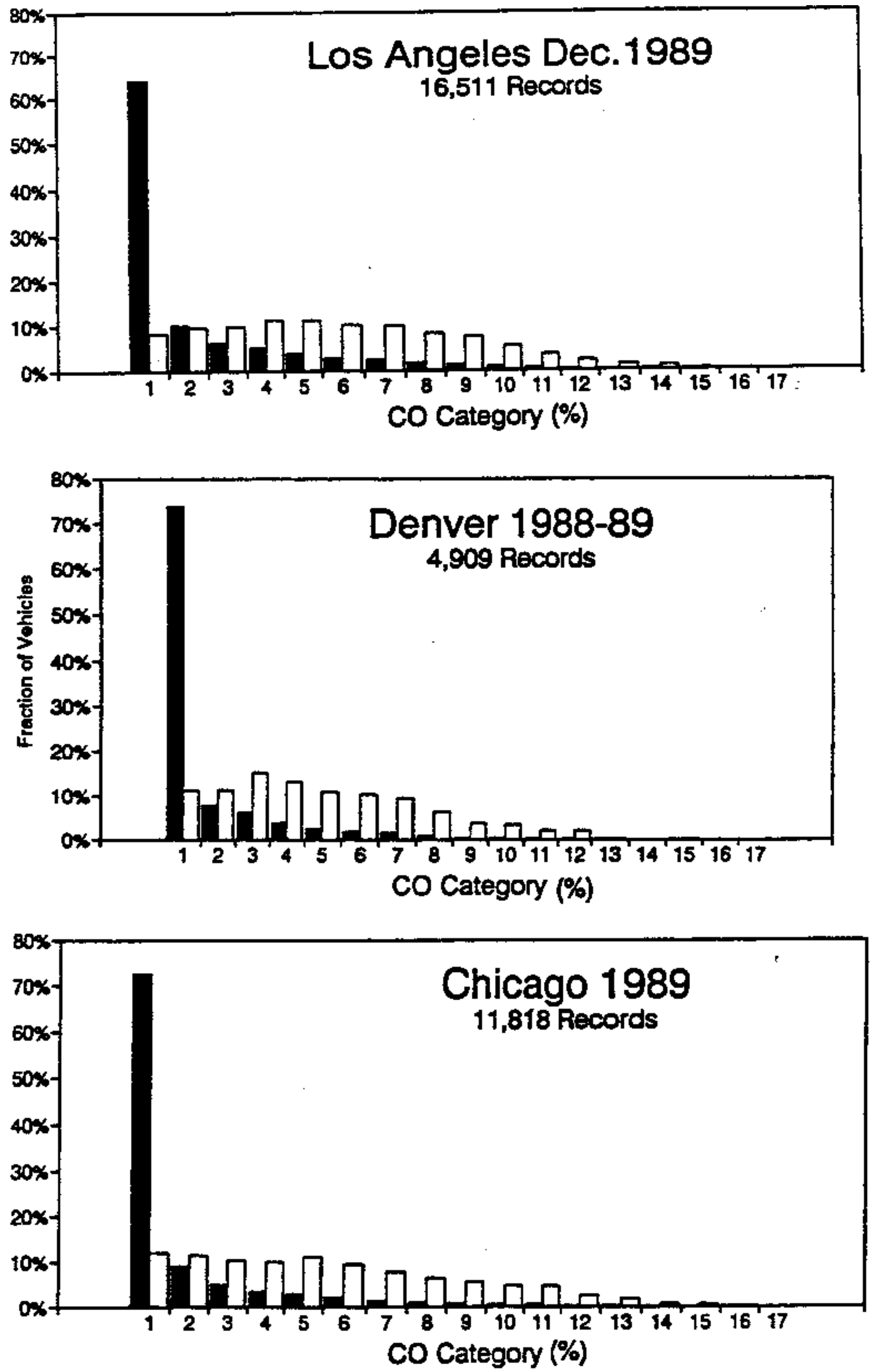

Figure 4. Normalized histogram showing as black bars the percentage of the fleet of vehicles with emissions less than the stated %CO category. Clear bars show the percentage of the emissions. a) Los Angeles data b) Denver c) Chicago.

(population) values since the emissions picture is dominated by a few high emitters (i.e. the tail really does wag the dog).

The ten bars shown in Figure 5 illustrate in deciles the emissions of a fleet of ten vehicles matching the observed total emissions and statistics of the observed data (Figure 4). Each bar corresponds to the emissions of one tenth (a decile) of the total fleet. Note that the cleanest seven bars have been averaged together. This has been done because the tiny differences between low emission averages of the cleanest seventy percent of the fleet are within the error bars of the FEAT measurement capability. These decile plots illustrate that Denver, Los Angeles and Illinois have very similar CO emission distributions, and that most vehicles are very low emitters. The lower panels again show that the Los Angeles fleet emissions are very similar to those from other locations, even though the altitude (5,000 ft.) in Denver and the I/M programs are different. The I/M programs in Denver and Los Angeles are decentralized, annual in Denver, biennial in Los Angeles. The I/M program in Illinois was annual and centralized at the time these studies were undertaken.

As a part of this analysis we were asked by the ARB Research Division to answer several questions. Each question is given below in bold type followed by the answer.

Representativeness of the fleet

1. Is the distribution of emissions in the final data set the same as the distribution in the entire data set? That is, after eliminating measurements for which we could not obtain Department of Motor Vehicle (DMV) information, is the remaining data set a representative sample?

Of 27,766 valid CO emissions readings 16,511 (60%) were successfully matched to DMV records. The matched fleet is believed to be a representative sample of the total fleet observed with unreadable plates accounting for the majority of the difference. These were most often the result of a vehicle's position in the roadway, such that the license plate was not within the camera's field of view. This process will eliminate vehicles randomly. In California, older plates showed far less contrast and were harder to read. This effect removes older and therefore on average higher polluting vehicles. The third principal cause of unreadable plates was missing, dirty or obscured plates.

Overall, there is a cumulative effect of preferential removal of older or dirtier vehicles. This is apparent in the percentile plot of raw FEAT data versus DMV matched data shown in Figure 6. Although the difference is visible, it is also apparent that the difference is small. The small difference which accumulates through the high polluting tail of the population shows up as a noticeable difference in the means of the two data sets. The final DMV matched data set at 1.56%CO is lower than the adjusted (raw data base with only invalid records removed) FEAT mean %CO of 1.70. This effect would be observed if the total fleet were on average 3/4 model year older.

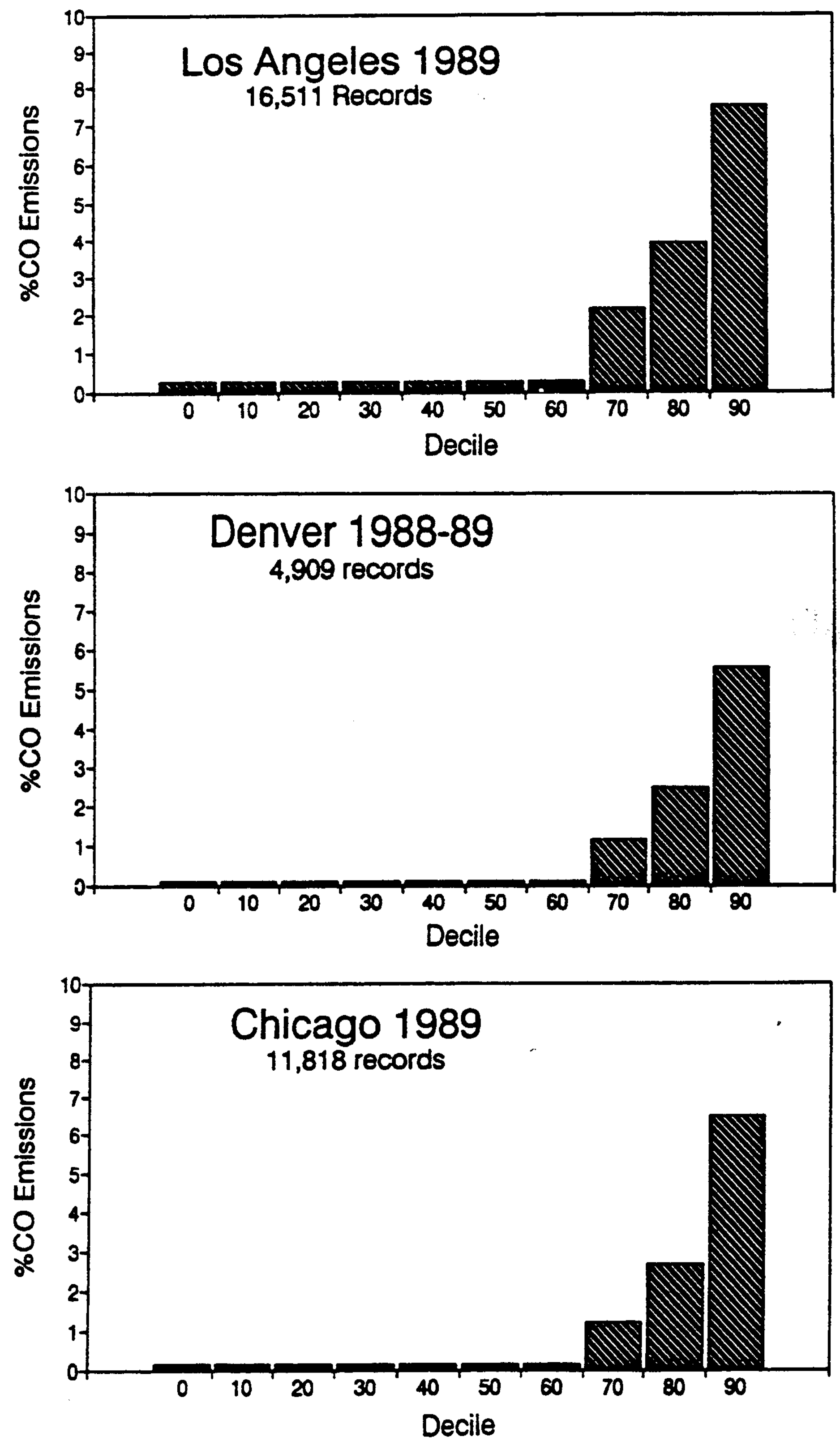

Figure 5. A fleet representation divided into ten vehicles whose %CO emissions match the observed fleet. a) LA, b) Denver, c) Chicago. Because of such small differences the cleanest seven deciles are given the average of all.

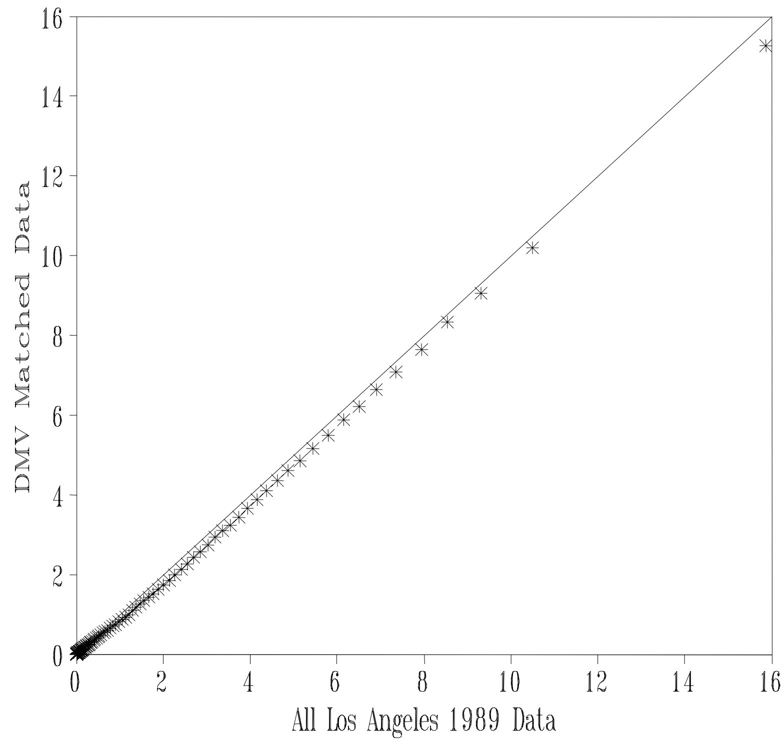

Figure 6. Each percentile of the DMV matched data by %CO plotted against each percentile of the total data set on the same scale. The solid line is where the data would fall if the two distributions where identical.

The study plan did not attempt to obtain a representative fleet, only to observe the wide variability possible in the Los Angeles area with a particular emphasis to the fleet in the Lynwood area. In view of the relatively small number of locations at which monitoring was carried out we would make no claims as to the representativeness of our data to the total fleet in the Los Angeles basin were it not for the fact that all fleets measured in the US and Canada seem to fall in a common population to be discussed herein.

Factors affecting differences between locations

2. Examine the difference in mean %CO at the different sites. Are the differences between Lynwood and the other areas caused by a different distribution of vehicles or a different distribution of emissions? Or is there another explanation?

Figure 7a shows %CO versus age correlation for all DMV matched data sets available to the University of Denver as of March 1, 1991 divided into one hour collection times. Using only the data collected below 7,000 feet altitude and for those sets containing at least 100 records, a correlation was determined of mean %CO vs hourly average age.

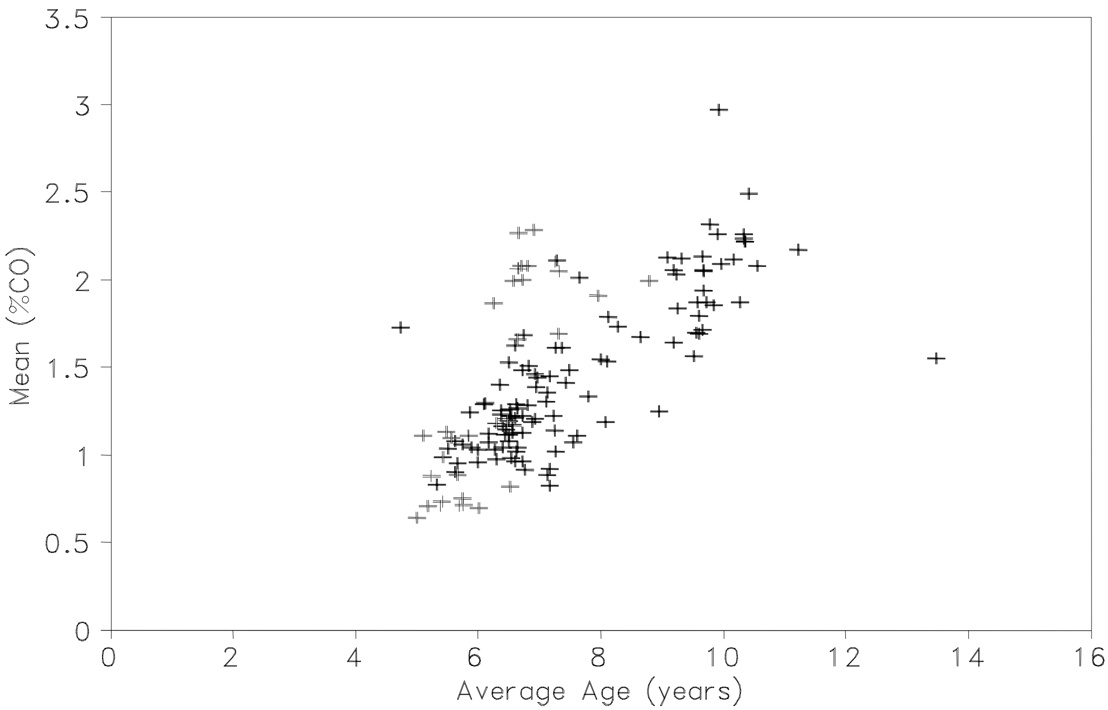

Figure 7a. Hourly measured %CO emissions plotted against hourly average age for all of the available data from US sites.

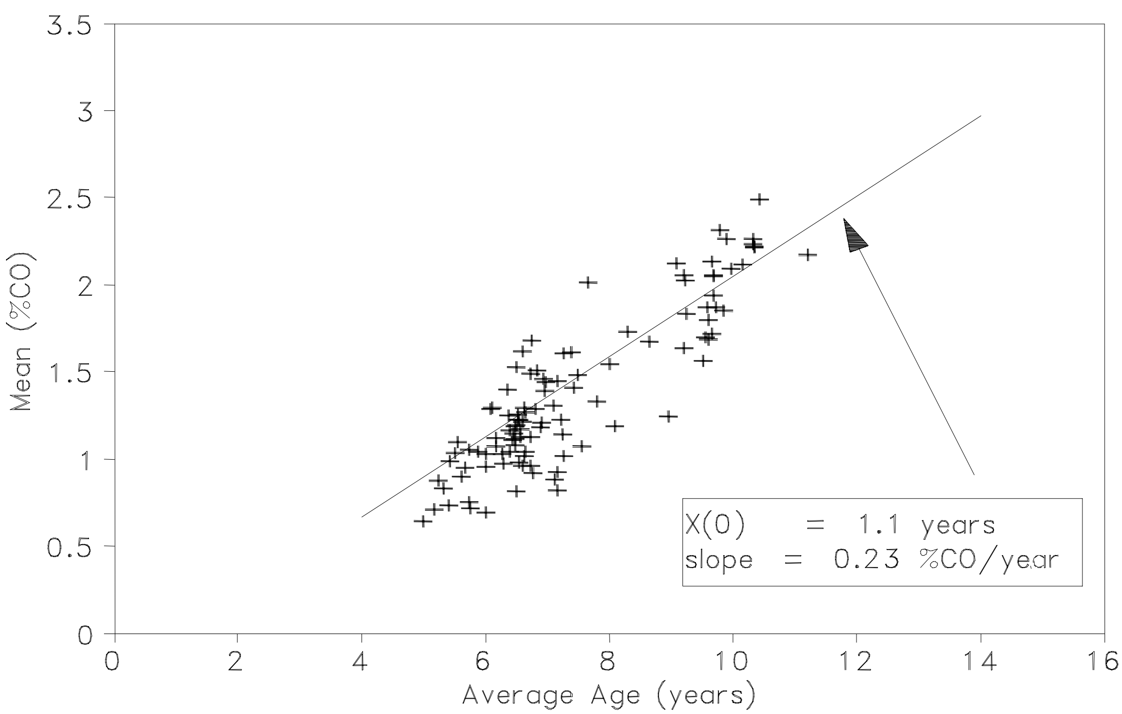

Figure 7b. A subset of Figure 7a, where only hourly averages which contain more than 100 vehicles and were collected below 7000 ft. in altitude remain. The regression line is weighted according to the number of vehicles in each point.

These selected data are shown in Figure 7b. A weighted regression line of slope 0.23 %CO per year and an X intercept at 1.1 years has a highly significant R^2 of 0.78 with 107 degrees of freedom. Figure 7a which shows all data irrespective of altitude, load and number of vehicles measured in the given hour, not surprisingly evidences more scatter, but the underlying correlation is still clear. The scatter observed when hourly fleets of less than 100 vehicles are included reinforces the conclusion about the need for large N values to obtain statistically valid data.

The fleet-averaged CO emissions model derived from these data is as follows:

$$\%CO = 0.23 * (AGE - 1.1) \quad \textbf{(1)}$$

where

$$AGE = Test\ year - Model\ year \quad \textbf{(2)}$$

From %CO the mass emissions in grams CO per gallon of gasoline used can also be derived (Stedman and Bishop, 1990a)

$$\frac{grams\ of\ CO}{gallon} = 15{,}800 * \frac{\%CO}{42 + 2.07 * \%CO} \quad \textbf{(3)}$$

As an example the average %CO for the 16,511 vehicle fleet is 1.56%. This translates into 545 gmsCO/gallon. If for some reason mass emissions in gmsCO/mile are required then gmsCO/gallon must be converted to gmsCO/mile by means of gas mileage data. For the purposes of illustration, assuming an average gas mileage of 17mpg, then the average emissions of 1.56%CO corresponds to an average gm/mile of 32. For the purposes of obtaining emissions inventories it is likely that accurate data for gallons sold in an area are more easily obtainable than accurate vehicle miles travelled (VMT) data. According to Wolcott and Kahlbaum (1990), in many cases VMT for use with MOBILE4 are actually estimated from fuel tax data.

Figures 7c through h illustrate the same data, but with various subsets highlighted. It is important to note that the Chicago, Denver and Los Angeles data are clearly members of the same set. The only data set which lies distinctly off the line is the Ute Pass study which measured vehicles at an altitude of 7,500 ft under a heavy uphill load at high speed.

The dominant variable responsible for variation in hourly average fleet %CO emissions is hourly average fleet age. Even though the age effect dominates, more subtle effects of vehicle speed/load are observable beneath the underlying data scatter. Figure 7d shows that the on-ramp emissions are significantly greater than the off-ramp emissions for fleet of similar age. This illustrates not only that different operating modes were monitored, but that when age factors are taken into account the effect of driving mode differences can be distinguished.

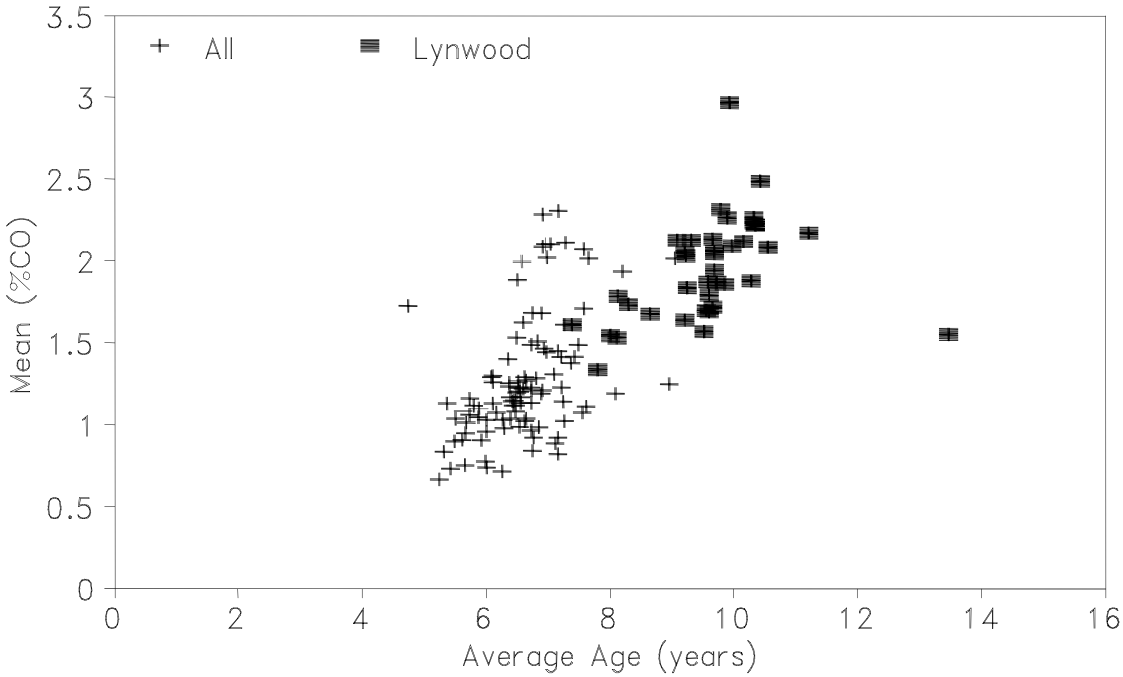

Figure 7c. Figure 7a with the hourly average data collected in Lynwood, CA highlighted as squares.

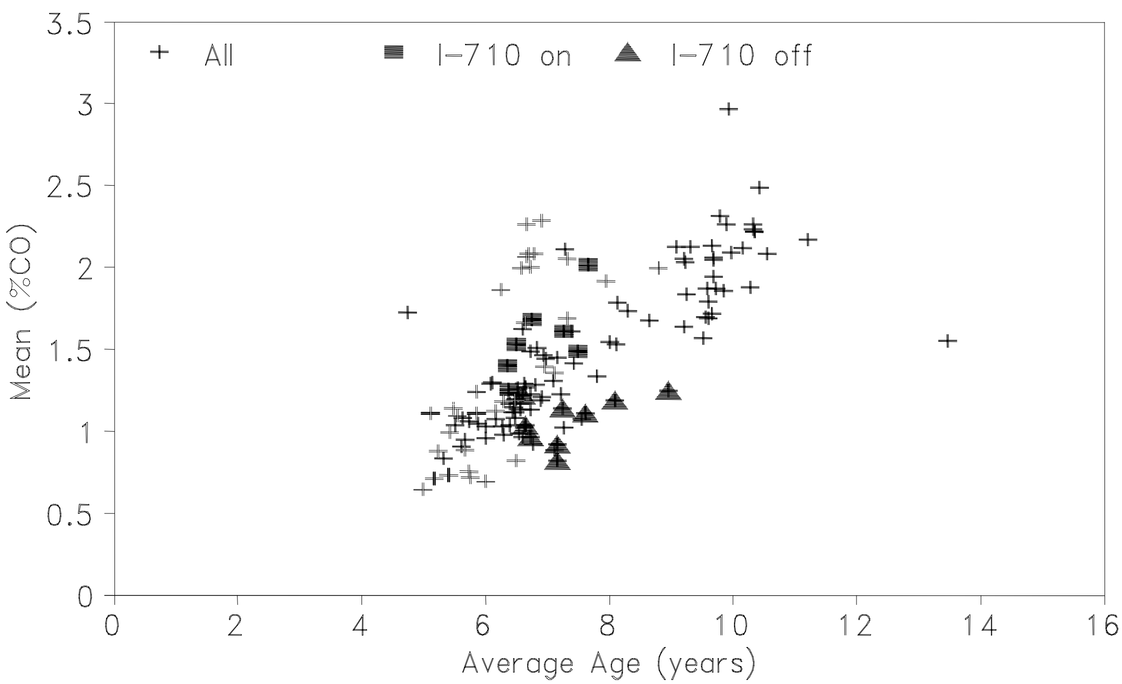

Figure 7d. Figure 7a with the hourly average data collected in Los Angeles at the I-710 on-ramp highlighted as squares and the I-710 off-ramp highlighted as triangles.

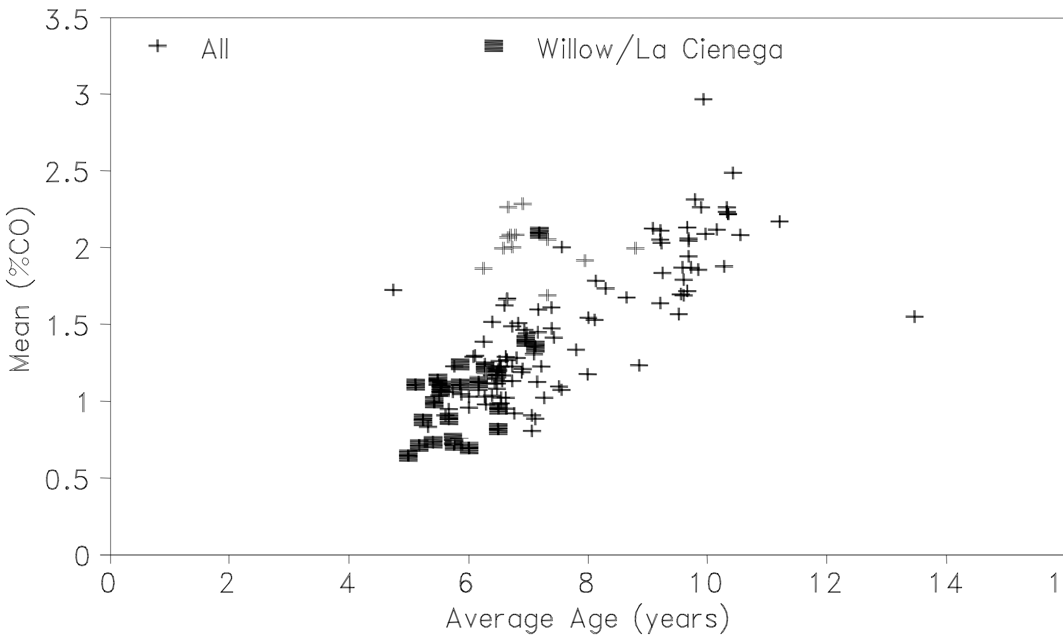

Figure 7e. Figure 7a with the hourly average data collected at the Willow/Katella and La Cienega sites in Los Angeles highlighted as squares.

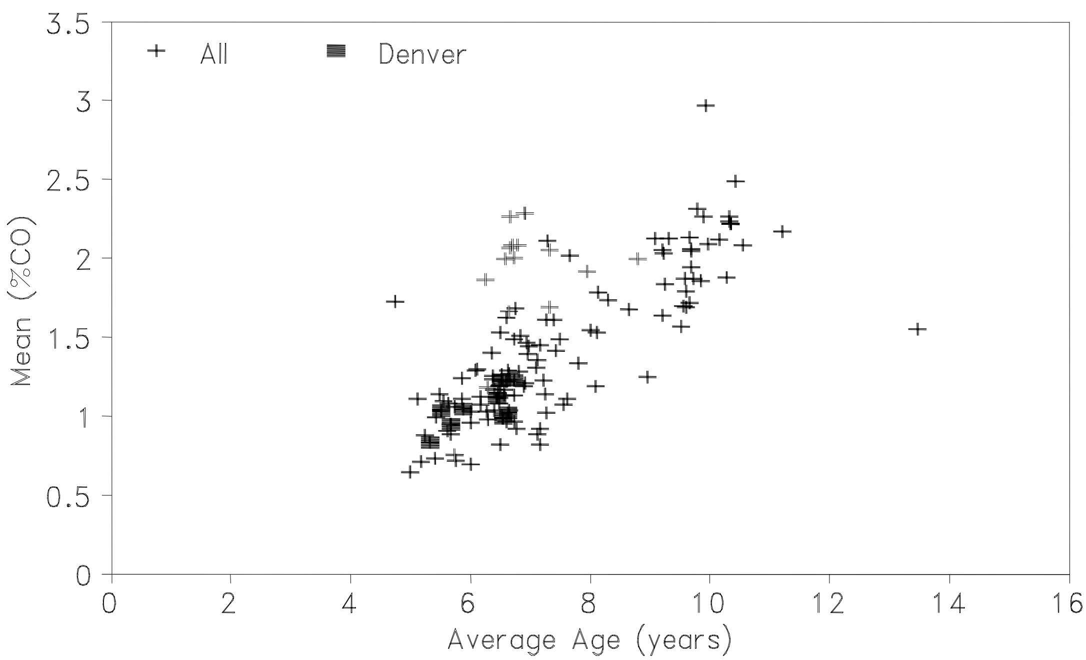

Figure 7f. Figure 7a with the hourly average data collected in Denver, CO highlighted as squares.

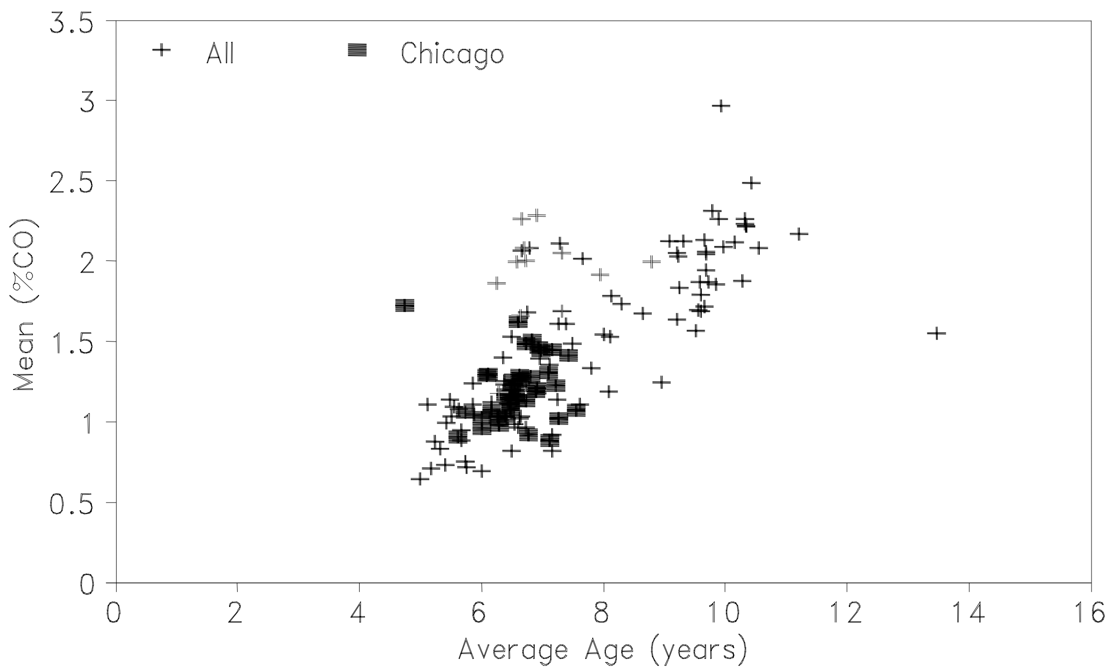

Figure 7g. Figure 7a with the hourly average data collected in Chicago, IL highlighted as squares.

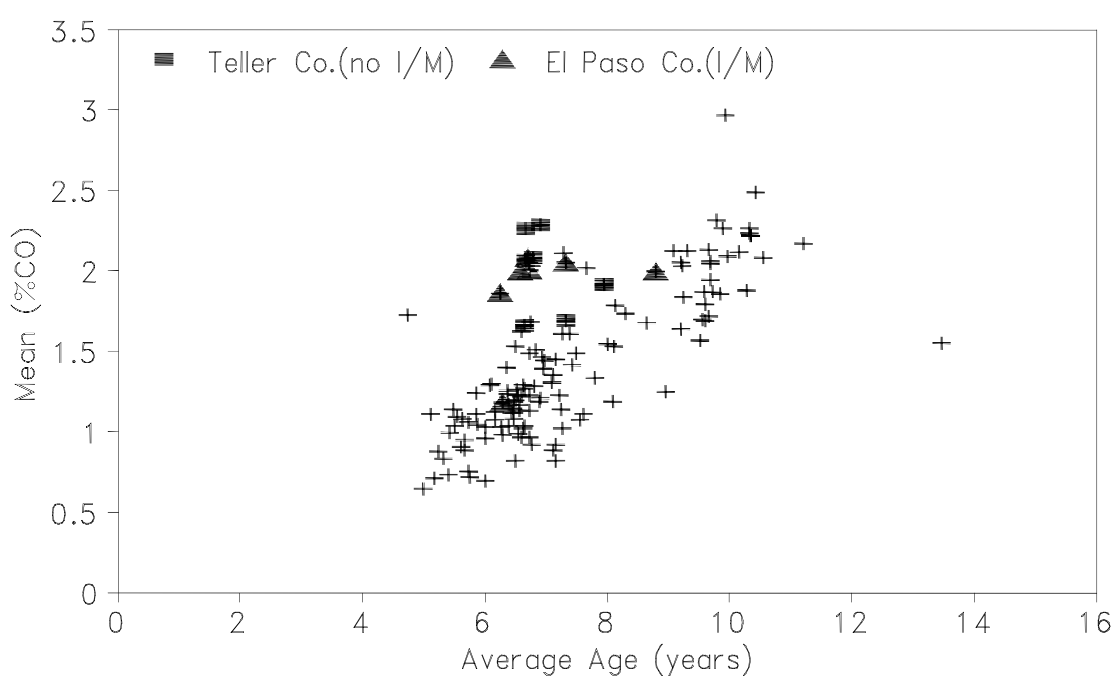

Figure 7h. Figure 7a with the hourly average data collected at Ute Pass (7,500 ft. located in Bust, CO). The data are segregated according to county of registration which distinguishes I/M program status.

Table II. Data from Los Angeles and Chicago containing a minimum of 100 vehicles.

SITE	DATE	MEAN AGE	MEAN %CO
Long Beach Blvd.	12/06/89	8.31	1.94
Long Beach Blvd.	12/08/89	8.86	1.71
Long Beach Blvd.	12/11/89	8.91	2.13
Long Beach Blvd.	12/12/89	8.91	2.01
Long Beach Blvd.	12/15/89	9.14	2.24
Imperial Highway	12/07/89	7.71	1.67
Cumulative Site Averages		8.73	1.95
Standard Deviations			0.207
I-710 [on]	12/13/89	6.09	1.57
I-710 [off]	12/14/89	6.63	1.09
Cumulative Site Averages		6.39	1.33
Standard Deviations			0.24
La Cienega	12/18/89	5.73	1.16
La Cienega	12/19/89	5.66	1.04
Willow/Katella	12/16/89	4.86	0.76
Cumulative Site Averages		5.31	0.99
Standard Deviations			0.168
Chicago	12/07/88	5.48	1.16
Chicago	12/08/88	5.59	1.20
Chicago	12/09/88	5.57	1.14
Chicago	12/10/88	5.49	1.11
Chicago	12/11/88	5.61	1.21
Cumulative Site Averages		5.53	1.164
Standard Deviations			0.037
REGRESSION ANALYSIS			
Slope 0.23% CO/year 0.01			
Y Intercept -0.3% CO 0.2			

Table II lists the measured emissions from each site in the Los Angeles basin, together with the five days of data from Chicago. Average %CO varies from 1.95 in Lynwood to 0.99 at the Willow and La Cienega sites. The variance of the four site averages is 0.175. When all data are adjusted by means of the slope of equation 1 to the average age of approximately six years the extremes are then 1.24 %CO for I-710 and 1.32 %CO for the Lynwood sites. The variance of the four site averages about their mean is reduced from 0.175 to 0.004. Most of the variation in fleet means between various locations in Los Angeles, and between Los Angeles and other locations is attributable to the changes in average fleet age. The Lynwood area fleet is considerably older than any other site, and the CO emissions reflect that age difference. The only average emission factors which vary between similar age locations are those from the on and off-ramps to I-710 in which the accelerating on-ramp is significantly higher in emissions than the tightly curled uphill off-ramp, even though both data sets fall within the overall spread of the total data set. There is no evidence of significantly different average emission factors between Los Angeles, Denver or Chicago when age is taken into account.

Factors affecting variations at the same site

3. Examine the variability within sites. In particular, mean %CO at the Long Beach Blvd. site ranged from 1.7 to 2.2 on different days. Why did this occur? Is it variability in the remote sensor, the vehicle fleet characteristics, operating conditions or some other cause?

The daily mean emissions from similar sites in Lynwood vary from 1.71 to 2.24 %CO The first set of numbers in Table II shows these means grouped together with the one measurement from Imperial Highway in the same area. Some of the observed variation in the means can be explained because the average age of the observed fleet was not constant. Since the values under discussion are means not individual measurements it is valid to use normal (Gaussian) descriptive statistical parameters. When adjusted for the different average age observed from each site at Lynwood the variance (sigma squared) is reduced from 0.044 to 0.023 (from Table II). There is still residual variance after the age factor is taken into account. This may possibly arise from the differences in the observed driving modes at the various locations. The only site which was measured more than once was Long Beach Blvd. on the 11th, 12th and 15th, which are in good agreement.

The daily means from the Imperial/I-710 on-ramp and off-ramp show a difference which increases when age adjusted. This reinforces our previous suggestion that the difference results from the effect of the higher speed/load operating condition at the on-ramp site.

In Chicago the data were collected at a single site. Notice that even before age correction the Chicago site, which was intentionally at exactly the same spot every day, shows a much smaller standard deviation than the Lynwood sites for which identical locations were not a criterion. A later starting time or an early quitting time for the on-road measurements can change the average age of the sampled fleet even when no change in the site has taken place. This age difference correspondingly alters the mean emissions, age adjustments even for the small age differences observed in Chicago reduce the observed variance from 1.4 to 0.8 (x 10^{-3}).

Comparison of data to other locations

4. Examine the variability between Los Angeles, Denver, and Chicago. What differences exist in the fleet characteristics and how does this relate to emissions?

Among the three cities, as among the different days in Los Angeles, adjusting the mean to an equal age of six years eliminates most of the variation. Examination of the quintile emission factor distributions from the three cities (Figures 8a, 9a, 10a) shows that for each model year the emission factors are similar. The value of the mean %CO in all three fleets rises smoothly back to 1980 when the fifth quintile mean reaches about 6 %CO At this point the dirtiest quintiles for Chicago and Denver stop rising. The Los Angeles dirtiest quintile continues to rise until it averages above 7 %CO The overall averages of gamma distributions are controlled by the tails, and the tails contain the vehicles which we call the gross polluters. Table III shows that the rise in the fifth quintile for the Los Angeles data set corresponds to an increase in the percent of gross polluting vehicles and not to an increase in the emissions for the "average" vehicle in the model year. The table is organized to represent the basic divisions in emissions control technology, i.e. 83-90 are closed-loop, 3-way catalyst equipped, 81-82 are a transition between 83-90 and 75-80 technologies, 75-80 are vehicles with oxidation catalyst and 74 & older are the pre-catalyst vehicles. Table III also points out how strikingly clean most new cars are. The 1989-90 model year contains more total vehicles than the 1981-82 classification, yet a factor of 13 less gross polluting vehicles. This increase from almost no gross polluters to a 20-30% minority has also been observed in Denver and Chicago (Bishop and Stedman, 1990, Stedman and Bishop, 1990b) and attributed to increasingly poor maintenance and tampering (EPA, 1990) with age. This conclusion is supported by three lines of evidence. The quintile plots show no sign of any breaks in emission factors for model years when emissions technology or emissions standards were changed. The comparison between Denver, Chicago and Los Angeles show no large differences despite the fact that California CO new vehicle standards have been a factor of two less stringent (seven g/mi) than those in the other locations. A dirty new vehicle is significantly dirtier than a clean old vehicle as seen from comparing the fifth quintile of the new vehicles against the first quintile of any age.

The second panels, Figures 8b, 9b and 10b show the observed age distributions of the three measured fleets. The combined effects of recessions, rust and riches (socioeconomic status) of the locations chosen cause significant differences in the observed age distributions. When the emissions factors are multiplied by the age distributions the lowest panels Figures 8c, 9c, 10c are obtained. These show the emissions contributions to the urban areas by the measured fleets. In all cases the

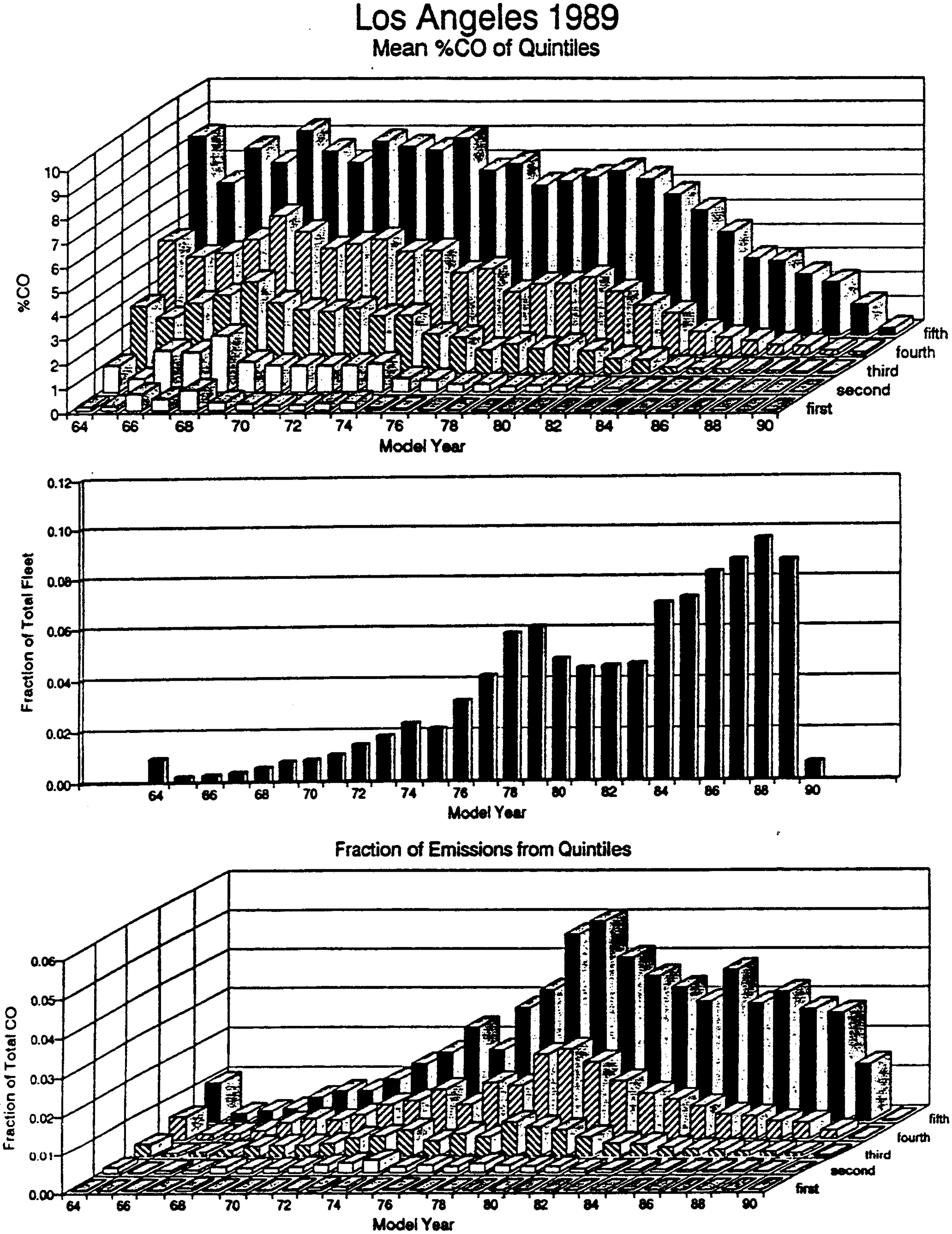

Figure 8. The Los Angeles data presented as, a) Emission factors by model year divided into quintiles, b) Fleet model year distribution and c) The product of graphs a and b. Note that the dirtiest 20% of 1976 models and newer dominates the total.

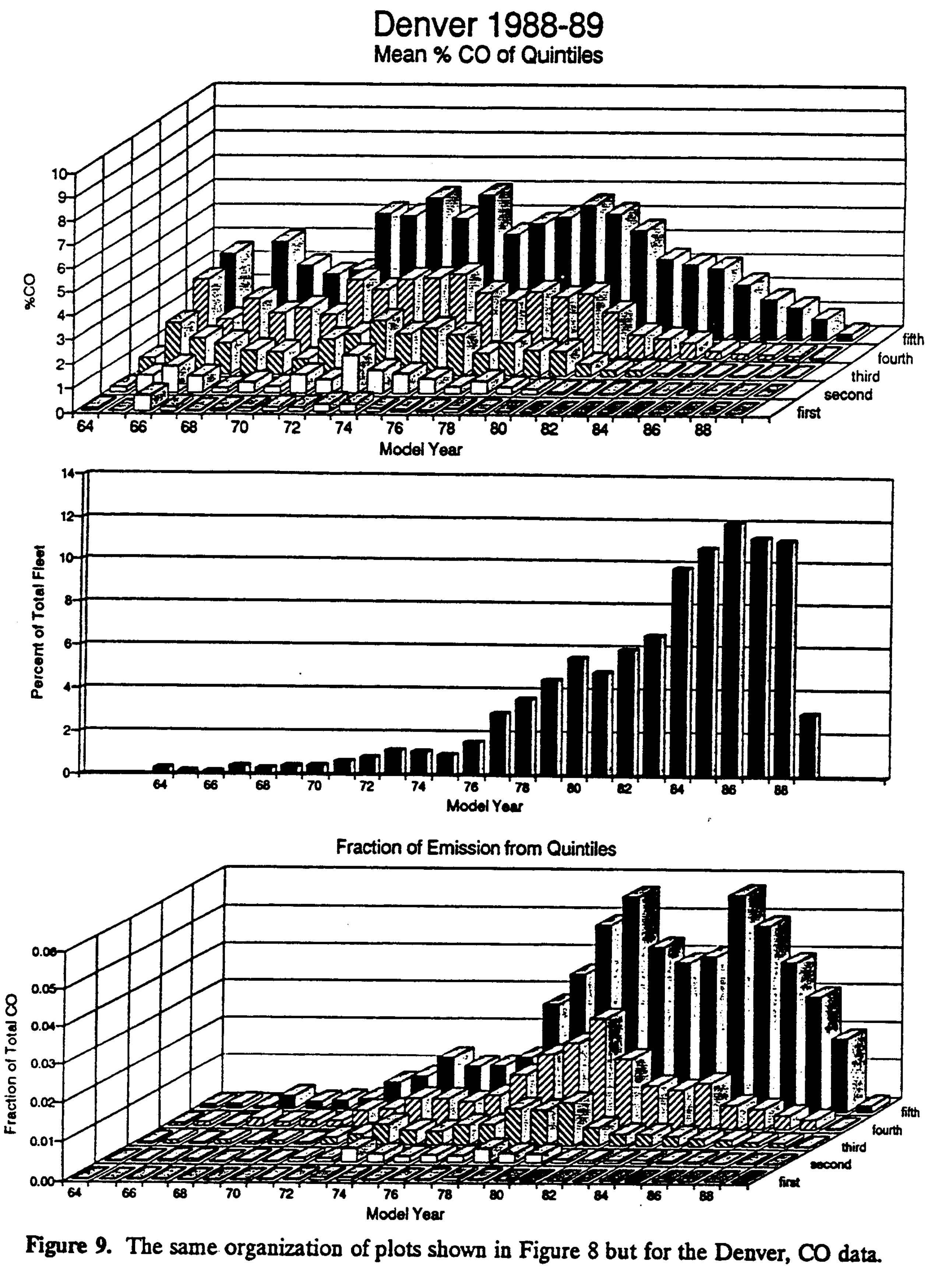

Figure 9. The same organization of plots shown in Figure 8 but for the Denver, CO data.

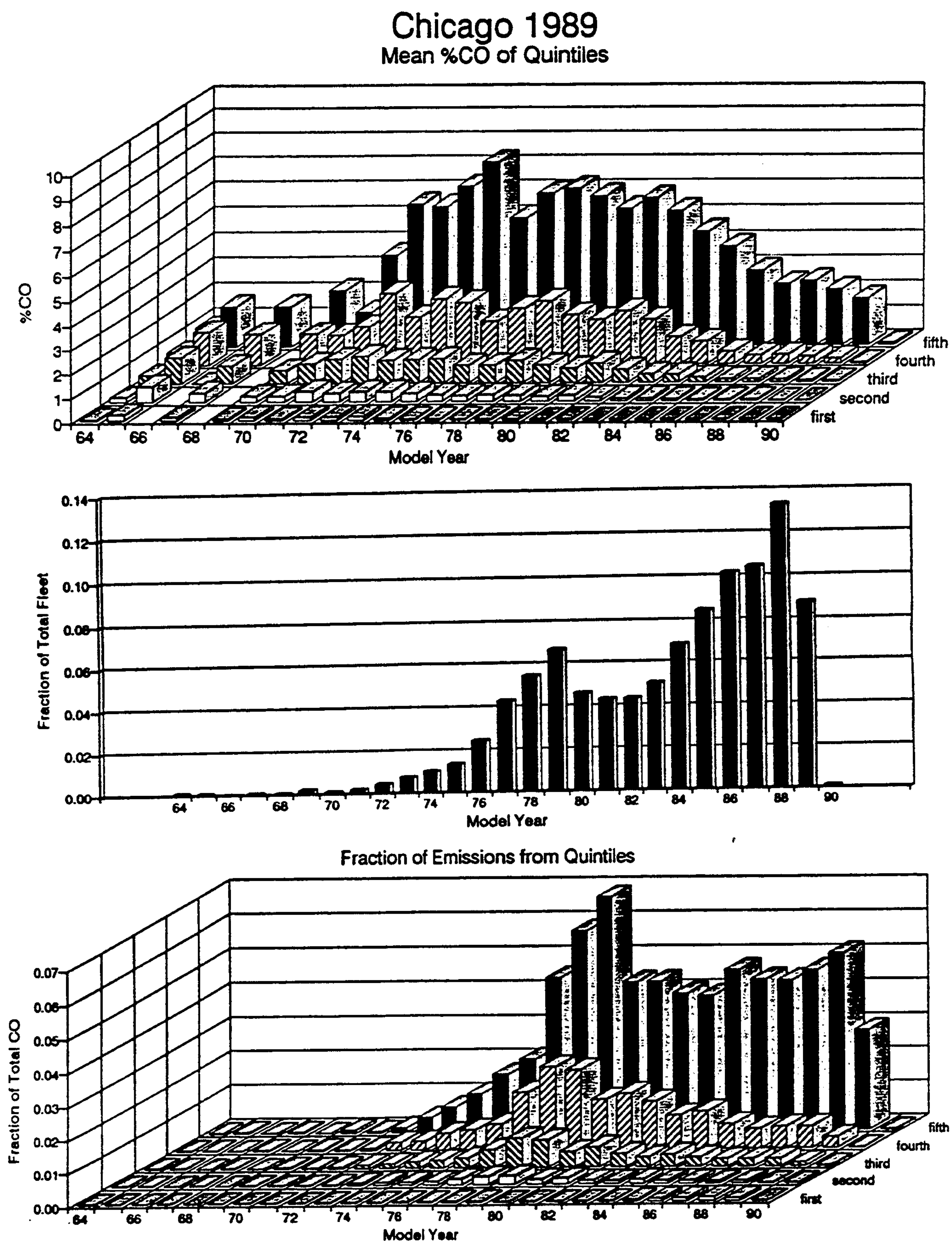

Figure 10. The same organization of plots shown in Figure 8 but for the Chicago, IL data.

Table III. Gross polluters (4.98%CO and above) by approximate emissions control categories in Los Angeles, 1989.

MODEL YEAR CATEGORY	NUMBER OF GROSS POLLUTERS	NUMBER OF VEHICLES	PERCENT OF VEHICLES
89 - 90	15	1549	1
83 – 90	328	9004	4
81 – 82	196	1472	13
75 – 80	718	4277	17
74 & Older	504	1758	29

oldest vehicles are almost irrelevant to total fleet emissions because they are not numerous, and most new vehicles are irrelevant because they are low emitters. In all three cases the dirtiest 20% of the vehicles between two and twelve years of age stand out as the vehicles in most need of improvement. The quintiles show that even for the oldest vehicles the median emissions (almost equal to the third quintile illustrated) are quite a lot smaller than the emissions of the dirtiest quintile. On-road remote sensing can identify the gross polluting vehicles of any age or technology category which have emissions much greater than most other vehicles, even those of the same age or technology category.

There are very few vehicles in the Chicago fleet older than model year 1975. Thus the data become noisy and differences between fleets can not be resolved from the noise. Quintiles were not calculated for model years 1966 and 1968 where the total number of measured vehicles is less than five. The three fleets are very similar when compared in terms of the emissions of each model year. Denver is more variable but the sample size is smaller (4,909 total vehicles). Among the older vehicles, Los Angeles emissions are greater than Chicago or Denver.

The Chicago fleet shows the dirtiest quintiles of the 1-4 year old vehicles, noticeably higher than the same data from Denver or Los Angeles. That effect has been attributed to the fact that the single site used in Chicago is a straight uphill on-ramp, and is a location in which some vehicles will evidence "off cycle" or "power enrichment" emissions. Even at this site the contribution to the total fleet emissions from new vehicles in a power enrichment mode seems to be less than ten percent (R. Stephens General Motors, Private Communication March 1991). Note that the on-ramp emissions in Los Angeles discussed earlier when age corrected were noticeably larger then the corresponding off-ramp.

In summary, the major source of high CO in all three fleets is the dirtiest quintile of model years 1976 to 1988 vehicles. The observed differences both internal to the Los Angeles database and between Los Angeles and the other locations tested is the average age distribution of the tested fleet (Figures 7a - 7h). Driving mode and possibly altitude of the measurements when above 7,000 ft. show lesser effects. A linear model (equation 1) of CO emissions depending only on fleet average age has been derived which appears to predict fleet CO emissions from all measured US fleets except that at 7,500 ft to within 0.5% CO The fraction of gross polluters rises from 1% of the 1989 and 1990 model year vehicles to 30% of the oldest vehicles. Most old vehicles (>70%) are not found in the gross polluting category. Note however that although the emission factors are similar for all three locations measured (Figures 8a, 9a and 10a), the older fleet in Los Angeles leads to a higher average %CO and a higher gross polluter cut point (five percent CO) than found in Chicago or Denver.

Repeat measurements of the same vehicle

5. Examine repeated measurements of the same vehicle at different times. What fraction of the vehicles are always clean, always dirty, or flip back and forth?

Only 77 vehicles were measured four or more times in the Los Angeles study when the GM test vehicles (Lawson et al. 1990) were removed from the analysis. These vehicles and their CO emissions are summarized in Table IV and listed in Appendix 2. The %CO readings are listed in order from the lowest on the left to the highest on the right. The vehicles are placed in three groups in order of decreasing variance of the %CO readings. The groups are defined as; lowest %CO reading greater than three (very dirty vehicles): lowest %CO reading greater than one (intermediate vehicles) and lowest %CO less than one (clean vehicles which might be new vehicles subject to power enrichment {off cycle emissions} at the instant of measurement). If the list is scanned for new vehicles in the last category two stand out, namely the 89 GMC and the 88 HOND. Peak power for many engines occurs at the air to fuel ratio corresponding to about 5%CO The two vehicles identified show 6.2 and 3.6 %CO respectively as their highest readings. Some older vehicles appear to go much richer in their power enrichment mode. The 79 MAZD, 75 PONT and 82 FORD go to 11, 9 and 8 %CO respectively. Whether this high a reading is actually the peak power point for these vehicles or whether the power enrichment mechanism actually needs adjustment can not be determined.

At the University of Denver we define the term "gross polluter" to mean those vehicles that contribute half of the total measured CO emissions. In Chicago all measurements were at the same location. The gross polluter cut point (4.48 %CO) is site specific. For Los Angeles the gross polluter cut point (4.98 %CO) is a fleet average but dominated by the older fleet from six days in Lynwood. We also have a working definition of a clean vehicle as one measured with exhaust CO less than one percent (63% of the measured Los Angeles fleet). If one were to attempt a control program based on

Table IV. Vehicles which were measured four or more times at the various locations in Los Angeles 1989. (n=77)

CATEGORY	NUMBER OF VEHICLES	PERCENT OF 77	PERCENT OF EMISSIONS
Always clean <1%	33	43	4
>1% sometimes but never > 4.98%	20	26	18
> 4.98% only once	5	6	9
> 4.98% at least twice*	19	25	69
Totals	77	100	100
*Always > 4.98%	1	1.3	6.6

identifying those vehicles with emissions greater than the gross polluter cut point twice or more, then the newest vehicle which would be identified would be the 83 FORD for which the lowest CO emissions were 2.87 %CO

Of these 77 vehicles 33 were consistently clean (<1%CO). These constitute 43% of the fleet and emit only 4% of the CO At the other extreme one vehicle from among the "Gross at least twice" category was always in the gross polluting category. This vehicle emitted more CO than the 34 clean vehicles put together and was responsible for 6.3% of the total CO emissions. Twenty vehicles were occasionally over 1% but always less than 4.98 %CO They constitute 26% of the fleet and emit 18% of the CO Twenty four vehicles showed more variable emissions. Of these vehicles 19 were over the gross polluter cut point at least twice. This 25% of the fleet emitted 69% of the CO Because the fleet of Los Angeles repeat vehicles is so small (< 100 vehicles) it is worth illustrating their similarity to the statistics of vehicles from Chicago. Table V summarizes a similar study in the Chicago area which was carried out at a single site only, and monitored a larger fleet of repeat vehicles.

As in Los Angeles, of the multiply-measured vehicles about half are always clean (less than 1 %CO whenever measured). These clean vehicles generate less than 10% of the total emissions. Vehicles measured as gross polluters at least twice are responsible for approximately half of the total CO emissions.

Table III. Vehicles measured four or more times in Chicago in 1989. (n=671)

CATEGORY	NUMBER OF VEHICLES	PERCENT OF 671	PERCENT OF EMISSIONS
Always clean <1%	425	63	9
>1% sometimes but never > 4.48%	113	17	18
> 4.48% only once	75	11	25
> 4.48% at least twice*	58	9	48
Totals	671	100	100
*Always > 4.48%	12	1.8	13

As will be discussed later, it can be shown that only a small fraction of the total observed emissions can be ascribed to cold start or to off-cycle hard accelerations which can lead to intentional fuel enrichment.

Video tape reading errors

There are several ways to check on the accuracy with which the video tapes have been read, and the accuracy with which the DMV records reflect the on-road fleet. A previous study in Colorado in which the video tapes were reviewed for positive identification showed that the proportion of misread tags and DMV errors was less than 1%. One way to flag potential plate reading or DMV errors is to look at vehicles whose emissions readings or whose registration status are not possible if the laws of California are being adhered to. There is a category of "dismantled" in the DMV records. Of the 50 vehicles (out of 18,836 submitted) reported in this category, all but one turn out to be misread plates, or plates with the alphanumerics correctly read, but not registered in California. The remaining vehicle's license was correctly identified.

Appendix 3 lists the vehicles identified as diesel in order of their CO emissions. This listing was utilized to provide a further check on the accuracy of the license plate transcription process. Since diesel vehicles are clearly a minority compared to their gasoline counterparts, their random interspersion would provide an excellent check for the entire database. One hundred of the diesel vehicles were searched for and located in the collection of video tapes and the license plate was checked for accuracy and the make/model of the car was compared against the DMV records. Only four vehicles were found to have been misidentified. Three were incorrectly typed in license plates from cars with difficult to read tags. The last vehicle's tag appeared to have been correctly read, however the DMV make was a Mercedes while the vehicle was obviously a Ford.

Inspection and maintenance

Only 32 vehicles were identified as registered in counties without an I/M program at the time of measurement. In view of the skewed statistics of vehicle emissions it is not possible to use so small a fleet to draw meaningful conclusions when comparing I/M to non-I/M fleets. When a similar study was carried out in Colorado there was much less difference between I/M and non-I/M fleets than predicted by the EPA computer models (Stedman et al., 1991).

It has been suggested (Austin et al., 1990) that the ten percent of the fleet which we observe to be gross polluters are in actual fact clean vehicles (as measured for instance by the FTP) which we find accidentally to be either in a cold start mode or engaging in an off-cycle acceleration and associated fuel enrichment. While these are valid criticisms, this and our previous data show conclusively that cold start and off-cycle emissions are small contributors to the total emissions. Figure 11 summarizes the results illustrated in more detail in Figure 8a. From Figure 11 it is apparent that the average emissions of new vehicles measured when new is small, and the median emissions from vehicles up to four years old are negligible. It is reasonable to assume that cold start and off cycle (power enrichment) emissions are just as likely to afflict new as old vehicles. It is therefore possible to determine a very conservative upper limit for the contribution of these two modes to the total emissions by assuming that **ALL** the emissions from the 1990 model year vehicles are a result of cold start and off cycle emissions. The average total fleet emissions for the Los Angeles database is 1.56 %CO The average 1990 fleet %CO is 0.232. This provides an upper limit of 14.9 percent of the total emissions which could possibly arise from off cycle or cold start operation. Similar results are obtained from Denver and Chicago.

This conclusion is based on a logical argument based on three assumptions:

1) It must be an overestimate to assume that ALL 1990 vehicle emissions arise from cold start and off cycle emissions.

2) It is reasonable to assume that cold start and off cycle emissions do not vary with model year.

3) If all model years are assigned the 1990 vehicle emissions this will be an overestimate of the total emissions arising from cold start and off cycle operating conditions.

There is no doubt that emissions vary with operating mode (Austin et al., 1988), but concentration (%CO or gmsCO/gallon) emissions are less variable than emissions per

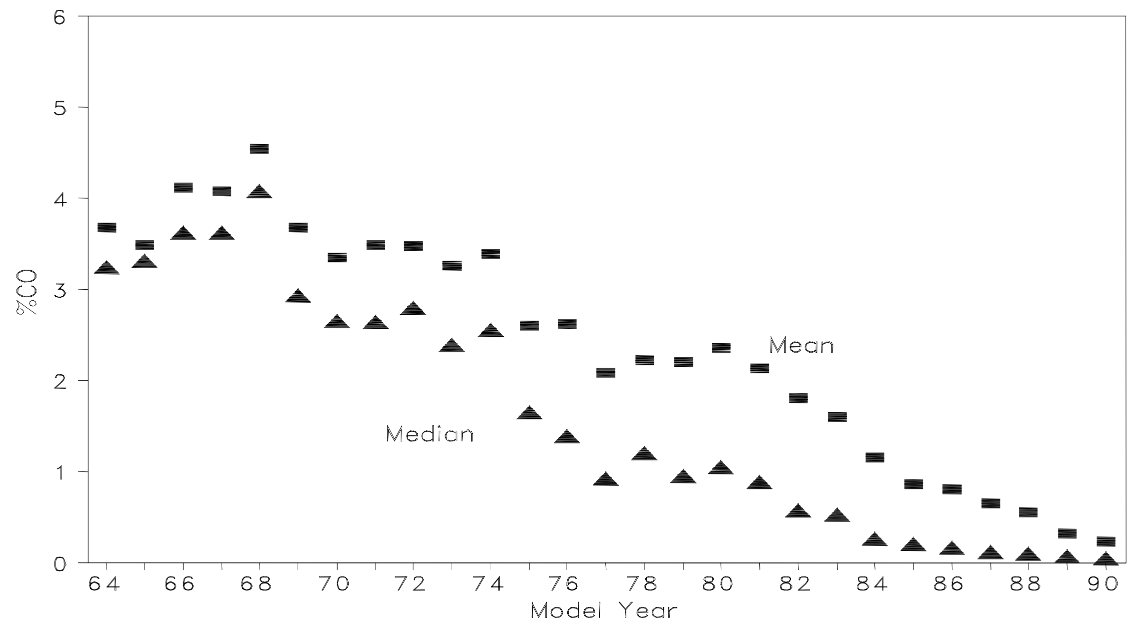

Figure 11. Mean (upper points) and Median (lower points) %CO emissions by model year from the Los Angeles database.

mile since they do not depend on the transmission selection, only on the engine air to fuel ratio and the emissions system status. Vehicles with variable emissions as measured by the remote sensor do contribute to the emissions picture, but if only those few vehicles which are frequently observed as gross polluters are required to undertake further testing and appropriate repair, then a large fraction (more than half of the current fleet emissions, see Tables IV and V) could be controlled. In view of the fact that most vehicles are measured consistently as clean, we believe that many of the variable emitters will be found to have some emissions related problem. The pilot study (Lawson et al., 1990) indicated when the remote sensor was used with a four percent CO cut point, the fleet identified thereby consisted of vehicles with almost a fifty percent tampering rate and a 91% I/M test failure rate. This result is all the more remarkable since Smith, (1988) has shown that I/M test scores of properly maintained vehicles are highly variable.

The emissions variability observed in this data set is similar to the emissions variability observed when vehicles are repetitively subjected to conventional I/M testing (Smith, 1988). These results imply that an inspection and maintenance program incorporating remote sensing, which targets gross polluters with multiple violations, has the potential to identify a significant fraction of the CO emissions while inconveniencing only a small fraction of the vehicle owners. Our analysis concludes that on-road remote sensing as a **component** of an I/M program has the advantages of being representative of the on-road emissions of the vehicle in question, being an emissions test which is almost impossible to circumvent, and incorporates a "fairness factor" such that the more a vehicle is driven, the more frequently it will be tested. On road remote sensing can be carried out at a per-test cost and at a vehicle throughput at least ten times more advantageous than any other type of I/M program.

Emissions characteristics segregated by vehicle make

Altogether the remote sensing data for CO available to the University of Denver amounts to over 35,000 records collected from Los Angeles, Denver and Chicago. With a database this size it becomes possible to analyze the emissions from various segments of the fleet without losing statistical significance. The first analysis of this type considers the effect on CO emissions of the continent of origin of the vehicle fleet. In this analysis the continent of origin is derived strictly from the maker's name. No attempt has been made to separate vehicles made in the USA by manufacturers outside the USA, thus all Renault and Volkswagen are classified as European, all Honda, Toyota and Subaru as Asian, all Ford, GM or Chrysler are treated as US wherever manufactured. Figure 12 shows the results of this analysis. The line labelled "ALL" is the overall weighted regression discussed earlier. The points are the fleet averages labelled by the location of measurement (L, D, C) and the origin of make (A, U, E). For all three fleets the same pattern emerges. In each case the Asian manufactured fleet is newer and for that reason lower in average %CO than the US fleet from the same location. In each case the European manufactured fleet stands out as falling below the regression line (i.e. cleaner) than the US fleet even though there is no consistent trend as to whether the European fleets are on average older (Denver) or newer (Chicago) than the US fleets.

The Los Angeles fleet has been further segregated in order to investigate the cause of the relationships shown in Figure 12. Figure 13 shows the data coded by the same symbols (A, U, E) as a function of model year as registered. As discussed earlier, the new vehicles are on average quite clean. Furthermore, there is no evidence of significant differences in the emissions of the new fleet depending on their continent of origin. For vehicles from one to six years old the Asian manufactured fleet appear systematically as the dirtiest on this graph. It is important to note that the gas mileage of the Asian fleet is higher on average than the US fleet, thus higher emissions in %CO or in the equivalent gm/gallon units may not in every case correspond to a higher fleet average in gm/mile units (Stephens and Cadle, 1990). For vehicles registered as 1974 and older the data lose significance because the total numbers of vehicles in the database are too small to make meaningful distinctions. For the fleet manufactured between 1975 and 1983 the US manufactured vehicles stand out as having the highest emissions in %CO or gm/gallon units. In per-mile units they would stand out even further, particularly in the 1980 to 1982 model years. For all model years from 1975 to 1989 the European manufactured fleet is the cleanest.

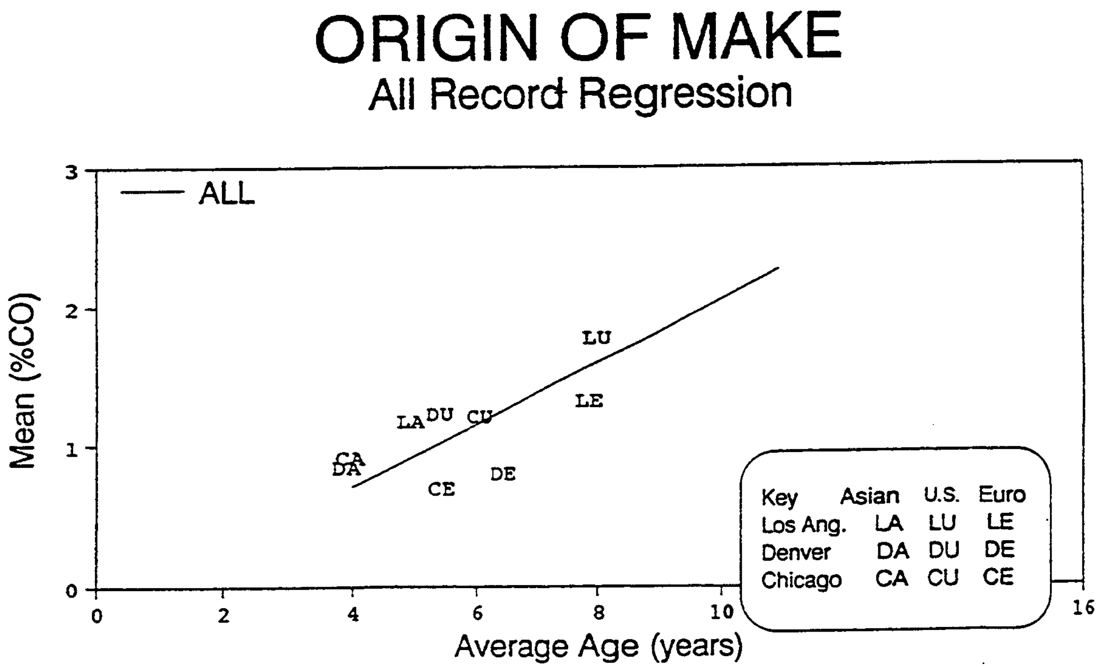

Figure 12. A plot of Mean %CO versus average fleet age based on origin of production, Asian, US, or European. The regression line drawn was previously determined in Figure 7b.

Since the 1990 fleets from different origins all have the same low emissions, and since the average emissions of all fleets is dominated by a small percentage of dirty vehicles, we believe that the differences over time are caused by maintenance factors. There are two factors affecting maintenance, the owner's willingness to pay for required maintenance, and the manufacturer's ability to provide a vehicle which either requires little maintenance, or can be easily maintained when maintenance is required.

One further analysis attempts to differentiate between these factors. The entire US database has been searched for vehicles with the maker's names Ford (>4,000), Chevrolet (>6,000) and Cadillac (>1,000 vehicles). All vehicles with these names are included regardless of whether the vehicles are listed as pickups or as passenger vehicles. Figure 14 shows this analysis again as a function of model year. In the Los Angeles data the model years 1980-1982 stood out as showing the US fleet to be particularly high emitters. For two of those years the Ford fleet appears to be significantly higher emitting than the Chevrolet fleet. For other model years the differences are not as important, although Ford CO emissions are most often larger than Chevrolet. What does stand out from this graph is that average Cadillac emissions are almost always the lowest, often less than half the Ford/Chevrolet group. Since the new vehicle average %CO emissions are both small and similar for all fleets the inclusion of pickups in the Ford and Chevrolet fleets would not appear to be the cause of the large differences in the 1980-1986 time frame. Since the average emissions are again to dominated by the number of gross polluters, we ascribe the differences again to

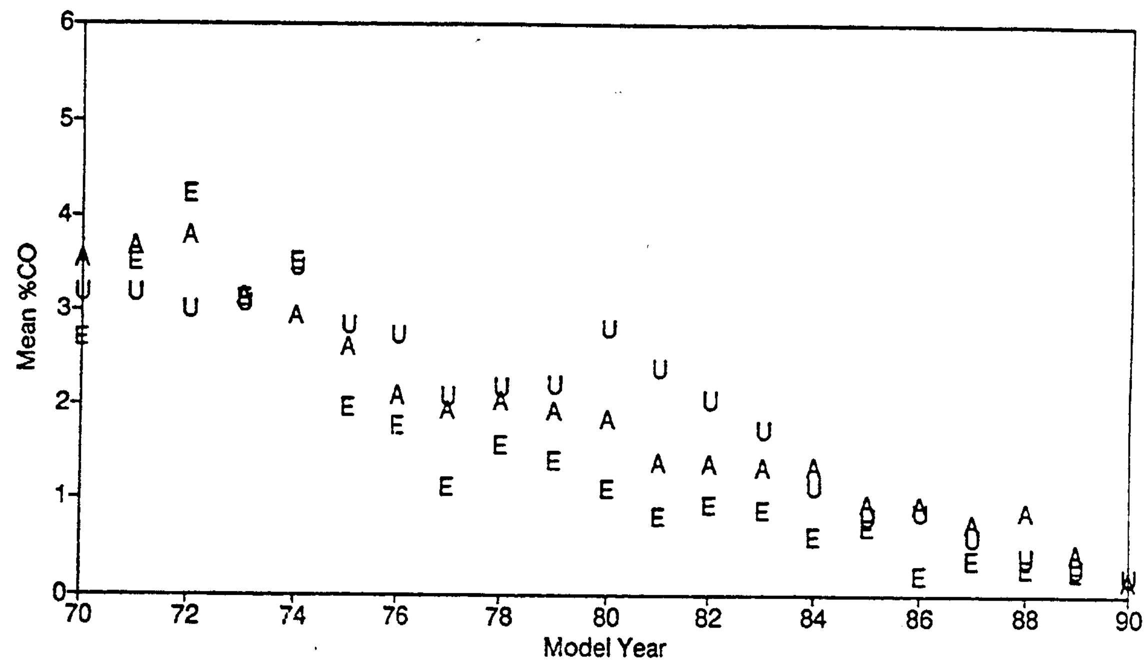

Figure 13. A plot of Mean %CO versus Model year for the Los Angeles data segregated according to origin of production. Asian (A), US (U) and European (E).

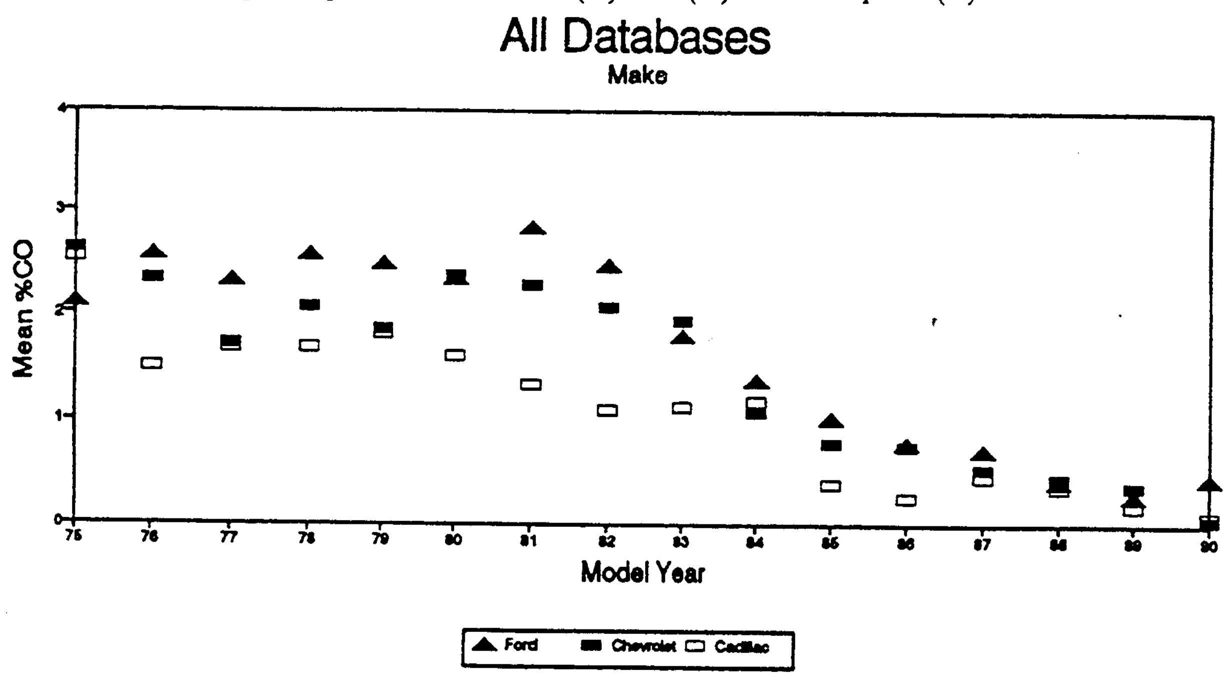

Figure 14. A plot of Mean %CO versus Model year for Fords (triangles), Chevrolets (squares), and Cadillacs (open squares) obtained from all of the US data sets.

maintenance. We believe that owners who have spent more money initially to purchase a vehicle are more likely to spend the money required to maintain the vehicle, hence

Cadillacs with fewer gross polluters than Chevrolets. This is observable despite the diesel to gas engine switching discussed below, which affects Cadillacs but not Chevrolets. To the extent that many of the European manufactured vehicles are also in the higher price range when new, their lower average emissions may also be ascribable to the fact that their owners are willing to spend the money necessary for proper maintenance.

We have analyzed the Los Angeles data base to compare 87-89 model Ford, Chevrolet, Toyota, Honda and Nissan with Hyundai. In this comparison the average %CO emissions for all but Hyundai are less than 0.55% while the Hyundai's average is more than 1.6 %CO. Although most 1987-89 Hyundais were measured at less than 1 %CO, a larger than expected fraction are observed with higher emissions. It is possible that this problem is not maintenance related, and represents a problem caused by the manufacturer.

Based on on-road emission studies in London, Toronto and Mexico City, there can be no doubt that Federal New Vehicle Emission Standards have caused a dramatic reduction in fleet emissions. This reduction is the reason that all new and most older vehicles in the US and Canadian fleet are consistently very low emitters regardless of make or country of origin. In view of the fact that high CO emissions are dominated by a few badly maintained gross polluters, and that there is no evidence that the fleet average on-road emissions show any evidence of major breaks due to changes in technology or changes in new vehicle emission standards, we believe that further analysis based on maker or technology classification is not warranted. If these analyses are correct there is still considerable room for improvement in average on-road CO emissions of the current USA fleets as measured by on-road remote sensing, provided that the required maintenance is correctly performed and illegal emissions system tampering eliminated.

Vehicles registered as diesel powered

Appendix 3 gives a tabular listing of all of the vehicles which the Department of Motor Vehicles has registered as diesel powered. As can be seen a number of these vehicles are high emitters. With the exception of some trucks which display a diesel logo on their front grills it is impossible from the video tapes to positively identify whether a vehicle is gasoline or diesel powered. One of these vehicles is the 1984 GMC pickup which was measured on La Cienega Blvd. at 8.09 %CO and was positively identified to have switched its engine to a gasoline powered engine (Lawson et al., 1990). Considering the probabilities of finding such a vehicle in only two days of testing, it can be concluded that this type of vehicle (GM diesel switched to gas) exists in sizable numbers in the Los Angeles basin. With this in mind all of the diesel vehicles which registered readings above 2% CO were organized according to make. Out of 47 vehicles, 39 or 80% were General Motors products, mostly 79 - 82 model year

Oldsmobiles, Buicks and Cadillacs. These are vehicles for which it is very easy to insert a gasoline engine to replace the originally installed diesel. The California diesel exemption from the Smog Check program provides an incentive not to report the engine switch.

An examination of those vehicles registered as FUEL = "D" show values that are inconsistent with the known emissions from dynamometer measured diesel engines. The high compression, excess air and operating temperatures in diesel engines minimize the emission of CO in the exhaust. The question arises as to the probability that the anomalous 1979-1982 GM manufactured "diesel" fleet contains some vehicles whose engines have been exchanged and the DMV has not been notified of the engine switch.

In order to address a formal statistical answer to this question we defined the 1979-82 GM diesel fleet (GMD) as all 65 vehicles regardless of CO emissions which were identified as manufactured by GMC and powered by diesel engines. The first test is to determine whether this fleet is statistically different from the other vehicles registered as having diesel engines. The Cumulative Distribution Function (CDF) for the GMD fleet was compared with the CDF of other assumed pure diesel fleets using the Kolmogorov-Smirnov (K-S) Q-statistic (Press et. al., 1989 and von Mises, 1964). This analysis yields a probability that the two subsets could be random subsets of a single parent population. Figure 15 shows a plot of the CDF of all the above diesel subfleets and the CDF of the total LA90 fleet. There is 0% probability that the GMD fleet has a common parent population with any diesel subfleet that does not contain the vehicles in question. The GMD fleet is not only higher emitting than the other diesel labeled fleets but is obviously much dirtier than the LA90 fleet as a whole.

What fraction of the 65 GM diesel vehicles have probably had an engine exchange? To answer this question we make the following assumptions.

1. The GMD fleet contains some diesel powered vehicles.
2. These diesel vehicles resemble the fleet of all non-GM diesels in emissions.
3. The GMD fleet contains some gasoline powered vehicles.

The final assumption revolves around the question as to the emission distribution of gasoline powered subset to be merged with the diesel vehicles to match the GMD emission distribution. There is no incentive to add emission controls as long as the engine switch is not reported to the DMV and since there is a cost incentive not to install pollution controls it is therefore assumed that the exchanged engines have no emission controls. Since the diesel fleet has lower emissions than the GMD fleet, the gasoline fleet must be dirtier than the GMD fleet. Several sub-fleets were compared to the GMD fleet to find one suitable for mixing with a diesel fleet. The fleet of all Volkswagens older than 1982 is cleaner than the GMD fleet and therefore not usable. The fleet of all cars with model year from 1965 to 1975 is very similar to the GMD fleet and therefore still not usable. The fleet of cars with model years from 1955 to 1970 is

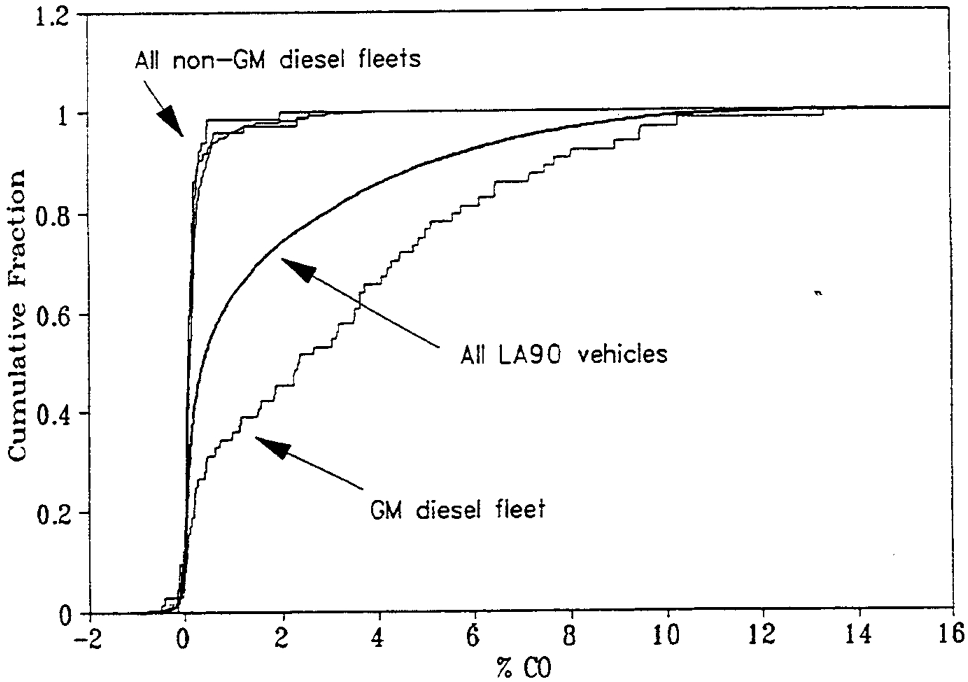

Figure 15. A plot of the CDF for the total LA90 fleet and various sub-fleets showing the relationship of the 1979-1982 GM diesel fleet. The All non-GM diesel fleet includes sub-fleets such as Ford, Mercedes Benz and all medium duty diesels.

suitable for mixing. These vehicles have no emission control devices and there are few incentives for extraordinary maintenance on these old vehicles. Our final assumption is then:

4. The "engine switched" vehicles resemble the fleet of 1955-1970 cars.

A model fleet was derived using X percent 55-70 cars and (100 - X) percentage from the non-GM diesel fleet. X represents the percentage of vehicles with engines exchanged. Again using the K-S statistic, X was adjusted to maximize the K-S probability that the model fleet and the GMD fleet came from the same parent population. A mixture of 77 percent 55-70 cars with only 23 percent diesels gave a model fleet with >99% probability of single parent population (Figure 16). All non-GM diesel fleets include fleets from Chicago and Toronto. Many heavy duty diesel powered vehicles have elevated exhaust systems and are thus infrequently observed by the current FEAT system. For this reason the observed diesel fleets at all locations are mostly the light and medium duty vehicles with exhaust pipes emitting at a level comparable to the FEAT light beam.

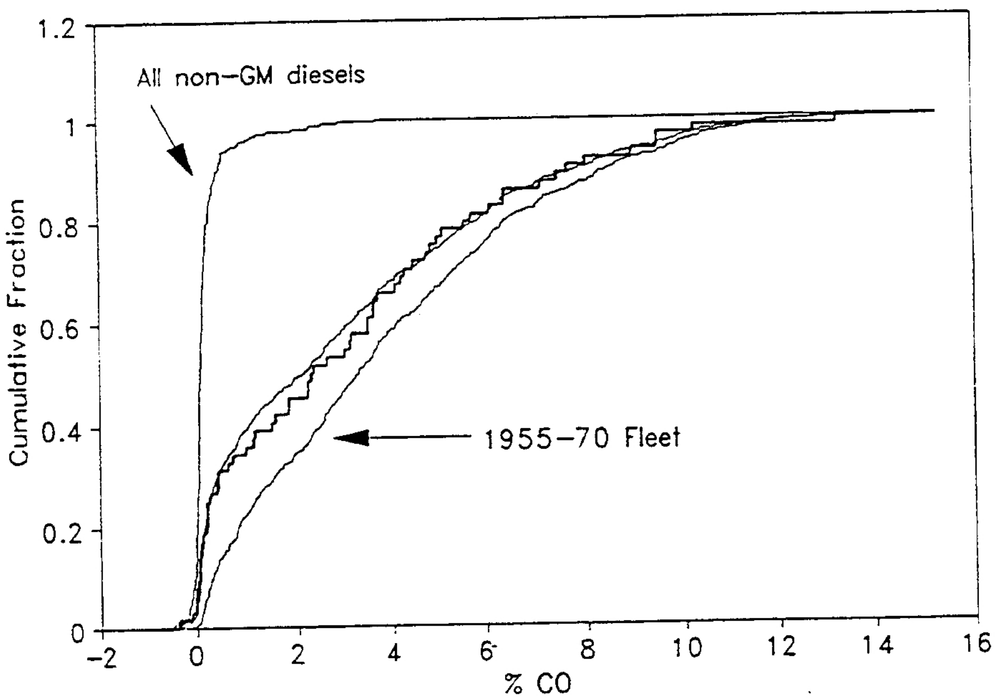

Figure 16. The two parent populations bracketing the model fleet (thin line) showing it similarities to the GMD Fleet (thick line). Max P(K-S) > 99.5% for N(gas)=500, n(GMD)=65; Fraction(gas)=0.773.

This statistical analysis implies that 77% of the cars identified as GMD are not diesels. For this percentage to be lower, a dirtier gas fleet must be used for modeling. An unmentioned reason for choosing 1955-70 cars is that they are the dirtiest subfleet found. To imply that the percentage of engine exchange is less than 77% means that those cars that have had engine exchanges are dirtier as a group than any other identifiable sub fleet in the LA90 database. On the other hand, if the exchanged vehicles are cleaner than the 1955-70 fleet, the percentage of engine exchanged vehicles will increase. A 60 - 80% "engine switch" rate would be a statistically justifiable estimate within a 95% confidence. Even though the 1979-1982 GMD fleet only contains 65 vehicles, we believe that this analysis implies that over half of all vehicles registered in this category in LA county are likely to have switched their engines and neither installed emission controls nor informed the proper authorities.

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APPENDIX 1

Lawson, D.R., Groblicki, P.L., Stedman, D.H., Bishop, G.A., & Guenther, P.L. (1990). Emissions from in-use motor vehicles in Los Angeles: A pilot study of remote sensing and the inspection and maintenance program. Journal of the Air & Waste Management Association, 40(8), 1096-1105.

APPENDIX 2 Repeat Vehicle Measurements

epeat measurements of vehicles

YEAR	MAKE	PERCENT CO	PERCENT CO	PERCENT CO	PERCENT CO	PERCENT CO	PERCENT CO	PERCENT CO	MEAN	VARIANCE
79	MAZD	0.47	0.55	1.1	10.82				3.24	19.24
75	PONT	0.25	0.26	3.17	5	9.13			3.56	11.02
71	DODG	3.08	3.65	9.52	9.75				6.50	9.88
82	FORD	-0.05	1.01	1.78	4.18	7.24	8.22		3.73	9.70
78	PLY	-0.07	0.01	0.07	7.15				1.79	9.58
		4.08	5	8.49	11.23	11.43			8.05	9.36
79	OLDS	1.73	3.87	5	9.57				5.04	8.21
78	BUIC	2.21	8.17	8.84	8.86				7.02	7.79
81	BUIC	3.48	6.35	7.31	10.17	10.6			7.58	6.84
74	CHE	2.82	4.51	8.28	9.16				6.19	6.84
79	MERC	0.92	1.27	5.6	6.59				3.60	6.39
77	CHEV	0.12	0.33	1.24	5.56	5.66			2.58	6.26
79	DODG	0.51	3.53	6.13	6.77				4.24	6.10
83	FORD	2.87	3.59	6.32	8.8				5.40	5.52
68	BUICK	1.93	1.96	6.59	6.67				4.29	5.49
89	GMC	0.04	0.61	0.7	1	4.44	6.22		2.17	5.34
72	FORD	5.18	6.91	9.05	10.42	11.25			8.56	5.02
79	CAPRI	3.79	6.28	8.34	9.38				6.95	4.57
83	BUIC	1.49	2.01	3.56	6.65				3.43	4.04
80	OLDS	2.41	6.54	6.88	7.36				5.80	3.91
76	CHEV	0.14	0.18	3.37	3.97				1.92	3.13
84	NISS	2.11	2.85	3.76	6.45				3.79	2.70
70	CHRYS	2.21	5.15	5.7	5.99	7.05			5.22	2.65
88	HOND	0.08	0.09	2.95	3.6				1.68	2.60
69	FORD	0.42	2.56	3.12	4.4				2.63	2.07
81	CHEV	1.82	3.14	4.25	4.68	5.44	6.08		4.24	2.01
82	CHEV	0.43	0.61	1.21	1.38	1.48	3.87	4.15	1.88	1.96
74	FORD	3.79	5.32	6.69	6.69				5.62	1.43
80	BUIC	1.61	3.17	3.2	4.56				3.14	1.09
80	OLDS	-0.09	-0.02	0.01	0.18	0.2	1.75	2.56	0.66	0.96
85	TOYT	0.01	0.14	0.23	0.33	2.34			0.61	0.76
84	RENA	0.01	0.11	0.65	1.1	1.77	2.43		1.01	0.76
81	BUIC	1.17	1.37	2.39	3.34				2.07	0.75
80	VLK	1.05	1.47	1.81	2.2	3.31			1.97	0.59
88	MITSU	-0.12	0.02	1.14	1.36	1.79			0.84	0.57
86	ISU	0.09	0.23	0.38	1.56				0.57	0.34
89	FORD	0.05	0.06	0.29	0.72	1.28			0.48	0.22
89	CHEV	0.11	0.12	0.13	0.2	1.3			0.37	0.22
78	CHEV	0.21	1.14	1.18	1.36				0.97	0.20
78	CHEV	0.15	0.2	0.24	1.17				0.44	0.18
78	CHEV	-0.27	0.1	0.24	0.31	0.84	0.94		0.36	0.17
81	CHEV	0.64	0.73	1.27	1.56				1.05	0.14
78	CHEV	-0.02	0.21	0.78	0.85				0.46	0.14
85	CHEV	-0.01	0.11	0.14	0.3	0.99			0.31	0.13
78	TOYT	0.41	0.58	0.65	1.01	1.09	1.41		0.86	0.12
88	DODG	0.07	0.15	0.18	0.28	0.3	1.09		0.35	0.12

86	CHEV	-0.04	0.01	0.17	0.7			0.21	0.09
89	FORD	0.00	0.01	0.01	0.06	0.13	0.76	0.16	0.07
72	CADI	1.54	1.82	1.83	2.21	2.23		1.93	0.07
81	CHEV	0.31	0.45	0.66	0.98			0.60	0.06
88	MAZD	0.04	0.05	0.32	0.38	0.72		0.30	0.06
86	TOYT	0.06	0.21	0.3	0.44	0.59	0.76	0.39	0.05
81	DATS	0.11	0.21	0.23	0.69			0.31	0.05
85	CADI	-0.01	0.2	0.38	0.59			0.29	0.05
87	PONT	-0.01	0.01	0.06	0.48			0.14	0.04
82	CHEV	-0.28	0.05	0.12	0.18	0.31		0.08	0.04
90	TOYT	-0.15	0.02	0.18	0.33			0.10	0.03
84	FORD	0.04	0.08	0.1	0.48			0.18	0.03
77	FORD	-0.01	0.02	0.04	0.42			0.12	0.03
64	CHEV	0.25	0.61	0.64	0.69			0.55	0.03
80	CHEV	-0.03	0.03	0.04	0.4			0.11	0.03
78	CHEV	-0.16	-0.09	0.1	0.25			0.03	0.03
81	BUIC	0.05	0.05	0.29	0.39			0.20	0.02
89	PONT	-0.07	-0.02	0.01	0.02	0.03	0.38	0.06	0.02
87	HOND	-0.13	0.03	0.07	0.07	0.28		0.06	0.02
84	FORD	0.07	0.11	0.11	0.32	0.39		0.20	0.02
86	FORD	0.08	0.19	0.34	0.36			0.24	0.01
89	BMW	-0.10	-0.03	0	0.08	0.15	0.22	0.05	0.01
85	BUIC	0.03	0.04	0.05	0.24			0.09	0.01
78	VOLVO	-0.02	0.07	0.08	0.21			0.09	0.01
88	FORD	0.01	0.02	0.03	0.2			0.07	0.01
84	TOYT	0.03	0.05	0.17	0.18			0.11	0.00
83	BUICK	-0.04	-0.02	0.01	0.12			0.02	0.00
84	BUIC	0.02	0.14	0.16	0.18	0.19		0.14	0.00
89	BUICK	0.01	0.01	0.03	0.13			0.05	0.00
85	CHEV	-0.09	-0.04	-0.01	0.01	0.05		-0.02	0.00
86	PONT	-0.03	-0.02	0.02	0.08			0.01	0.00

APPENDIX 3 Diesel Vehicles

Date	Time	%CO	Make	Year	Fuel
12/11/89	11:48:14	-0.49	FORD	86	D
12/18/89	13:25:00	-0.43	FORD	87	D
12/13/89	10:31:06	-0.42	GMC	89	D
12/19/89	11:53:26	-0.34	CHEV	81	D
12/13/89	09:02:55	-0.30	KW	84	D
12/14/89	16:05:38	-0.25	ISU	88	D
12/14/89	09:35:28	-0.21	MACK	84	D
12/12/89	11:41:31	-0.17	GMC	71	D
12/13/89	13:24:29	-0.17	INTL	89	D
12/07/89	10:00:03	-0.17	FORD	88	D
12/16/89	09:43:04	-0.16	INTL	89	D
12/18/89	11:29:07	-0.15	MAGIS	82	D
12/16/89	09:22:57	-0.15	MBZ	80	D
12/12/89	13:27:17	-0.14	FORD	86	D
12/16/89	12:58:20	-0.14	FORD	87	D
12/14/89	08:44:41	-0.12	MBZ	80	D
12/07/89	10:46:32	-0.11	VOLK	82	D
12/14/89	12:05:21	-0.11	GMC	87	D
12/08/89	11:58:35	-0.11	FORD	84	D
12/14/89	12:24:51	-0.10	FORD	81	D
12/14/89	10:39:31	-0.10	BUIC	82	D
12/13/89	10:53:55	-0.09	INTL	90	D
12/18/89	17:22:06	-0.08	HINO	87	D
12/06/89	13:47:36	-0.08	MERZ	79	D
12/12/89	11:42:44	-0.08	VLKSW	82	D
12/16/89	10:07:34	-0.08	MERZ	77	D
12/07/89	09:31:39	-0.05	TOYT	84	D
12/14/89	15:07:40	-0.05	MERZ	76	D
12/14/89	13:55:44	-0.05	IVEC	86	D
12/16/89	09:26:41	-0.05	ISU	88	D
12/16/89	14:37:34	-0.04	MERZ	77	D
12/15/89	10:29:16	-0.03	FORD	89	D
12/16/89	09:28:08	-0.03	FORD	88	D
12/12/89	12:39:47	-0.02	CHEV	83	D
12/13/89	10:22:07	-0.02	HINO	87	D
12/08/89	12:20:05	-0.02	INTL	89	D
12/13/89	09:44:53	-0.02	INTL	90	D
12/14/89	08:49:01	-0.02	GMC	89	D
12/11/89	13:50:27	-0.02	MERZ	79	D
12/12/89	12:28:51	-0.02	MERZ	82	D
12/08/89	09:45:36	-0.02	GMC	85	D
12/08/89	12:01:51	-0.02	GMC	80	D
12/07/89	11:58:21	-0.02	PEUG	82	D
12/14/89	13:13:15	-0.01	GMC	86	D
12/07/89	09:24:56	-0.01	MBZ	81	D
12/16/89	13:30:28	-0.01	OLDS	79	D
12/08/89	12:16:36	-0.01	MERZ	84	D
12/16/89	11:05:31	-0.01	FORD	89	D
12/11/89	11:09:10	-0.01	GMC	82	D
12/08/89	11:28:44	-0.01	FORD	87	D
12/08/89	09:39:37	0.00	FORD	87	D
12/14/89	10:02:20	0.00	MERZ	84	D
12/14/89	13:57:11	0.00	MBZ	83	D

Date	Time	%CO	Make	Year	Fuel
12/08/89	12:14:23	0.00	GMC	83	D
12/18/89	11:34:59	0.00	MERZ	87	D
12/12/89	15:41:43	0.01	GMC	86	D
12/16/89	13:48:15	0.01	MERZ	79	D
12/13/89	11:11:23	0.01	MERZ	80	D
12/14/89	14:20:00	0.01	FORD	89	D
12/14/89	11:47:00	0.01	FORD	87	D
12/16/89	09:28:03	0.01	FORD	88	D
12/14/89	10:38:37	0.02	MBZ	79	D
12/13/89	13:22:44	0.02	FORD	87	D
12/14/89	13:30:25	0.02	INTL	79	D
12/14/89	14:56:58	0.02	MACK	84	D
12/16/89	13:27:20	0.02	FORD	89	D
12/14/89	10:29:31	0.02	FORD	89	D
12/14/89	15:15:31	0.02	PETRB	84	D
12/14/89	11:52:52	0.02	GMC	89	D
12/14/89	13:50:36	0.02	GMC	83	D
12/13/89	08:24:07	0.02	INTL	90	D
12/12/89	14:55:19	0.02	GMC	85	D
12/13/89	13:18:31	0.02	INTL	86	D
12/07/89	13:34:24	0.02	MBZ	81	D
12/14/89	16:13:21	0.02	VOLV	84	D
12/14/89	13:40:44	0.02	FORD	84	D
12/14/89	13:01:00	0.02	GMC	86	D
12/13/89	11:06:48	0.02	VLKSW	81	D
12/15/89	11:29:18	0.03	INTL	83	D
12/13/89	13:50:38	0.03	INTL	84	D
12/13/89	10:26:10	0.03	CADI	82	D
12/13/89	11:25:40	0.03	FORD	85	D
12/14/89	10:16:34	0.03	VOLK	82	D
12/16/89	14:52:21	0.03	FORD	86	D
12/16/89	14:00:30	0.03	MZB	84	D
12/15/89	14:33:35	0.03	FORD	89	D
12/13/89	09:26:20	0.03	GMC	85	D
12/13/89	08:45:27	0.03	FORD	87	D
12/14/89	11:20:21	0.03	GMC	88	D
12/13/89	13:56:47	0.04	FORD	86	D
12/14/89	15:36:35	0.04	CHEV	87	D
12/16/89	12:57:18	0.04	FORD	88	D
12/13/89	10:59:47	0.04	FORD	88	D
12/16/89	13:27:27	0.04	FORD	86	D
12/14/89	10:32:23	0.04	FORD	89	D
12/14/89	12:26:36	0.04	MERZ	84	D
12/15/89	13:57:50	0.04	INTL	87	D
12/18/89	15:25:35	0.04	FORD	86	D
12/07/89	09:29:51	0.04	MERZ	82	D
12/12/89	15:22:27	0.05	GMC	86	D
12/13/89	12:24:56	0.05	INTL	80	D
12/11/89	14:16:34	0.05	MERZ	83	D
12/14/89	14:16:03	0.05	DATS	82	D
12/16/89	12:08:03	0.05	MERZ	84	D
12/14/89	12:09:49	0.05	OLDS	81	D
12/12/89	12:47:33	0.05	ISU	85	D

Date	Time	%CO	Make	Year	Fuel
12/16/89	13:35:53	0.05	MERZ	87	D
12/13/89	11:22:36	0.05	ISUZU	83	D
12/14/89	10:09:16	0.05	FORD	84	D
12/14/89	14:13:02	0.05	GMC	81	D
12/14/89	09:50:44	0.05	CADI	79	D
12/08/89	09:39:44	0.05	FORD	87	D
12/13/89	12:56:15	0.05	FORD	88	D
12/19/89	09:56:53	0.05	CHEV	84	D
12/14/89	14:07:07	0.05	FORD	88	D
12/14/89	12:08:48	0.06	MERZ	87	D
12/13/89	12:29:42	0.06	KENWO	88	D
12/08/89	11:45:01	0.06	INTL	89	D
12/14/89	10:38:29	0.06	MERZ	89	D
12/14/89	11:30:02	0.06	FORD	89	D
12/16/89	12:57:36	0.06	MERZ	79	D
12/13/89	13:13:44	0.06	GMC	83	D
12/14/89	16:05:56	0.06	MERZ	84	D
12/14/89	10:38:59	0.06	MERZ	87	D
12/08/89	15:09:20	0.06	CHEV	85	D
12/14/89	10:35:18	0.06	FORD	86	D
12/13/89	10:46:32	0.06	FORD	86	D
12/13/89	08:29:47	0.06	INTL	86	D
12/14/89	08:58:55	0.06	VOLV	83	D
12/19/89	13:06:22	0.06	MERZ	84	D
12/19/89	14:56:44	0.06	MERZ	85	D
12/14/89	11:18:57	0.06	PEUG	84	D
12/13/89	12:27:39	0.06	FORD	84	D
12/14/89	10:59:23	0.06	PEUG	79	D
12/12/89	14:08:57	0.06	GMC	86	D
12/13/89	13:35:01	0.07	OLD	80	D
12/14/89	14:14:47	0.07	MITSU	84	D
12/13/89	08:33:05	0.07	INTL	90	D
12/13/89	09:24:51	0.07	GMC	85	D
12/19/89	13:01:01	0.07	CHEV	84	D
12/18/89	15:42:24	0.07	MBZ	83	D
12/19/89	11:53:34	0.07	IVEC	88	D
12/13/89	10:45:38	0.07	FORD	88	D
12/14/89	13:17:15	0.07	IVECO	89	D
12/16/89	10:56:01	0.07	MACK	89	D
12/15/89	14:36:00	0.07	NISS	87	D
12/13/89	13:20:54	0.07	INTL	87	D
12/08/89	14:58:01	0.08	FORD	86	D
12/13/89	10:20:31	0.08	HINO	87	D
12/15/89	10:58:08	0.08	FORD	87	D
12/15/89	13:30:44	0.08	FORD	87	D
12/13/89	08:35:39	0.08	GMC	85	D
12/12/89	11:44:18	0.08	INTL	88	D
12/12/89	10:33:05	0.08	PTRB	89	D
12/14/89	09:22:11	0.08	CROWN	70	D
12/14/89	11:29:01	0.08	INTL	84	D
12/16/89	15:02:09	0.08	MERZ	79	D
12/14/89	10:52:18	0.08	FORD	86	D
12/15/89	14:56:10	0.08	FORD	85	D

Date	Time	%CO	Make	Year	Fuel
12/08/89	14:04:29	0.09	GMC	87	D
12/13/89	08:48:04	0.09	INTL	82	D
12/14/89	12:11:31	0.09	FORD	83	D
12/18/89	15:41:27	0.09	BUICK	83	D
12/18/89	11:04:11	0.09	INTL	84	D
12/14/89	11:05:59	0.09	MERZ	84	D
12/13/89	08:32:00	0.09	INTL	81	D
12/12/89	13:42:53	0.09	DODG	89	D
12/13/89	08:48:45	0.09	FORD	89	D
12/14/89	14:33:45	0.09	INTL	77	D
12/08/89	12:08:06	0.10	INTL	87	D
12/11/89	14:44:24	0.10	VLKSW	79	D
12/19/89	14:41:37	0.10	YORD	86	D
12/19/89	13:31:43	0.10	CAD	80	D
12/14/89	11:30:48	0.11	OLDS	78	D
12/13/89	11:16:47	0.11	FORD	80	D
12/14/89	13:02:28	0.11	GMC	86	D
12/14/89	13:17:32	0.11	MERZ	87	D
12/14/89	09:43:34	0.11	GMC	87	D
12/15/89	10:20:43	0.11	INTL	83	D
12/07/89	14:29:27	0.11	CADI	78	D
12/13/89	13:36:41	0.11	WHITE	78	D
12/15/89	10:58:19	0.11	FORD	87	D
12/12/89	13:54:45	0.11	FORD	88	D
12/13/89	12:06:40	0.12	ISU	86	D
12/16/89	11:23:11	0.12	FORD	86	D
12/14/89	08:54:43	0.12	FORD	88	D
12/19/89	15:22:48	0.12	FORD	89	D
12/14/89	09:27:56	0.12	MACK	85	D
12/14/89	11:37:46	0.12	MERZ	83	D
12/07/89	11:41:55	0.12	PEUG	81	D
12/16/89	09:34:12	0.12	MERZ	86	D
12/18/89	15:21:10	0.13	TOYT	85	D
12/16/89	12:01:16	0.13	IVECO	84	D
12/14/89	09:11:24	0.13	MBZ	83	D
12/13/89	09:19:49	0.13	MBZ	84	D
12/13/89	10:46:45	0.13	CADI	82	D
12/16/89	14:33:14	0.13	INTL	84	D
12/07/89	13:25:38	0.13	MERZ	78	D
12/13/89	10:21:18	0.13	MERZ	84	D
12/13/89	12:18:26	0.13	MAGUS	82	D
12/13/89	13:06:28	0.13	ISU	89	D
12/13/89	09:29:58	0.13	INTL	90	D
12/13/89	08:28:41	0.13	CHEV	86	D
12/13/89	10:40:13	0.13	FORD	87	D
12/13/89	10:16:20	0.14	GMC	86	D
12/14/89	13:11:39	0.14	CHEV	86	D
12/14/89	10:28:50	0.14	MERZ	82	D
12/13/89	09:40:22	0.14	FORD	80	D
12/16/89	14:44:25	0.14	MERZ	82	D
12/19/89	11:56:40	0.14	TOYT	83	D
12/14/89	09:19:24	0.15	VOLK	84	D
12/14/89	09:55:58	0.15	INTL	80	D

Date	Time	%CO	Make	Year	Fuel
12/08/89	13:02:51	0.15	ISU	86	D
12/14/89	09:37:34	0.15	VLKSW	81	D
12/16/89	12:53:04	0.15	VOLV	83	D
12/14/89	09:54:35	0.15	MERZ	0	D
12/14/89	15:29:34	0.15	INTL	87	D
12/08/89	14:08:05	0.15	MERZ	63	D
12/14/89	13:13:58	0.15	FORD	83	D
12/13/89	13:03:50	0.15	INTL	79	D
12/13/89	11:25:22	0.15	FORD	86	D
12/08/89	14:02:33	0.15	NISS	87	D
12/08/89	09:55:14	0.15	FORD	84	D
12/14/89	12:47:56	0.15	FORD	88	D
12/13/89	08:04:02	0.16	UD	87	D
12/14/89	14:52:56	0.16	MERZ	88	D
12/14/89	10:43:15	0.16	IVECO	82	D
12/11/89	14:10:32	0.16	MERZ	82	D
12/07/89	11:42:39	0.16	MERZ	85	D
12/13/89	10:16:17	0.17	FORD	78	D
12/12/89	13:31:44	0.17	CHEV	84	D
12/16/89	11:40:51	0.17	FORD	86	D
12/13/89	09:33:43	0.17	PETER	87	D
12/18/89	11:39:55	0.17	GMC	83	D
12/19/89	14:04:03	0.18	FORD	87	D
12/14/89	08:59:40	0.18	MERZ	78	D
12/16/89	14:27:28	0.18	MERZ	82	D
12/07/89	14:10:26	0.18	FORD	86	D
12/14/89	15:57:23	0.18	INTL	78	D
12/13/89	10:38:07	0.18	COLNS	87	D
12/14/89	15:03:09	0.19	FORD	82	D
12/16/89	12:38:53	0.19	MERZ	80	D
12/06/89	14:47:02	0.19	DATS	82	D
12/14/89	13:44:52	0.19	ISU	88	D
12/08/89	09:57:10	0.20	GMC	87	D
12/19/89	14:04:00	0.20	FORD	87	D
12/13/89	11:22:34	0.20	MERZ	76	D
12/13/89	12:02:32	0.20	MERZ	84	D
12/14/89	15:33:19	0.20	MERZ	79	D
12/14/89	13:16:27	0.20	OLDS	82	D
12/13/89	10:54:32	0.20	MERZ	84	D
12/13/89	11:30:26	0.21	OLDS	81	D
12/13/89	13:31:11	0.21	IZUZU	81	D
12/12/89	11:21:33	0.21	OLDS	79	D
12/07/89	13:58:40	0.21	CHEV	82	D
12/13/89	11:27:43	0.21	INTL	80	D
12/14/89	09:02:19	0.22	INTL	89	D
12/14/89	10:32:36	0.22	VOLK	80	D
12/16/89	13:32:00	0.22	VLKSW	82	D
12/14/89	09:19:03	0.23	MBZ	83	D
12/14/89	13:35:31	0.23	PETER	78	D
12/14/89	14:33:47	0.23	INTL	77	D
12/14/89	12:04:48	0.23	ISU	88	D
12/14/89	09:19:58	0.24	INTL	79	D
12/18/89	14:44:35	0.24	FORD	87	D

Date	Time	%CO	Make	Year	Fuel
12/14/89	13:39:24	0.24	PTRB	0	D
12/13/89	10:54:27	0.24	INTL	81	D
12/13/89	07:38:26	0.24	CADI	83	D
12/14/89	15:41:21	0.25	KW	85	D
12/13/89	13:09:52	0.26	MACK	87	D
12/16/89	10:08:44	0.26	MERZ	87	D
12/07/89	10:25:49	0.26	PEUG	83	D
12/16/89	14:47:29	0.26	MBZ	84	D
12/14/89	13:46:39	0.27	CHEV	82	D
12/18/89	10:15:08	0.27	FORD	87	D
12/13/89	07:38:53	0.27	HINO	88	D
12/06/89	15:29:05	0.28	MERZ	78	D
12/13/89	08:18:19	0.28	GMC	78	D
12/13/89	11:25:52	0.28	IVECO	84	D
12/12/89	13:42:58	0.28	GMC	83	D
12/19/89	15:09:45	0.30	CHEV	86	D
12/13/89	08:35:52	0.30	MACK	88	D
12/07/89	10:34:43	0.30	FORD	88	D
12/07/89	12:55:28	0.30	MERZ	78	D
12/13/89	09:32:32	0.31	MACK	87	D
12/19/89	14:44:36	0.32	MBZ	83	D
12/15/89	14:56:47	0.33	VOLK	85	D
12/13/89	12:17:18	0.33	MACK	86	D
12/06/89	15:21:34	0.34	GMC	86	D
12/12/89	10:11:13	0.35	WARD	78	D
12/14/89	11:59:48	0.35	MERZ	74	D
12/07/89	11:37:52	0.36	VOLK	82	D
12/13/89	12:10:31	0.36	INTL	81	D
12/11/89	16:11:20	0.37	CROWN	82	D
12/13/89	09:13:42	0.38	FORD	80	D
12/19/89	13:42:21	0.39	TYOTA	84	D
12/08/89	14:39:21	0.41	OLDS	80	D
12/13/89	11:53:12	0.41	MACK	85	D
12/14/89	15:37:39	0.42	OLDS	0	D
12/07/89	08:58:50	0.43	CAD	81	D
12/18/89	15:43:44	0.43	FORD	86	D
12/13/89	09:16:37	0.44	MACK	88	D
12/13/89	08:12:13	0.44	OLDS	79	D
12/12/89	11:56:12	0.45	MERZ	82	D
12/07/89	09:16:46	0.45	MERZ	80	D
12/16/89	14:40:14	0.48	MERZ	85	D
12/13/89	12:15:47	0.49	FORD	85	D
12/14/89	10:29:21	0.49	PTRB	89	D
12/07/89	10:34:51	0.51	VOLK	80	D
12/15/89	10:22:49	0.52	PTRB	68	D
12/14/89	14:07:20	0.54	HINO	86	D
12/13/89	08:58:46	0.54	MACK	85	D
12/13/89	13:07:06	0.56	MACK	82	D
12/13/89	11:11:43	0.56	MACK	84	D
12/19/89	12:15:31	0.56	FORD	89	D
12/08/89	12:00:18	0.60	FORD	87	D
12/15/89	12:05:49	0.62	OLDS	82	D
12/13/89	12:07:29	0.68	MACK	84	D

Date	Time	%CO	Make	Year	Fuel
12/08/89	11:52:46	0.68	GMC	83	D
12/13/89	10:27:12	0.72	MACK	85	D
12/13/89	08:23:43	0.72	GMC	82	D
12/14/89	13:51:15	0.85	MACK	89	D
12/14/89	16:24:55	0.90	INTL	79	D
12/15/89	09:47:27	0.91	MACK	87	D
12/15/89	11:21:51	0.97	OLDS	80	D
12/11/89	12:25:32	1.03	INTL	80	D
12/08/89	14:29:45	1.11	HINO	88	D
12/13/89	08:00:20	1.12	CHEV	79	D
12/12/89	15:28:32	1.14	BUIC	82	D
12/13/89	11:27:05	1.17	MAGI	80	D
12/12/89	11:19:21	1.24	FORD	87	D
12/07/89	12:17:46	1.36	CHEV	84	D
12/12/89	13:36:38	1.46	DATS	82	D
12/15/89	14:23:58	1.50	OLDS	81	D
12/08/89	10:56:41	1.56	CADI	79	D
12/14/89	15:48:19	1.83	CHEV	82	D
12/14/89	13:57:09	1.85	OLDS	79	D
12/13/89	08:42:55	1.96	MERZ	80	D
12/11/89	12:47:12	2.22	CADI	78	D
12/15/89	10:49:10	2.23	OLDS	80	D
12/08/89	11:47:10	2.24	OLDS	80	D
12/07/89	09:33:12	2.31	FGTLN	79	D
12/07/89	11:02:14	2.31	OLDS	80	D
12/13/89	10:39:30	2.32	FORD	87	D
12/08/89	10:03:37	2.56	FORD	87	D
12/14/89	11:57:05	2.63	OLDS	81	D
12/08/89	13:57:03	2.81	CADI	78	D
12/08/89	09:36:40	2.92	FRHT	87	D
12/07/89	13:58:17	3.01	CADI	79	D
12/15/89	12:16:45	3.12	CADI	79	D
12/14/89	14:52:36	3.15	CADI	79	D
12/12/89	15:44:38	3.49	OLDS	79	D
12/13/89	12:29:22	3.50	CHEV	80	D
12/06/89	15:20:25	3.61	OLDS	81	D
12/13/89	11:21:07	3.62	CADI	80	D
12/11/89	12:19:22	3.71	VOLK	79	D
12/12/89	10:13:54	3.71	BUIC	81	D
12/07/89	09:15:15	4.08	CADI	79	D
12/08/89	11:10:04	4.20	CADI	79	D
12/08/89	15:02:20	4.29	OLDS	79	D
12/14/89	12:41:34	4.31	MACK	87	D
12/12/89	12:25:44	4.46	BUIC	81	D
12/07/89	11:11:39	4.64	CADI	75	D
12/11/89	11:22:53	4.74	OLDS	79	D
12/14/89	15:47:30	4.85	OLDS	80	D
12/14/89	12:48:58	4.98	CADI	79	D
12/07/89	09:48:15	5.10	CADI	79	D
12/12/89	12:53:43	5.55	BUIC	82	D
12/12/89	12:09:20	5.72	OLDS	80	D
12/14/89	15:15:16	5.97	MACK	76	D
12/15/89	14:54:21	6.11	OLDS	80	D

Date	Time	%CO	Make	Year	Fuel
12/12/89	13:47:43	6.43	OLDS	79	D
12/15/89	09:12:33	6.44	OLDS	79	D
12/14/89	15:35:21	6.69	MACK	89	D
12/14/89	13:55:28	6.78	GMC	84	D
12/08/89	13:35:21	7.16	OLDS	79	D
12/13/89	13:43:10	7.19	GMC	84	D
12/15/89	12:51:46	7.47	OLDS	80	D
12/11/89	16:07:11	7.68	OLDS	79	D
12/15/89	11:18:36	8.03	OLDS	80	D
12/19/89	11:58:52	8.09	GMC	84	D
12/11/89	11:41:37	8.97	CHEV	79	D
12/12/89	12:02:19	9.48	OLDS	79	D
12/08/89	13:04:00	9.49	OLDS	80	D
12/19/89	12:26:22	10.26	GMC	82	D
12/15/89	13:31:21	13.29	OLDS	81	D