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Remote Sensing Institute and Denver Research Institute
University of Denver, Department of Chemistry

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FINAL REPORT

ON

VEHICLE MEASUREMENTS FOR CO HC AND NO

IN EL PASO, TEXAS AND JUAREZ, MEXICO

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Starting on March 15, 1993 in El Paso and ending on March 25 in Juarez, 31,493 successful readings of CO and a lesser number of HC readings were obtained with FEAT unit #3002. This unit has been used to make measurements all over the world. The data from other locations are summarized in Table I. The data from El Paso and Juarez are summarized in Table II. The 3002 unit was calibrated before each day's operation using a gas cylinder containing known CO, CO_2 and Propane concentrations.

For the first three days the Remote Sensing Technologies unit was monitoring CO and HC from vehicles entering the USA over the Bridge of the Americas, mostly on the El Paso side. For those data contact Mr. Dennis Smith at Remote Sensing Technologies Inc., Phone: (602) 617-2710 in Tucson AZ.

There was much media interest in the instrument and the results for CO and HC. No NO results were analyzed in the field nor were the NO data on the screen discussed, except to point out that the system was new and experimental.

The weather throughout the weeks (45-85 °F range) was warm and dry enough that long periods of cold start would not be expected, nor were visible "steam" plumes ever observed. With the current hardware and software small visible "steam" plumes are read as high HC readings.

NO Measurements

The FEAT 3006 unit is the system which has been modified for the simultaneous analysis of CO, HC, NO, and CO_2. The HC detector on this unit did not operate well since a lead broke off and repairs were attempted. However, since all channels are independent, noisier HC data does not compromise our ability to investigate the results of the prototype NO system. NO system setup was attempted on the 15th but was not successful. On the 16th and each day when NO readings were attempted, the setup went very easily although the narrower UV beam means that optical alignment is trickier than for the traditional IR unit.

On March 16th, three vehicles were measured for NO when one of the operational amplifiers failed. Replacement of the op-amp resulted in successful measurements later on the 16th and on all other days on which the NO system was tested (17-19 and 23-25). NO measurement was always initiated after the 3002 unit was set up, calibrated, and fully operational. For this reason, and because there is more noise (and thus data rejection), and because the system was experimental, there are about 5,000 on-road NO readings which passed the experimental software confidence limit criteria.

Calibration critically effects our ability to determine on-road NO emission factors. However, it does not effect another goal of the program, namely, to investigate the correlation between on-road NO readings and the emissions of a computer-controlled vehicle (Ford Taurus operated by Jon Lesko). The Taurus not only has the ability to run in a closed-loop mode with

Table I On-road remote sensing data summary.

Location	Date	#Records	Mean %CO	Median %CO	Mean %HC	Median %HC
Bangkok	Aug.93	5,260	3.04	2.54	0.948	0.567
Chicago	Jun.92	8,733	1.04	0.25	0.088	0.064
Denmark	Oct.92	9,038	1.71	0.67	0.177	0.058
Denver	Nov.91	35,945	0.74	0.11	0.057	0.033
Edinburgh	Nov.92	4,524	1.48	0.69	0.129	0.084
Gothenburg	Sep.91	10,285	0.71	0.14	0.058	0.046
Hong Kong	Aug.93	5,891	0.96	0.18	0.054	0.037
Kathmandu	Aug.93	11,227	3.85	3.69	0.757	0.363
Leicester	Nov.92	4,992	2.32	1.61	0.212	0.131
London	Nov.92	11,666	0.96	0.17	0.136	0.071
Los Angeles	Jun.91	47,708	0.79	0.15	0.076	0.042
Melbourne	May 92	15,908	1.42	0.57	0.107	0.058
Mexico City	Feb.91	31,838	4.30	3.81	0.214	0.113
Provo	Dec.91	12,066	1.17	0.45	0.220	0.127
Seoul	Aug.93	3,104	0.82	0.26	0.044	0.019
Taipei	Aug.93	12,062	1.49	0.88	0.062	0.050
Thessaloniki	Sep.92	10,536	1.40	0.55	0.155	0.082
Toronto	Apr.90	11,290	0.75	0.15	N/A	N/A

Table II El Paso and Juarez data summary.

Site	Date	#Records	Mean %CO	Median %CO	Mean %HC	Median %HC
Yarborough	3/15/93	5,273	1.55	0.63	0.080	0.060
Yarborough	3/16/93	5,811	1.42	0.47	0.070	0.046
Sunland	3/17/93	4,035	0.84	0.26	0.082	0.050
Altura	3/18/93	2,220	1.59	0.53	0.073	0.045
Spaghetti	3/19/93	6,534	1.25	0.37	0.071	0.040
El Paso		15,986	1.22	0.37	0.073	0.044
Right Turn	3/22/93	391	3.48	2.73	0.193	0.109
San Lorenzo	3/22/93	1,802	2.90	2.20	0.176	0.103
Bridge Ramp	3/23/93	601	2.81	1.72	0.150	0.080
Cloverleaf	3/23/93	673	2.81	1.96	0.130	0.080
Industrial	3/24/93	1,303	2.72	1.87	0.171	0.077
Hotel	3/24/93	1,239	3.21	2.35	N/A	N/A
Municipal	3/25/93	1,631	3.04	2.41	0.179	0.093
Juarez		7,640	2.96	2.18	0.170	0.091

EGR, but also can be changed in a few seconds by the driver to operate at any pre-set air/fuel ratio with or without EGR. It is also equipped with on-board monitors for CO, CO_2, HC, oxygen, and a newly developed fast response on-board NO system. The Taurus was used for several on-road drive-bys at the locations described later. These were not ideal for this purpose, since the loops to legally get back to the site were rather long. For this reason, about 90 drive-bys were performed on two evenings in the hotel parking lot. In every case, hotel and on-road, the Taurus gave on-road averages less than 450 ppm NO when in closed-loop, EGR or in rich operation, and readings averaging over 2000 ppm NO when commanded stoichiometric or slightly lean with the EGR disabled.

Results and Discussion

Each site is described below.

El Paso

Yarborough

The Yarborough on-ramp to Eastbound I-10 in El Paso is a very good loaded-mode remote sensing location. Vehicles were measured at the end of the on-ramp with the light source on the tiled lane-divider after the end of the physical separation of the ramp from the freeway. The location is far enough away from most residential areas, and the wait at traffic lights is long enough that few vehicles are expected to be in a cold operating mode. The on-ramp is uphill (about 1%), but has a flat portion where we measured, and leads into a dedicated traffic lane. The traffic was heavy enough that hard acceleration was not possible for many vehicles because another vehicle was right in front. Speeds varied between 25 and 40 mph.

Because of the intense interest of TV stations, newspapers, and community college students, serious measurements were not initiated until after noon and continued till after 6:00 pm. The same site on the following day measurements started at 8:12 am. The lower readings on the second day turned out to be correlated with the average age of the observed fleets. The average age of the second day fleet was about half year younger than the first day fleet because of newer vehicles driven on morning commute trips. This effect has been observed in Chicago and is discussed in prior publications (Stedman *et al*, 1991).

Sunland

The Westbound on-ramp from Sunland Plaza onto I-10 was chosen with the intent of observing a fleet from one of the more upscale areas in El Paso. Higher socio-economic status is normally correlated with newer (and thus lower-emitting) vehicles. The actual location was at the end of a half-mile-long ramp entering slightly downhill onto I-10. The vehicles arrived at this site, generally at high speeds (50-70 mph est.), with their foot often off the gas. This is the kind of location in which remote sensing has the most trouble seeing adequate plume to measure (some vehicles actually turn off all fuel under the circumstances described). Nevertheless, over 4,000 successful measurements were obtained. As expected, CO emissions measured at this site were lower than measured in Yarborough since the fleet was over one year newer than the Yarborough fleet on average. The HC measurements would have been lower had it not been for the downhill driving mode which causes significantly higher per gallon HC readings as we have observed elsewhere (Zhang *et al*, 1993).

Altura

The Altura on-ramp to Southbound U.S. 54 takes traffic from Pershing (and thus Fort Bliss) uphill at about a 1% grade onto U.S. 54 which is a freeway at that point. Traffic was lighter but the situation was otherwise similar to the Yarborough site.

Spaghetti

U.S. 54, Northbound and Southbound vehicles, all have to get into one lane to enter Eastbound I-10 at the end of two ramps of a major interchange known locally as Spaghetti Junction. The lane which is entered continues on as an added lane to I-10. The instrument was set up as far out onto the I-10 freeway as possible so that the vehicles congested by the lane merges were looking at open road, and thus opening up the otherwise negligible gaps between them. In three hours 6534 valid CO readings and 6602 valid HC readings were obtained. With traffic this heavy, it was very hard to find enough between-vehicle gaps in which to puff the calibration gas. At one point we conducted a calibration in a half second under the body of a slowly passing eighteen wheeler. This is the first location at which we have measured over 2,000 valid readings per hour. Hardly surprising in view of its "middle of town" location, the readings are similar to the overall El Paso averages.

Juarez

Rt. Turn

The first morning we set up at a level right turn lane (sneak around to avoid the traffic lights) between northbound Lopez Mateos and Eastbound De La Raza. Because the traffic lights were always congested and the right turn traffic few, there were not very many cars measured at this site and the NO system was not used.

San Lorenzo

The afternoon set-up was at a much more productive location. Again, the vehicles were essentially starting up from stopped, but the situation is a single lane left turn (from southbound to eastbound) as a part of a traffic circle. The streets were labelled Thomas Fernandez and Raphael Perez but we were assured that the location was known by the name of the local church, namely San Lorenzo.

Bridge Ramp

The approach ramp to the Bridge of the Americas northbound from Collegio Militaria was chosen as a location with very similar operation to the ramps chosen in El Paso. The site is very distant from any possible cold start.

Cloverleaf

There is one cloverleaf junction in Juarez. We sampled the fairly steeply uphill on-ramp signposted to San Lorenzo from Nacional. The traffic was free-flowing at about 20 mph.

Industrial

The site in the industrial sector was another right turn lane, but much busier, as vehicles left eastbound Thomas Fernandez onto southbound Ave. de la Industria. The driving mode varied from stop/start to cruise at 30 mph depending upon the status of traffic to merge with.

Hotel

There is a single lane on the right side of Eastbound Republica outside the Lucerna Hotel. This lane was monitored for the afternoon. The NO system was not used. There appeared to be some roofers in the neighborhood from the smell of asphalt, and the HC calibrations looked terrible because of the interferences. For this reason HC data from this site are not considered reliable.

Municipal

There is a single lane right turn which must be used by anyone entering the parking lot of the main municipal building in Juarez. It is also used by a few vehicles actually turning right. The speeds were slow to stopped.

Overall

Overall there seems to be very little difference between all the Juarez sites. Relative to El Paso they look very high. Relative to Mexico City they look somewhat lower. At most sites in Juarez we took an informal survey of a few hundred license plates and found 50% frontier, 20% national, 15% Texas and 15% other (including New Mexico and Non-existent and the Texas paper plates which we noticed a lot at the Yarborough ramp).

According to the local information obtained, vehicles on the road in El Paso, and particularly in Juarez, are available at low cost from auctions in Dallas, Denver, and Phoenix. They may be so cheap because they do not meet the I/M requirements. Thus, I/M in those cities may be contributing to dirtier air in others. One suggestion which arose was that Mexico use a remote sensor, with proper warning, to charge a toll for any gross polluting vehicles entering from the U.S., the toll to be used to subsidize the repair, or at least proper tune, of the many broken vehicles already over there.

NO data

The NO remote sensor was built as an additional channel to the FEAT system in unit FEAT 3006. It was used on several occasions in El Paso and in Juarez. The data are summarized in Table III. In El Paso, drive-by comparisons with a fully instrumented Ford Taurus (computer controlled engine override, four gas analyzer (MPSI) and UV based NO exhaust analyzer and functional catalyst), were undertaken at several sites, and in the hotel parking lot under more controllable conditions. As an added test of the NO system it was taken to Dearborn Michigan and run on a test track against two vehicles, the Taurus, and a Ford Motor Co. Aerostar with on-board real-time exhaust FTIR and an inactive catalyst. The Taurus on-board unit was also compared to test cell instrumentation while the Taurus was operated on a dynamometer.

The Taurus test vehicle is a 1993 wagon equipped with a 3.8 liter PFI V-6 engine and automatic transmission. Both feedback and adaptive control systems are employed in the normal operating modes. The emissions control system uses dual oxygen sensors and catalysts in conjunction with a vacuum/electronic EGR. For the purposes of evaluating the FEAT NOx channel the air/fuel ratios in the Taurus were altered using a computer interface and locked in at values ranging from 0.95 to 1.1 with/without EGR. Signal information is recorded in both a raw data and calculated ppm format along with vehicle operating parameters in a comprehensive data acquisition system.

Exhaust gas sampling is conducted by two separate tailpipe probes of equal length, one for the NO detector and one for the four-gas analyzer. Figure 1 shows a schematic diagram of the set-up used for the two analysis systems. This method was selected to provide the best possible compromise between ease of use, system isolation, and instrument flexibility. Another consideration was the isolation of the newly developed NO analyzer and dilution pump system to minimize any potential negative interactions that may develop during its initial development.

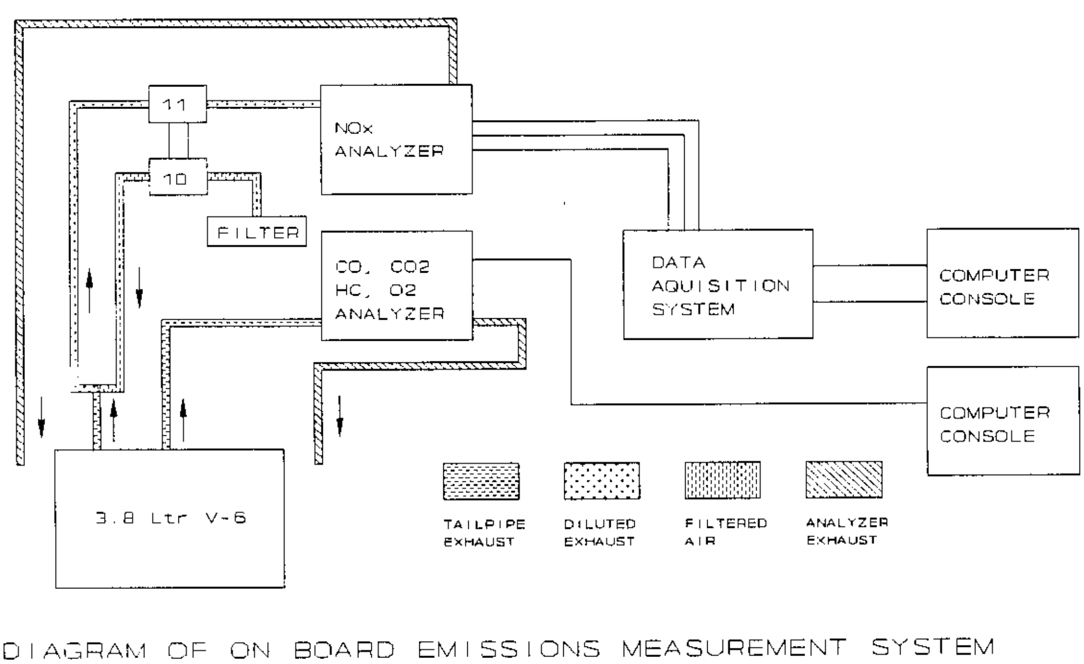

Figure 1 Schematic diagram of the measurement system.

Table III Measured on-road NO emissions from sites in El Paso and Juarez

Site	Mode	Hit rate %	Mean ppm NO	Median NO
Sunland	downhill	22	800	500
Altura	uphill	31	900	750
Spaghetti	uphill	69	420	190
Bridge. Ramp	uphill	38	330	150
Cloverleaf	steep up	47	380	180

In order to prevent condensation in the UV analyzer cell without dropping out moisture, the raw exhaust was diluted with approximately 10 parts ambient air before flowing through the UV cell. In this configuration fast response times on the order of 1.1 seconds was maintained without encountering water dropout. As an added precaution, small heater elements were placed around the lens assemblies to further insure against condensation.

The measurements of CO, HC, O_2, and CO_2 were conducted using an IR based "in flight" analyzer manufactured by MPSI. This unit was linked to a dedicated PC that was time correlated with the vehicle and NOx data acquisition system. Slight difficulties were encountered with condensation during long data runs, however, this did not affect test integrity as a periodic flush/purge procedure eliminated excess condensed moisture. The entire on-board system was powered from the vehicle battery and alternator.

There were three days of intercomparison in Dearborn. The results were described in full in a report by Dr. Jim Butler of Ford Motor Co. (Butler *et al*, 1994). On the last day there was a comparison of the Taurus on-board NO instrument to instruments on a dynamometer. In summary, the Taurus on-board unit demonstrated a precision of $\pm$100 ppm NO at low NO levels (<1000 ppm) although there was some question about the absolute calibration differences (20% difference) when comparing a cylinder standard calibration carried out in Denver with the dynamometer facility which used its own calibration standards. The correlation from both the Taurus and Aerostar on-board NO data combined, compared to the on-road data shows a slope of 0.81, again probably resulting from differences in the calibrations. The stated uncertainty from the regression r^2 of 0.6 is $\pm$860 ppm which we believe is mainly attributable to uncertainty in the remote sensing readings.

We conclude several things from the data. The first conclusion is that the new FEAT system measures vehicle NO emissions with an error of about $\pm$860 ppm. Since the reported error bars during calibration are less than 50 ppm and instrument vibration is not a problem during calibration, we believe that further attention to vibration elimination may lower the on-road measurement uncertainties. We also conclude that 860 ppm noise on an individual reading is small enough that high emitting vehicles (>3,000 ppm) can be easily distinguished from low (<1,000 ppm). Based upon the tests conducted so far, we did not yet find any way to drive the Taurus in a closed-loop mode with NO greater than 1,000 ppm. When intentionally malfunctioning, it is read above 3,000 ppm in some driving modes and less than 1,000 in others. If this were all the evidence we had, it would predict that broken vehicles would be measured sometimes high and sometimes low (flippers), whereas a properly controlled vehicle would never be identified as broken.

We believe that the best on-road data set is the 1552 vehicles measured on the last day in El Paso at the Spaghetti junction. Figure 2 shows the on-road NO emissions of the fleet divided into ten deciles to represent the distribution as well as the overall emissions picture. Figure 3 shows a further quality assurance procedure, namely a plot of measured CO versus measured NO. The graph shows data points scattered all over the place except no data showing high NO emissions >1000 ppm associated with high CO emissions from the same vehicle. This is encouraging since it is unusual for a vehicle which is operating very rich to be a high NO emitter. Stated another way, the data from 1552 vehicles show that the on-road NO detector is unlikely to incorrectly assign high NO emissions >1000 ppm to a vehicle in a rich operating mode.

Based upon this analysis it is not surprising that lower NO emissions are observed in

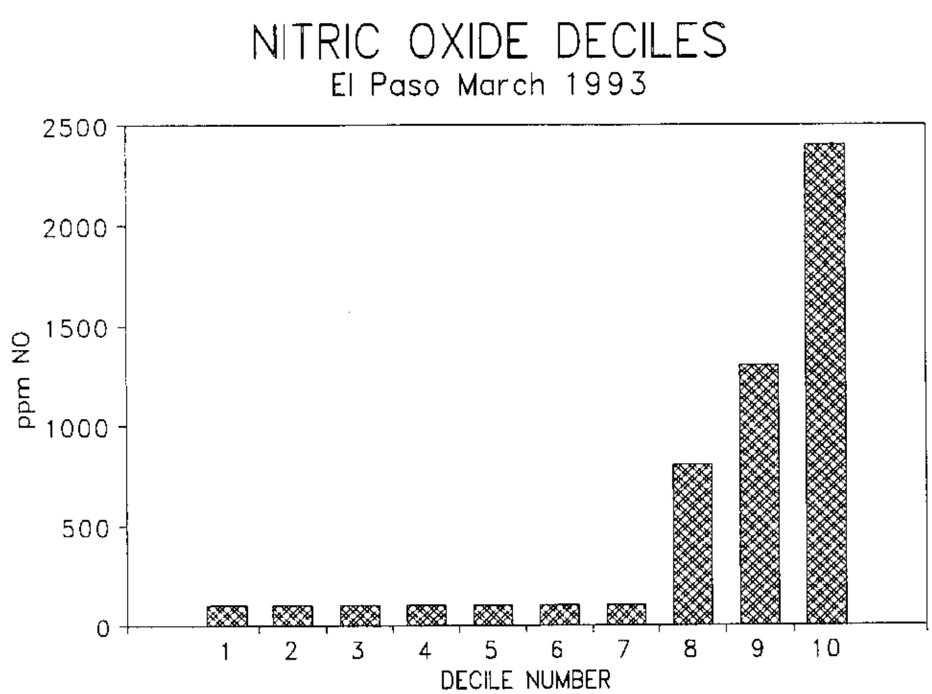

Figure 2 NO deciles from an on ramp in El Paso Texas

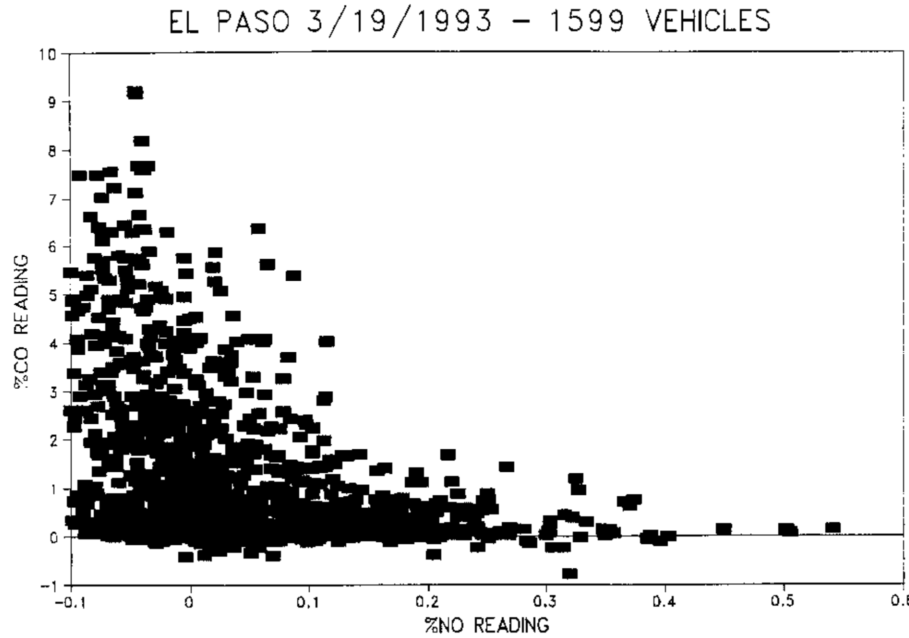

Figure 3 Measurements of %CO and %NO plotted against each other showing that high NO emitters are not high CO emitters and vice versa.

Juarez (Bridge, Ramp and Cloverleaf sites) in view of the much increased CO, and hence many more rich operating cars as discussed earlier in this report.

As discussed in earlier publications, there are two rather distinct potential uses of on-road emissions data. One is to detect individual high emitting vehicles; the second is to collect data from which emissions inventories can be obtained. On-road data can be converted directly into gms of tailpipe emissions per gallon of fuel burned, (the formulae are presented as an attachment to this document). Provided the noise is random, an NO detection system with a high noise level can be used for emission inventory estimates, even when the individual data points are not useful for high emitter detection, as long as statistically large numbers of data points are obtained.

We have further investigated the hypothesis that the system noise for NO can be reduced as expected by adding many vehicles together. It is a fundamental theorem of statistics that random noise can be reduced by averaging many readings, and that the reduction is proportional to the square root of the number of readings. Two hours of data from the spaghetti junction in El Paso were divided up into four, half-hour groups. Since each group contained 225 vehicles or more, a noise reduction of a factor of $\sqrt{225}=15$ would be expected. The observed result (420 $\pm$ 47 ppm) confirms this hypothesis, furthermore, this is an upper limit since some apparent noise will be contributed by actual fleet variations. Current plans are to reduce the noise on the NO_x readings to $\pm$ 200 ppm on an individual car. With fleets of over 400 vehicles, this would lead to a fleet average noise of only ± 10 ppm. If fleet average emissions are of order 300 ppm such a system will enable the detection of 5-10% changes in NO_x averages caused by external variables (changed speed/load or fuel parameters). We have tested in the laboratory and verified on-road a system capable of measuring speed to ± 0.1 mph/sec. on each passing vehicle.

The NO system was calibrated in the same way as all FEAT systems, by blowing a small puff of gas from a calibration cylinder with known CO, CO_2, propane and NO content in such a manner as to simulate the exhaust of a passing vehicle. This cylinder was the first ever prepared with these gases by Scott Specialty Gases in Longmont, Colorado. Scott initially reported trouble with stability of the NO content. Inter-calibrations of both detectors with this cylinder and another cylinder (containing CO, CO_2 and propane only) gave results within the expected errors for CO and HC, and within 10% of the laboratory values. The NO calibrations were harder to obtain free of noise. More purging of the system was required to obtain good NO calibrations than for CO or HC.

Other comments on El Paso measurements

The winter fuel in El Paso appears to be mostly oxygenated with ethanol. Vapor lock problems were observed twice in the EPA's 1972 Winnebago, and thrice with the newly reconditioned Onan Generator used to power the system. These problems have never been observed previously, and may be related to the fact that we were there just when the weather turned warm (80's °F) at the end of the winter RVP fuel period.

The Taurus has a computer-monitored gas-mileage system which reported 26.5 mpg on non-oxy fuel and 22.5 mpg on oxy fuels. This effect was confirmed by written fill-up and odometer records. The Taurus achieved peak NO emissions much closed to a commanded stoichiometric air/fuel ratio in El Paso (with Ethanol fuels) than in Dearborn where the fuels were not significantly oxygenated.

The HC and CO data provided earlier in this report have been further analyzed to show the CO and HC emissions from El Paso and Juarez as deciles. These decile plots (Figures 4 and 5) illustrate the large emissions differences between the two fleets, although it is interesting to notice that the highest CO emitting group in El Paso has a similar average %CO to the three highest CO emitters in Juarez. There are more broken vehicles in Juarez than El Paso, but the emissions of the broken vehicles are much the same in both locations. Also the low emitting vehicles in El Paso are a lot lower in emissions than the low emitting vehicles in Juarez, presumably the result of modern closed-loop technology.

In the previous report it was noted that the El Paso CO emissions appear to be 10 to 20% higher than one might expect compared to Denver or LA. In a thought experiment we took Denver data from the summer of 1992 and added 11% Juarez vehicles from 1993. The result looks statistically similar to the El Paso fleet. Informal surveys while on-road showed about

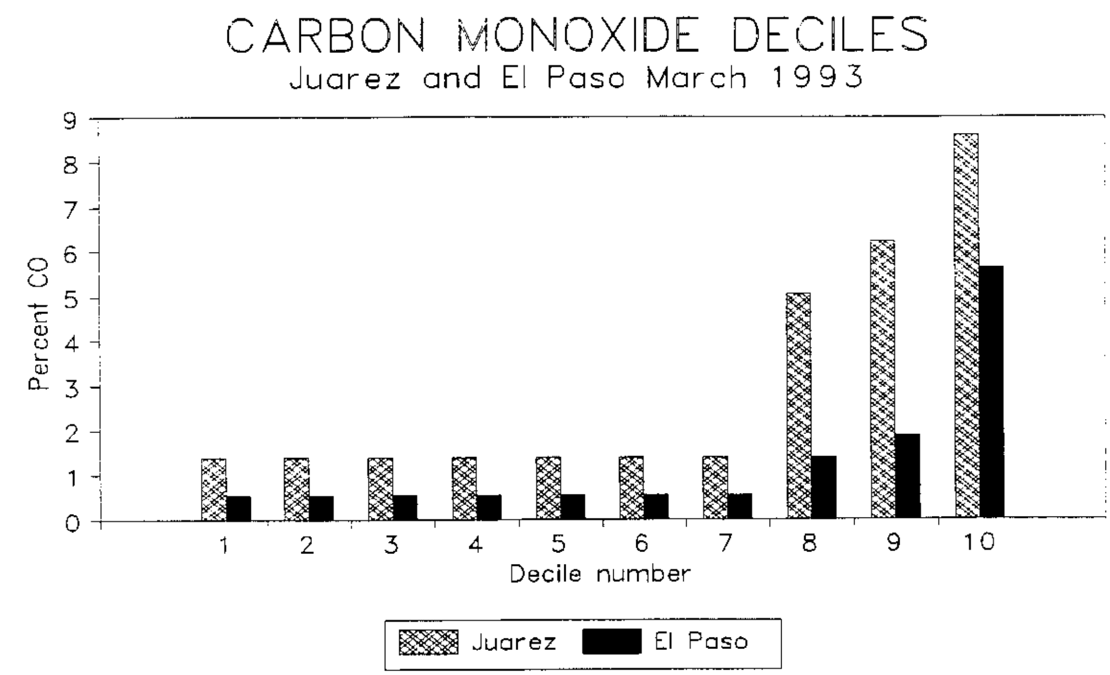

Figure 4 Decile emissions in %CO for vehicles measured in El Paso and Juarez.

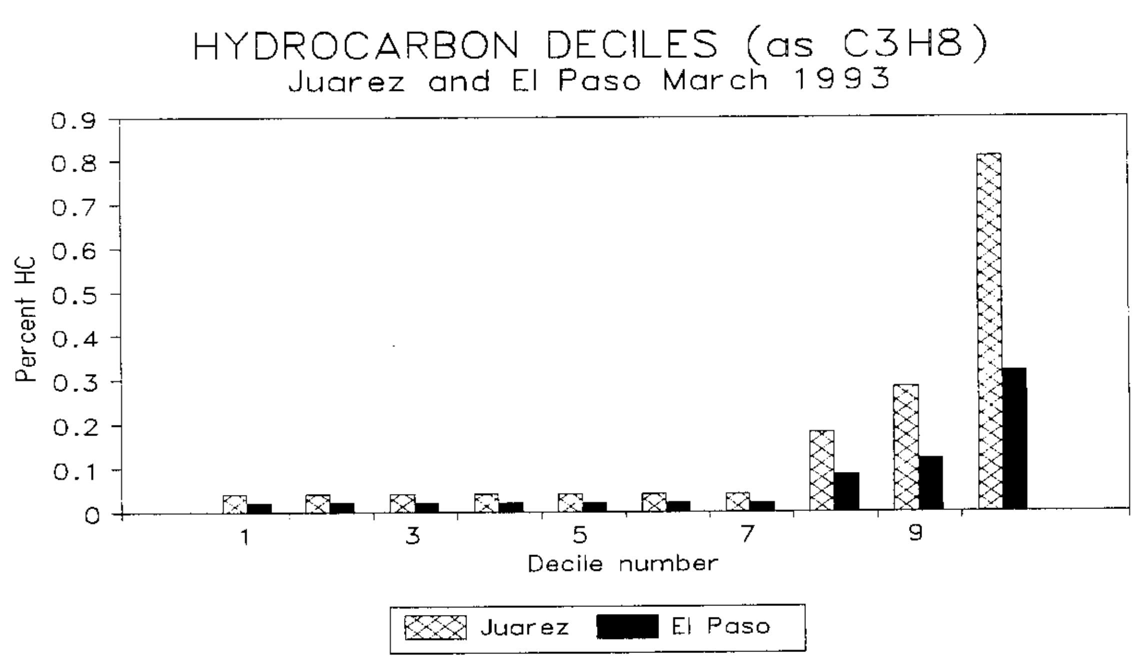

Figure 5 Decile emissions for HC in %propane for vehicles measured in El Paso and Juarez.

10% of the vehicles measured in El Paso equipped with Mexico plates. A more rigorous conclusion on this subject is available from the next section of this report in which the readable license plates are analyzed and enumerated.

License Plate Matched Data and I/M Effectiveness

The video tapes have been read and the license plates matched from the March 1993 El Paso study. There are four categories of non-matched plates, unreadable, Mexico State plates (coded M), Mexico Frontier Plates (coded F), paper plates where visible were coded (P) and out of state plates coded (O). The major analysis which was performed on the data was to compare emissions from Texas and New Mexico plates. We were assured by the TNRCC that all areas of El Paso County were engaged in a traditional decentralized I/M program at the time of our remote sensing study. According to Wolcott and Kahlbaum of EPA (presented at the 1990 Mobile Sources Clean Air Conference Boulder Colorado) the El Paso program was modelled with a credit for removing CO by 26% in 1992 over the situation which would prevail were there no I/M program.

The license plates from New Mexico were mostly from the Las Cruces area which does not have an I/M program. The results of the division into various data bases is shown in Table IV. Because Mexico plates are not computer accessible, only the Texas and New Mexico data have make and model year information. Note that the averages of integers such as vehicle model years can take decimal values while the integers themselves can not.

The effectiveness of the I/M program can best be evaluated by comparing emissions of

Table IV Summary of El Paso and Juarez data with model year information.

License	Count	Mean %CO	Mean %HC	Average Model year
EP_TEXAS	13,312	1.19	0.070	86.2
EP_NEWMX	797	1.41 (1.31)	0.083 (0.078)	85.5 (86.2)
EP_MEX	1,440	2.12	0.106	N/A
EP_US	5,139	1.37	0.077	N/A
JZ_TEXAS	395	1.62	0.102	84.8
JZ_MEX	3,264	3.15	0.181	N/A
JZ_US	465	2.37	0.156	N/A

I/M and non I/M fleets by model year. That comparison is shown in Figures 6 and 7 for CO and HC, respectively. The larger variability of the non-I/M fleet arises because of the small numbers in the older model years. In order to separate the overall effect of I/M from the expected effect if fleets of different age are observed, the age distribution of the two observed fleets has to be the same. The simplest method to carry out this normalization is to multiply the average emissions by model year of the non-I/M fleet by the age distribution of the I/M fleet. Two averages can now be compared, the observed average emissions of the I/M fleet, and the calculated average emissions of a fleet of vehicles having the same emissions by model year as the non-I/M fleet but the age distribution of the I/M fleet. This procedure has been used in other studies, for instance, the Radian report to Colo. State Auditor (Radian, 1993).

When the non-I/M (New Mexico) fleet emissions by model year are normalized to have the same vehicle count by model year as the I/M fleet, the difference in CO emissions is 9% and in HC is 10%. These differences are in the direction expected as if the I/M program were having an effect. A two tailed t-test of significant difference of the model year data pairs yields $t = 1.86$. The critical t values for $A = 0.1$ and $A = 0.05$ are 1.8 and 2.2 respectively, thus the difference is significant at the 95% ($t_{0.1}$) but not at the 97.5% ($t_{.05}$) level. In other words, one can be reasonably confidant that the observed difference is real but not as large as the 26% effect predicted by the EPA model.

There have been a number of other studies comparing the apparent on-road effectiveness of I/M programs with the EPA model. In Los Angeles (Stedman *et al*, 1994) and in Tucson (Zhang *et al*, 1994). In both cases insignificant effects were observed. There are two possible reasons for an apparent effect of an I/M program on on-road emissions from I/M and non-I/M vehicles measured at the same time and location, if a significant effect is observed. Either the I/M program is in fact reducing emissions from the I/M fleet, or the I/M program has caused the owners of high emitting vehicles to register their vehicle to a location where I/M is not required. We believe that these two possibilities can be sorted out by carrying out the comparison well inside the I/M county, and at the boundary of the county. In the latter case the fraction of the out-of-I/M plates which are not really owned by out-of-county residents decreases relative to a more central location.

The only state in which such a comparison has been carried out is Colorado, and the comparison was carried out at two very different times and places. At an I/M to non-I/M county boundary (Ostop and Ryder 1989) no significant effect on on-road CO emissions was observed. HC emissions were not measured. Two years later, close to downtown Denver a 15% effect of the I/M program on on-road CO and no effect on HC was reported (Radian, 1993). According to Wolcott and Kahlbaum (1990) in 1992 the Colorado I/M program was predicted by EPA to be having a 24% effect.

Without model year data one can not carry out very detailed further analysis of the Mexico registered vehicles, except to compare Frontier and State plates. The average %CO and %HC of 3522 Frontier plate vehicles were 2.9 and 0.17 respectively. The State plates numbered 1182 with average emissions of 2.6 %CO and 0.14 %HC. We were told that state registration

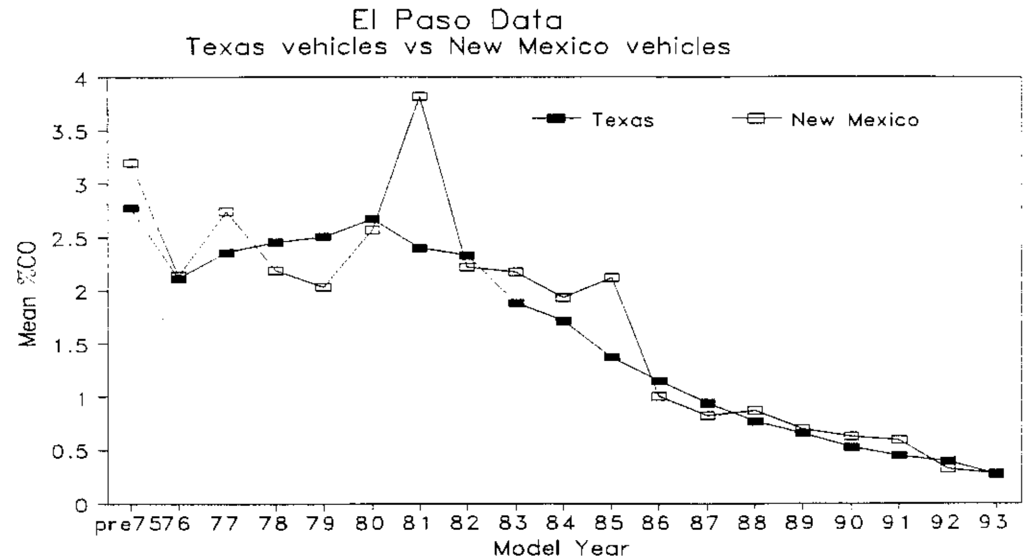

Figure 6 Comparison of mean %CO by model year for the I/M and non-I/M Vehicles measured in El Paso.

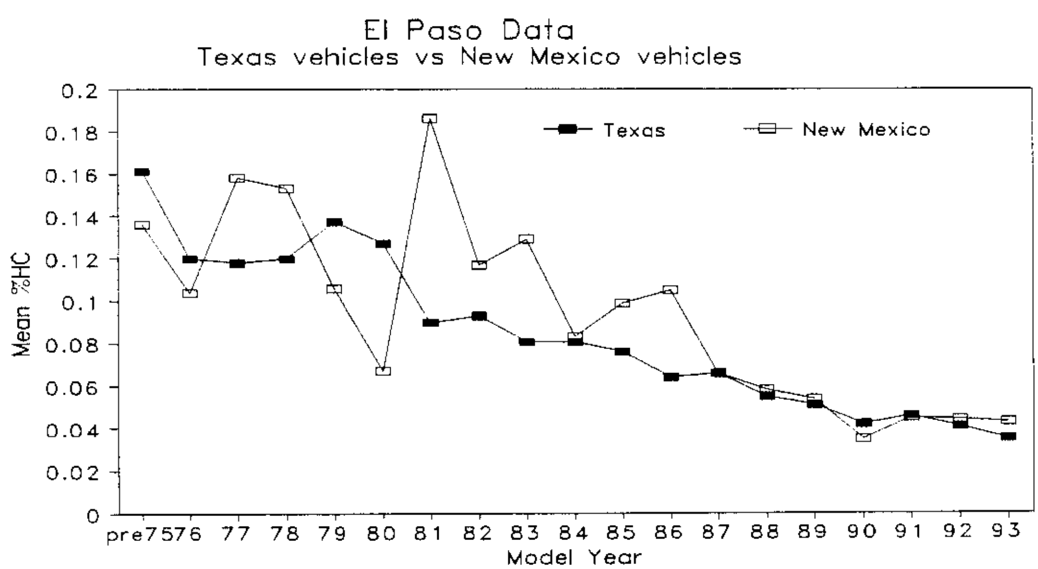

Figure 7 Same as Figure 6, but for HC data.

costs more than frontier registration giving rise to the expectation of a newer or better maintained fleet amongst the state registered vehicles. Without model year data we can not determine whether the increased emissions arise from an older, or a less well maintained fleet (or both).

The fleet of Texas registered vehicles measured in Juarez is on average 1.4 years older than the Texas registered vehicles measured in El Paso. This 1.4 year age difference is predicted to give rise to about 0.4 %CO increase, (Guenther *et al*, 1994) as observed. The observed age difference between Texas registered vehicles in Juarez and in El Paso can arise from two possible causes. When given a choice, an owner may choose to take his older vehicle to Juarez, or the socioeconomic status of Texas vehicle drivers in Juarez is such that on average they drive older vehicles than drive in El Paso.

The last set of data EP_US and JZ_US are vehicles measured in El Paso and Juarez respectively, but with license plates from other US states. The 5139 vehicles detected in El Paso with plates from other states than Texas and New Mexico appear to have significantly higher emissions than the Texas registered vehicles, but without detailed analysis one can not decide whether this effect is caused by an older, or by a less well maintained group.

Available data sets from the El Paso study are shown in Table IV. Those data sets with Average Model Year listed include the make, model year and emissions from vehicles measured on-road and identified by the Texas/New Mexico license plate authorities. Data are available on disk in D-base format from e-mail dstedman@du.edu. Numbers in parentheses are the New Mexico average emissions altered for the purpose of comparison to have the same model year distribution as the Texas data set.

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APPENDIX 1

These are the equations which convert measured % readings to mass emissions in gm/gallon assuming a carbon to hydrogen ratio of CH_2. If fuel density is 0.75 then the coefficients are 5685 and 8934 for the CO and HC equations respectively.

If we go with 0.726 gm/ml fuel density then:

$$gmCO/gal = 5506*\%CO/(\%CO + \%CO_2 + 3*\%HC)$$

$$gmHC/gal = 8644*\%HC/(\%CO + \%CO_2 + 3*\%HC)$$

$$gmNO/gal = 5900*\%NO/(\%CO + \%CO_2 + 3*\%HC)$$

Because $\%CO_2 = 15.06 - 0.715*\%CO - 0.132*\%HC$, one can rewrite the above equations as:

$$gmCO/gal = 5506*\%CO/(15 + 0.285*\%CO + 2.87*\%HC)$$

$$gmHC/gal = 8644*\%HC/(15 + 0.285*\%CO + 2.87*\%HC)$$

$$gmNO/gal = 5900*\%NO/(15 + 0.285*\%CO + 2.87*\%HC)$$

In the absence of HC data it is not a bad approximation to use HC = 1/12 of the CO and thus derive the equation:

$$gm\ CO/gal = 5506*\%CO/(15 + 0.524*\%CO)$$