SPREADSHEETS AND THEIR RELATION TO REALITY

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On-road remote sensing has been validated as a measurement of CO emissions on a dynamometer (Stedman and Bishop 1990) and on-road (Lawson et al 1990). A hydrocarbon remote sensor has recently been developed.

The current database of on-road gram per gallon carbon monoxide remote sensing measurements at the University of Denver consists of about 300,000 entries from Colorado Springs, Chicago, Denver, Los Angeles, and Toronto. The interpretation has included studies of the effectiveness of inspection and maintenance, wintertime mandatory fuel oxygenation, the differences between foreign and domestic vehicle emissions, the apparent deterioration rate of emissions with age, etc. The agreement between the data and the model predictions is quite variable. The agreements and discrepancies have led us to consider the structure of the emissions models which are basically large spreadsheets into which are input multiplicative parameters (emissions factors) which are designed to duplicate the behavior of the average vehicle in a given model year and weight class.

Figure 1 shows the emissions distribution from 106,000 vehicle measurements during a six-week period (Bishop and Stedman 1990). Almost 80,000 of the vehicles measured less than 1% CO (equivalent to about 20 gm/mile). Half the CO from the entire fleet was emitted by about 8% of the vehicles with emissions averaging 100 gm/mile. Because the distribution is skewed, the mean is significantly greater than the median, typically by a factor of four to five.

Figure 2 shows results from a 5,000 vehicle study of the Colorado I/M program. Vehicles were measured randomly, interspersed at one location, mostly under load, uphill at 8,000 feet. The upper curve (Figure 2a) shows median emissions from Teller County (out of I/M) by model year plotted against median emissions from El Paso County (inside I/M). If the I/M program were without effect on median emissions, the data would cluster about the indicated 1:1 line. Figure 2b shows the means. In this case, there is evidence (albeit weak) for points to lie below the line (i.e. for a statistically insignificant, but at least directionally correct influence of I/M).

The mean and median emissions for the 1980 and older model years are similar. The means and medians for the 1985 and new model years are very different.

Two recent analyses of remote sensing have been prepared (Austin, et.al. 1990 and Glover, 1990). Austin, et. al. show graphs of over 3,000 CARB in-use FTP results indicating a skewed distribution, much like remote sensing data. HC and CO are weakly correlated by CARB FTP on a roughly 10:1 scale selection. This phenomenon is also observed from remote sensing.

Most importantly, Glover (1990) shows that MOBILE4 comes quite close to predicting the MEDIAN emissions by model year from many published on-road remote sensing studies. From this, we conclude that MOBILE4 generally is likely to predict MEDIAN emissions, not MEAN emissions, at least for 1980 or newer vehicles. MOBILE4 over-predicts emissions from older vehicles because modelled deterioration continues ad infinitum, whereas, in reality it slows down between 10 and 20 years of vehicle age. The ratio of mean to median varies with vehicle age. Overall fleet ratios of four or five arise from higher ratios for new vehicles and lower ratios (often close to 1.0) for 1979 and older. Figure 3 shows mean and median emissions from a fleet of over 11,000 vehicles in Chicago. Overlayed on the graph is an approximate representation of the MOBILE4 prediction taken from Glover (1990). The model accurately represents the median emissions of the new vehicles, however deterioration sets in after about 1980, and then the prediction moves up closer to (and ultimately exceeding) the mean

Our current level of understanding suggests that vehicle to vehicle variability is so great that it may not be possible to model average emissions using average parameters to any satisfactory level of accuracy. This situation is analogous to the fact that weather cannot be predicted fifteen days into the future, regardless of extra expenses on computers or investments in data. Perhaps a better analogy would be our inability to predict the behavior of a finite crowd of people despite our best efforts to understand "the average person". Questions which arise from such an investigation include ... Is there any such thing as a representative driving cycle? If so, representative of which emission, at which temperature, for which class of vehicles?

Our suggestion for an alternative approach is based on the concept that emissions should be estimated by a statistical (Monte-Carlo) approach in which every "vehicle" is assigned a random probability whose distribution function resembles the on-road distribution function (to the extent that it can be estimated). The results of such modelling might not be any more accurate than the current spread-sheet approach, but every model run would automatically generate not only a result, but an estimate of the accuracy of the result. There would be no discrepancy between data and modelling for the tunnel study had the model included a factor of four inaccuracy estimate.

One important result of on-road measurements is that emissions are not normally distributed, but rather distributed in a gamma distribution. Because of the skewed nature of this distribution, it would be very easy (and entirely incorrect) to reject high emitters as statistical outliers (based on an assumption of a normal distribution) when fleets of only a few hundred vehicles have been measured.

Why does MOBILE4 predict the median emissions? Three reasons are apparent. The vast majority of vehicles cluster around the median. Some analyses intentionally reject outliers based on three sigma normal distributions, even though the data are not normally distributed (Haskew and Gumbleton 1986). It is difficult to recruit gross polluters for testing, particularly of attempting to recruit from private individuals who knowingly have tampered with their emissions systems. Many testing programs (such as the EPA study of idle emissions variability and the CRC study of the effects of fuel oxygenation) intentionally ensure that all vehicles are in good repair. This procedure ensures that the vehicle emissions are not so gross (and often, so grossly variable) that subtle fuel effects go unobserved. The procedure also ensures that the tested fleet emissions are not representative of the on-road emissions of an equivalent age/size fleet, since gross emitters are rejected before the testing begins. All procedures tend towards measuring the median, not the mean.

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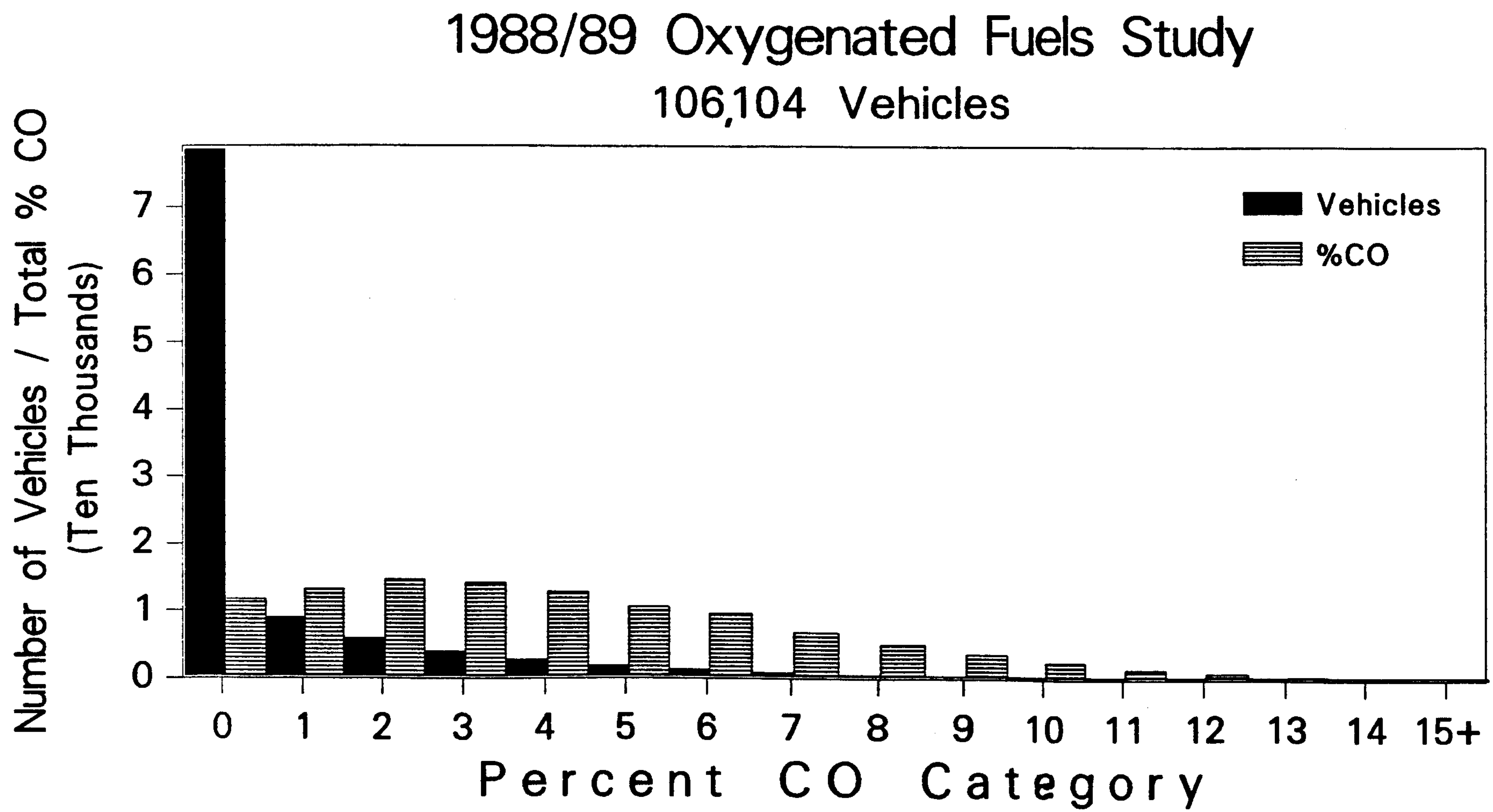


Figure 1. Carbon Monoxide Emissions distribution from 106,000 vehicles.

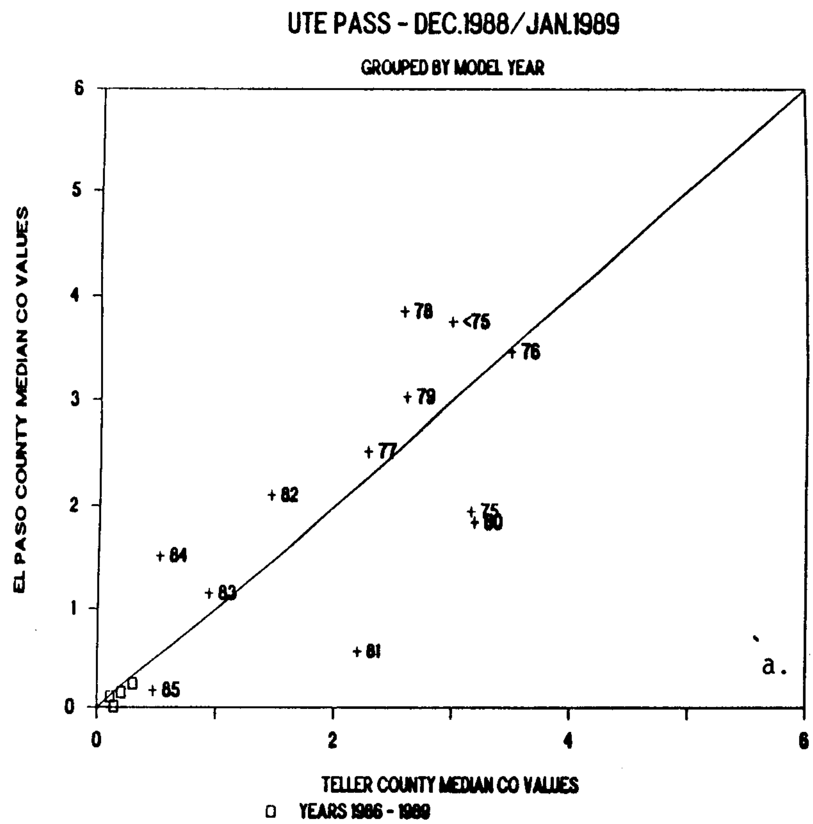
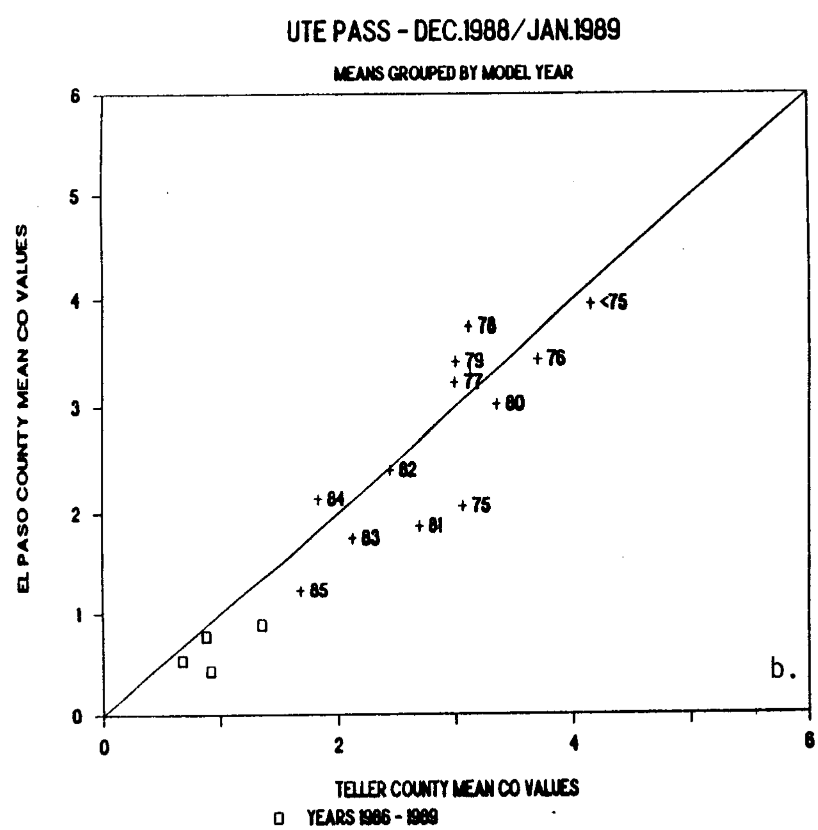


Figure 2: 5,000 Vehicle I/M Study.



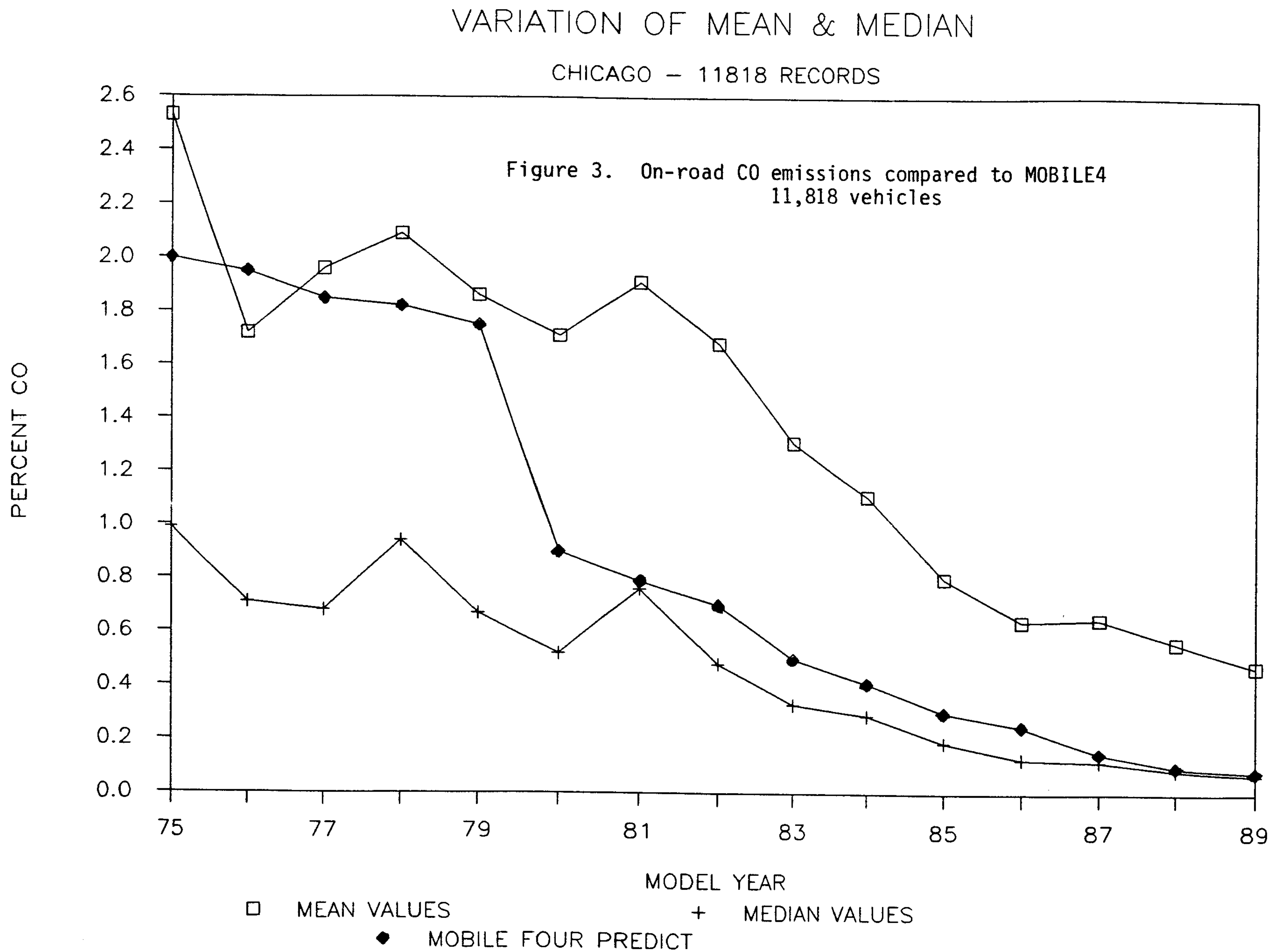


Figure 3. On-road CO emissions compared to MOBILE4
11,818 vehicles