Comments on MOVES Reports

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Acknowledgements

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- This report was not sponsored.

NCSU Study Limitations

- The limits on the NCSU study with respect to vehicle age and type led to conclusions that were specific to the limited data used.
  - NCSU pointed out that "Because this study focused upon Tier 1 vehicles, with much of the data spanning only a very limited range of model years, it is possible that the influence of model year is understated with respect to this analysis and that it may be more important for other types of vehicles."
- Although new vehicles have been getting cleaner, and, based on I/M emissions and remote sensing data, staying cleaner longer, there is no way to know what the average emissions of today's "new" vehicles will be when these vehicles get older, and are in the hands of second, third, and fourth owners.
- Currently, the on-road emissions contributions of zero to four-year-old vehicles is a small fraction of the mobile source emissions.
- Therefore, the report's conclusions, which did not consider vehicle age, appear to be misleading when applied to the whole on-road fleet.
- This presentation describes why.

Extrapolation from a Small Sample

- To understand on-road fleet emissions it is necessary to have data on driving patterns, how vehicle emissions are affected by driving patterns and especially how vehicle emissions vary from one vehicle to another.
- Since vehicle emissions vary markedly from one vehicle to another, one cannot understand fleet emissions from a small sample without ensuring that the sample is representative of the on-road fleet.
- NCSU implies that large numbers of seconds-of-emissions-measurements from a few vehicles provides the necessary data for analysis, <u>but this will not result in the small sample representing the on-road fleet</u>. Making more measurements from the same vehicles or creating artificial measurements by bootstrapping from an even smaller sample of measurements, does not address the issue of selection bias. And most of the on-road emissions come from a small proportion of high emitting vehicles on the road.
- The numbers of vehicles used in the NCSU report were 17 in the shootout, 25 for the EPA SFTP, 311 in the Colorado IM240 set, and 74 at CE-CERT. The remote sensing analysis was based on over 50,000 Tier 1 LDGV's. However, NCSU recommended against using remote sensing.
- A more complete discussion of these considerations is in the reference, "Some Statistical Issues in the Statistical Analysis of Vehicle Emissions, Wenzel, T., Singer, B.C., Slott, R., Journal of Transportation and Statistics. 3:2, 1-14 (Sept 2000)." http://www.bts.gov/publications/jts/v3n2/index.html

Binning

- Vehicle to vehicle light duty gasoline tailpipe concentrations have been shown by Bishop and Stedman to follow Gamma or Weibull (i.e., non-normal or skewed) distributions. If measurements from large numbers of vehicles are binned, and if sufficiently large numbers of measurements are included in each bin, the average of bins will be normally distributed due to the Central Limit Theorem. Slott has been binning vehicle concentrations and analyzing average bin values with normal statistics (E-23 reports and presentations at CRC On-Road Workshops).
- The number of bins is limited by the number of measurements and the depth of analysis. When two independent variables, ***a*** and ***b***, are to be examined, there are more bins (***a***x***b)*** with fewer measurements in each.
- The independent variables which can explain more of the variation in the dependent variable should have more bins allocated to them.
- Multiple regression can be used to select which independent variables are most important. When this is done for remote sensing using Vehicle Age, Odometer, VSP, and Vehicle Type, <u>Vehicle Age is seen as the most important variable</u>. Odometer, VSP, and vehicle type are also important for explaining variation in CO and NO concentrations.
- Due to restrictions on the age of vehicles investigated, and the binning methodology used, NCSU ended up with 14 VSP bins, two odometer bins, two engine displacement bins and <u>no age bins</u>.

Comparison of Model Results

- The only way to objectively assess the uncertainty in an emission inventory model is to compare the modeled results with other, independent, ways of estimating the mobile source emissions inventory.
- Examples of alternate ways of estimating vehicles emissions include:
  - Using data from California's roadside dynamometer tests,
  - Creating a fuel-based emission inventory from remote sensing measurements (Singer and Harley),
  - Identifying vehicle emissions using source receptor analysis (Fujita, et al),
  - Using reverse air modeling where vehicles are the major emission source,
  - Using ambient CO measurements.
  - Analyzing the results of emissions from vehicle tunnels tests.
  - Looking at ratios of pollutants from remote sensing.

Propagation of Errors

- A lower bound of uncertainty can be estimated by identifying sources of error in the measurements used in the emissions inventory model, and propagating these errors through the model.
- This uncertainty estimate assumes that the model is correct, and so does not include errors due to use of the wrong model, omissions of data in the model (e.g., vehicle selection bias), assumptions about variables' linearity or normality that are incorrect, etc.
  - The uncertainty associated with VSP should include the effect of the delay in time from when emissions are generated in the engine until emissions emerge from the tailpipe as pointed out by Jimenez (1998) and the uncertainty in the speed measurement. Errors in VSP due to these factors in remote sensing measurements are greatest for vehicles traveling at slow or very high speed. Other uncertainties associated with VSP (or load) are the distribution of vehicle air drag and rolling resistance coefficients.

NCSU Remote Sensing Evaluation

- NCSU compared Missouri remote sensing on 50,000 vehicles with Colorado IM240 measurements from 311 vehicles.
- The Missouri remote sensing values should have been compared to IM240 measurements on the same vehicles. The data is available from the Missouri I/M program.
  - The data bases from Missouri and Colorado were not well described in the NCSU report. There is no description of how vehicle age, model year, or vehicle type were matched, or why only a subset of the Missouri and Colorado vehicles were used.
  - There was no description of the conditions of the Colorado IM240 tests in the NCSU report. IM240 results are subject to errors from variable vehicle conditions prior to the test, the use of fast pass or fast fail, etc.
- NCSU had concerns about using remote sensing data including:
  - Odometer not available: Odometer is less important than vehicle age, which is available for remote sensing data, and, for the Missouri data (or any area that has an I/M program) odometer-values are available from I/M records.
  - Only 1 second of measurement: On page 63, NCSU said there was no advantage in averaging over more than 1 second of data from on-board instrumented vehicles.
  - Fuel rate data are not available: A remote sensing gm/mile emission inventory would require an estimate of the instantaneous fuel rate. Second-by-second dynamometer data may generate a correlation if additional information on acceleration change were available from remote sensing measurements. ESP plans to introduce, in 2003, remote sensing equipment with the capability to measure and retain two sets of multiple accelerations, one measured upstream from the tailpipe emission measurement.

Consequences of Omitting Remote Sensing Data from MOVES

- If only on-board, on-road volunteer vehicles are used to create or update MOVES:
  - Very limited vehicle populations will be available with
  - Unknown selection bias.
  - The participant drivers' knowledge that they are part of a test may disturb their normal driving pattern (the "Hawthorne Effect").
- If only IM240 data from existing I/M programs are used to create or update MOVES uncertainty about vehicle condition prior to test and vehicle selection bias will result. Vehicle samples cannot include:
  - No-I/M locations
  - Vehicles that avoid testing
  - OBDII tested vehicles (model year 1996+)
  - I/M locations with tests other than IM240
  - Newer vehicle exempt from testing.
- If remote sensing is not used to update MOVES additional cost will be incurred by having to make additional special studies and EPA
  - Cannot make use of extensive remote sensing data from clean screen programs in Missouri and Colorado.
  - Results will be challenged on selection bias issue.

High Emitters

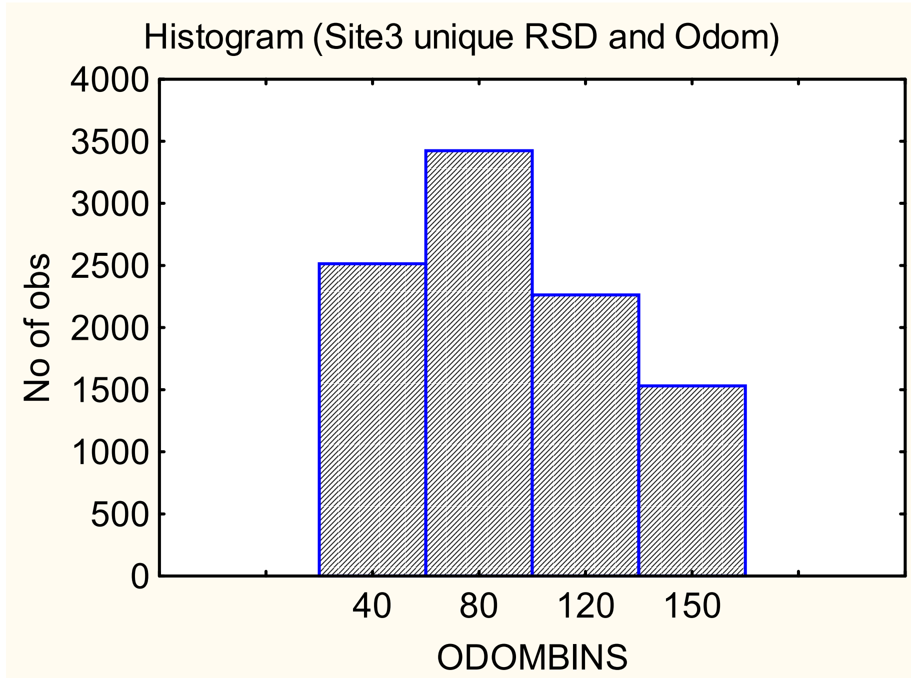
- High emitters are defined as vehicles with emissions of at least one pollutant (CO, HC, NO, etc.) which is a large multiple of the certification standard for that vehicle.
- Heuristic information leads to classifications for finding high emitters.
  - Eastern Research Group, ERG, developed high emitter profiles based on I/M history, vehicle age, etc. (http://www.erg.com/enviro/hepup.htm)
  - Wenzel has shown higher average remote sensing emissions
    - in vehicles before they fail an I/M test compared to vehicle that pass, and
    - vehicles that failed and then passed I/M tests compared to vehicles of the same model year that initially passed the I/M test. Vehicles that failed and never passed had higher average remote sensing emissions.
  - The probability of a vehicle having a high remote sensing reading increases with the number of times the vehicle has been seen previously having a high remote sensing reading.
- High emitter populations can only be estimated by having emission data on large numbers of vehicles. Sufficient data are only possible from an I/M program with emission tests or by a remote sensing measurement program.

New Remote Sensing Binning Analysis

- The Missouri Gateway Clean Air Program uses remote sensing for clean screening. From late1999 through March 2001 over 4 million remote sensing readings were made on over 1 million separate vehicles.
- In the year 2000, the site with the most measurements was Site 3.
- Remote sensing measurements from Missouri Site 3 in 2000 were used to examine the relative importance of four variables on CO, HC, NO, concentrations
  - Vehicle type, VSP, vehicle age, and odometer.
  - Vehicle type is a surrogate for engine size and trucks had less stringent certification standards than cars, and vehicle age incorporates both age and vehicle technology change since model year and age are confounded in this analysis.
- Measurements used had VSP between 2.5 and 22.5 kW/t and the vehicle had an odometer reading within 3 months of the remote sensing reading. Odometer readings and vehicle types were obtained from the Missouri I/M database.
- Of 10,825 measurements that met the criteria, 7064 were unique vehicle measurements, 2668 were multiple remote sensing readings on the same vehicle with the same odometer reading, and 1093 were repeats of remote sensing readings with different odometer readings. The 1093 were removed, leaving 9732 measurements for the analysis.
- Uncertainty of the average bin concentrations in this analysis is due to the concentrations variation within the bins. An alternative way to treat uncertainty is to obtain the uncertainty of the average of the bins. This requires generating an additional random bin variable. An analysis with a random bin variable for NO concentrations by AGEBIN and ODOMBIN gave very similar uncertainties.

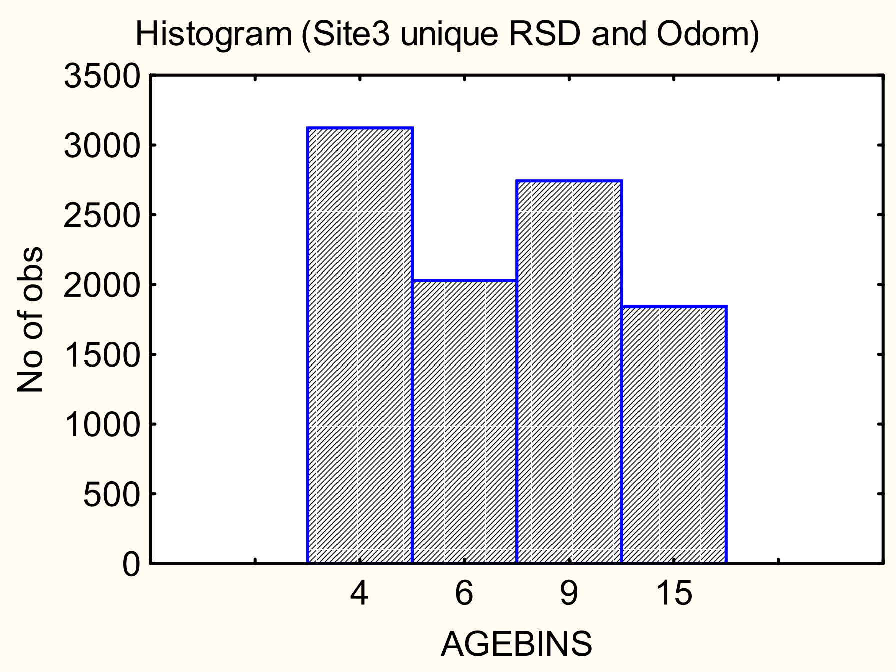
Defining Site 3 Odometer Bins in 2000

- The upper bounds for the odometer bins are shown on the x-axis of the histogram in thousands of miles. The last bin, labeled 150, includes all values over 120,000 miles.
- The y-axis shows the number of measurements at Site 3 made in year 2000 with odometer readings within 3 months of the remote sensing measurement and VSP between 2.5 and 22.5 kW/t.



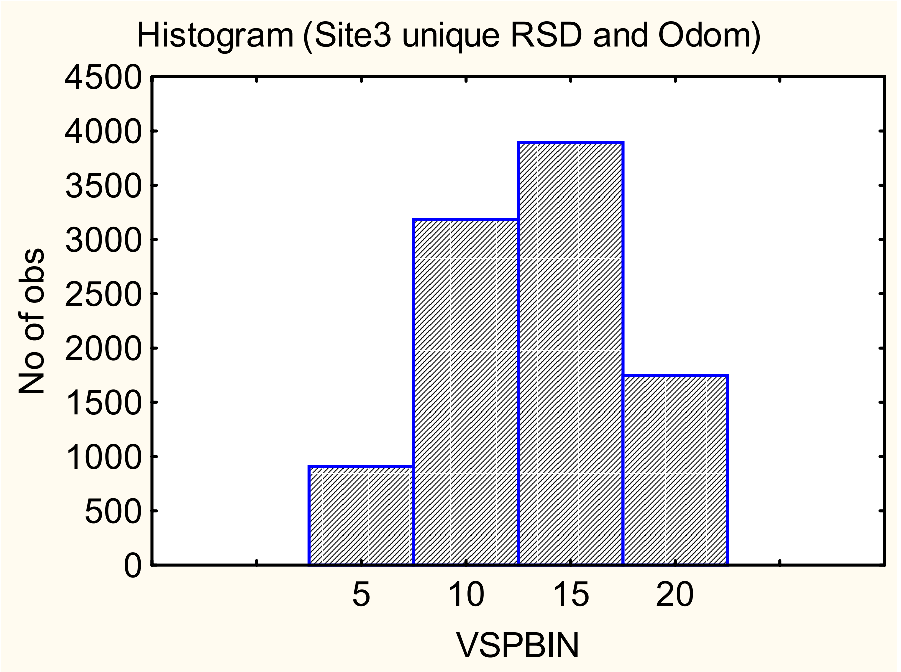
Defining Site 3 Age Bins in 2000

- The upper bounds for the vehicle age bins are shown on the x-axis of the histogram in years of vehicle age, where vehicle age = year measured + 1 – model year. The last bin includes all vehicles older than 9 years old.
- The y-axis shows the number of measurements at Site 3 made in year 2000 with odometer readings within 3 months of the remote sensing measurement and VSP between 2.5 and 22.5 kW/t.



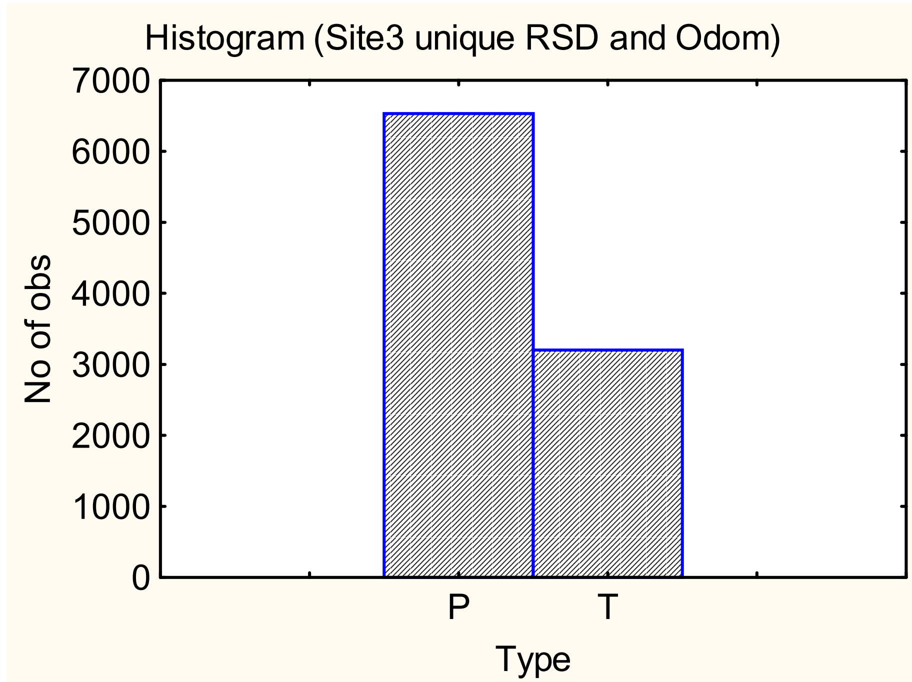
Defining Site 3 VSP Bins in 2000

- The center point for the 5 kW/t wide VSP bins are shown on the x-axis of the histogram.
- The y-axis shows the number of measurements at Site 3 made in year 2000 with odometer readings within 3 months of the remote sensing measurement and VSP between 2.5 and 22.5 kW/t.



Distribution of Vehicle Type

- The vehicle type is classified as P (passenger vehicle) or T (truck) in the Missouri I/M database.
- The y-axis shows the number of measurements on P or T vehicle types at Site 3 made in year 2000 with odometer readings within 3 months of the remote sensing measurement and VSP between 2.5 and 22.5 kW/t.



Importance of Vehicle Age

- Based on remote sensing measured in 2000 in Missouri at Site 3 and Missouri I/M records :
  - Vehicle age correlates with Odometer; older vehicles, on average, have been driven more.
  - Multiple regression of Vehicle Age, Odometer, VSP, and vehicle type shows that, among these variables, <u>Vehicle Age is the most important factor for explaining CO, HC, and NO concentrations</u>.
    - Interaction plots of vehicle Age and Odometer for CO, HC, and NO concentrations illustrate this visually.
  - VSP and Vehicle Type are independent variables that help explain variation in the concentrations data
  - Odometer, although correlated with vehicle age, adds value to explain concentrations data, especially for NO concentrations.

Correlation Among Binning Variables

- The chart below gives r-values for cross correlations among binning variables.
  - The r-value for a correlation pair is at the intersection of the row and column.
  - For example, correlation of Odometer Bin with Age Bin has an r-value of 0.62.
  - Significant correlations are shown in red. The larger the r-value, the stronger the correlation. Low r-value significant correlations should be discounted. Their statistical significance arises because of the large number of measurements.
- Positive values of r means increases in one variable are correlated with increases in the other variable. For the TYPE variable, Cars were indexed lower than Trucks.
  - Odometer increases with Vehicle Age.
  - The proportion of Trucks is slightly higher for newer vehicles.
  - Older vehicles and Trucks have a very slight tendency to be at lower VSP than newer vehicles and Cars at Site 3. This was observed in E-23 studies at other sites.

Cross Correlation
9732 Measurements in 2000
at Site 3 in Missouri Gateway RSD Program
and VSP values limited to 2.5 to 22.5 kW/t

r Values	Type	VSPBIN	ODOMBINS	AGEBINS
TYPE	1.00	-0.03	0.01	-0.11
VSPBIN	-0.03	1.00	-0.02	-0.04
ODOMBINS	0.01	-0.02	1.00	0.62
AGEBINS	-0.11	-0.04	0.62	1.00

Odometer x Age Analysis

- High average emissions are seen for older vehicles with low odometer readings. Some of the vehicles could have had their odometer rolled back (tampering), and/or some of the vehicles odometer readings could have been misread. Odometer errors confounded EPA's analysis of Dayton I/M data when EPA attempted to use odometer readings to correlate emissions.
- Newer vehicles (0 to 4 years old) with high odometer readings have higher NO concentrations than newer vehicles with low odometer readings, but this is not the case for CO or HC concentrations.
  - The low deterioration of CO and HC concentrations with mileage in newer vehicles could be due to improved, more robust, vehicle technology in these vehicles.
  - But it should highlight the uncertainty in using high mileage, newer vehicles to forecast the emissions of high mileage, older vehicles, especially for CO and HC emission estimates.

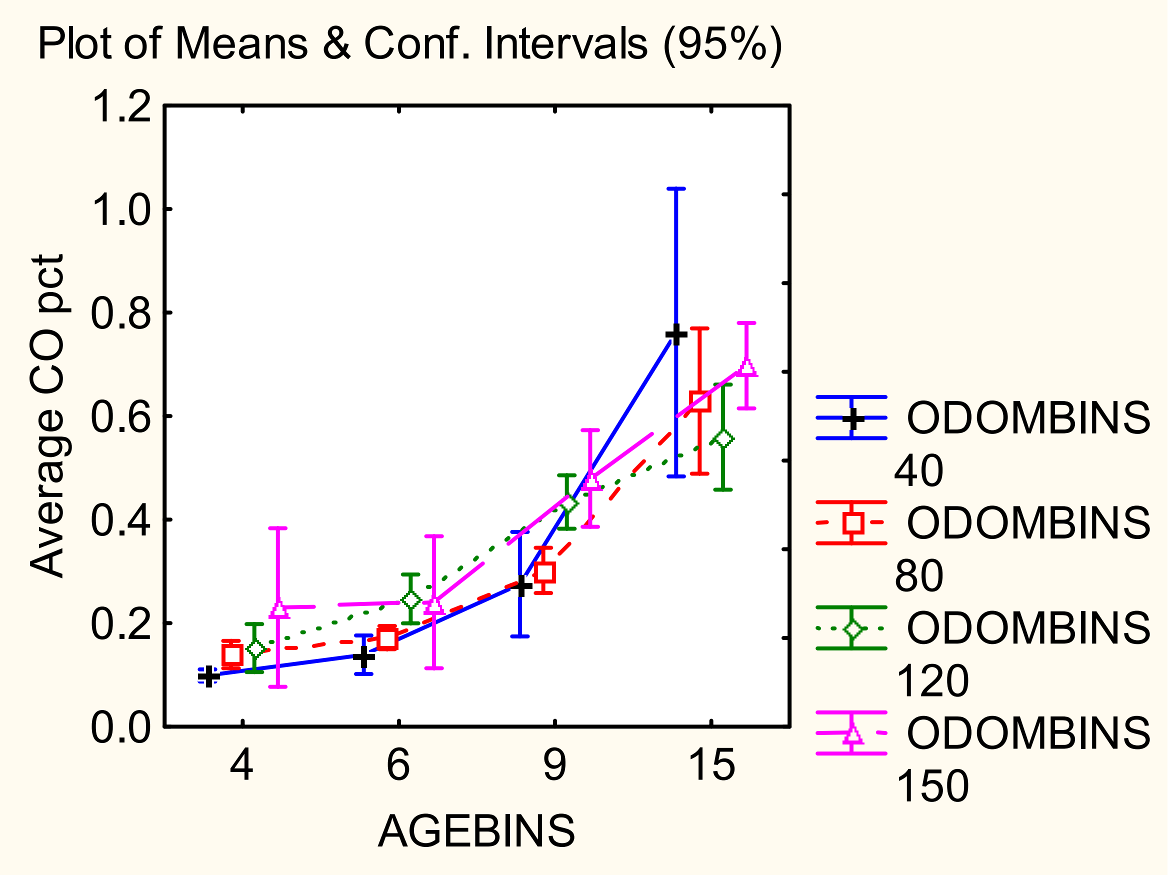
VSP, Type, Odometer, Age

- Beta Values from multiple regression analysis on remote sensing in Missouri show Vehicle AGE is a more important factor for explaining variation in CO, NO, and HC concentrations than Odometer, Vehicle Type, or VSP.
- Significant values are shown in red. Low r-value significant correlations should be discounted. Their statistical significance arises because of the large number of measurements.
- The ratio of AGEBIN to ODOMBIN beta values are shown in blue. The higher the ratio, the relatively more important the independent variable with the higher beta value is for explaining the variation in the dependent variable.

Multiple Regression 9732 Measurements in 2000 at Site 3 in Missouri Gateway RSD Program and VSP values limited to 2.5 to 22.5 kW/t			
Beta Values	CO pct	NO ppm	HC ppm
TYPE	0.03	0.09	0.01
VSPBIN	0.02	0.03	0.00
ODOMBINS	0.06	0.16	0.05
AGEBINS	0.22	0.35	0.23
AGEBIN/ODOMBIN	4.0	2.1	4.3

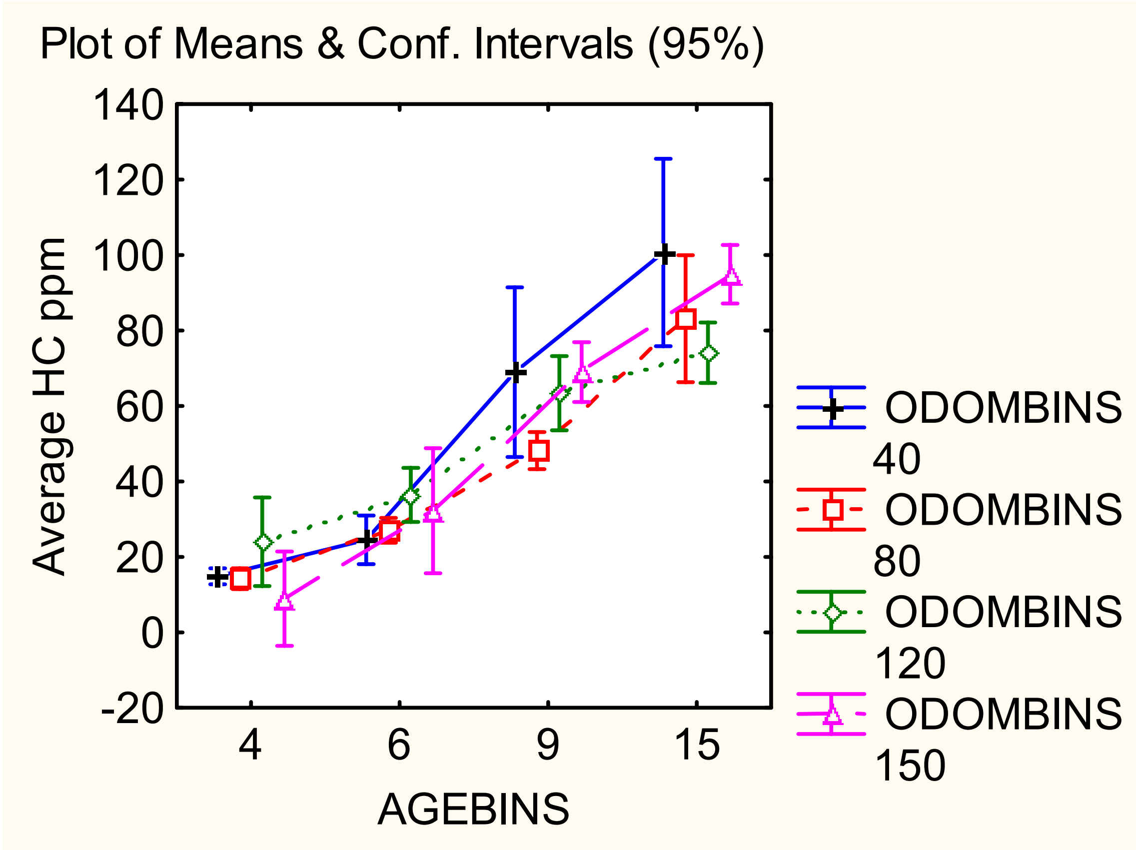
Variation of CO with Age BIN

- CO pct at Missouri Site 3 in 2000 with VSP between 2.5 and 22.5 kW/t and Odometer Readings within 3 months of the Remote Sensing Measurement,
- Minimum Measurements per AGE x ODOM Bin = 43



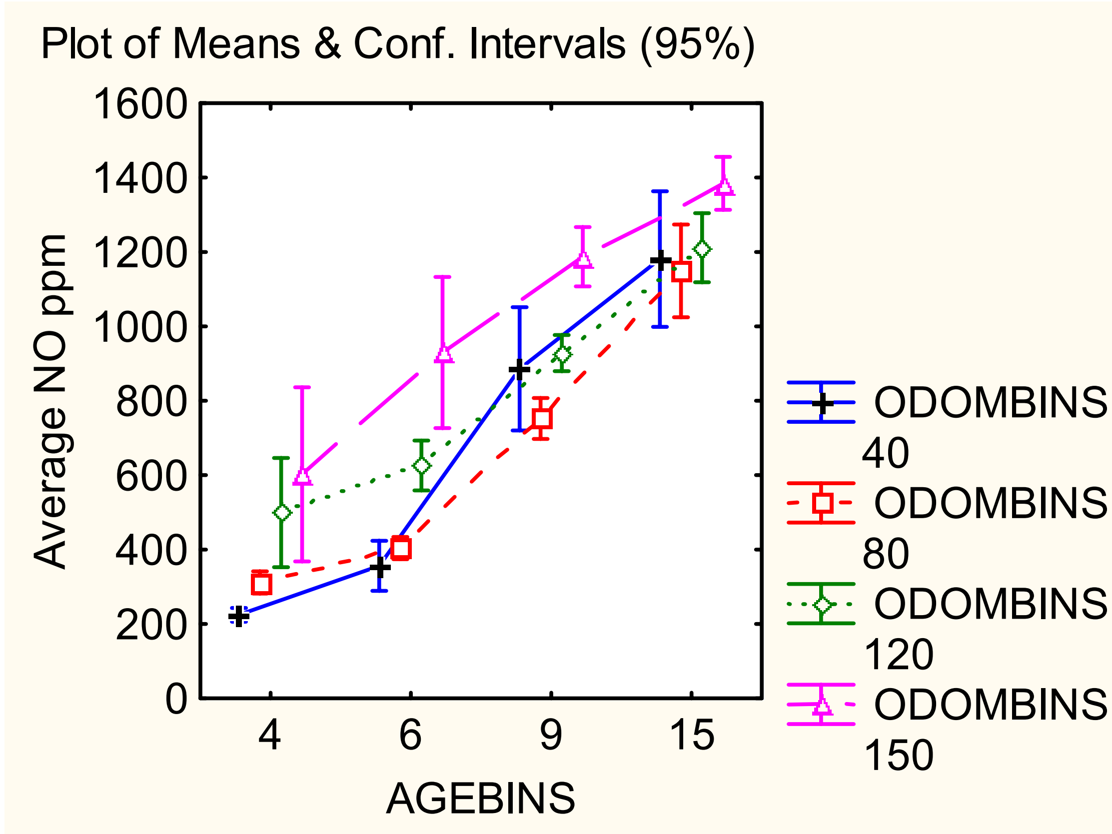
Variation of HC with Age BIN

- HC ppm at Missouri Site 3 in 2000 with VSP between 2.5 and 22.5 kW/t and Odometer Readings within 3 months of the Remote Sensing Measurement,
- Minimum Measurements per AGE x ODOM Bin = 43



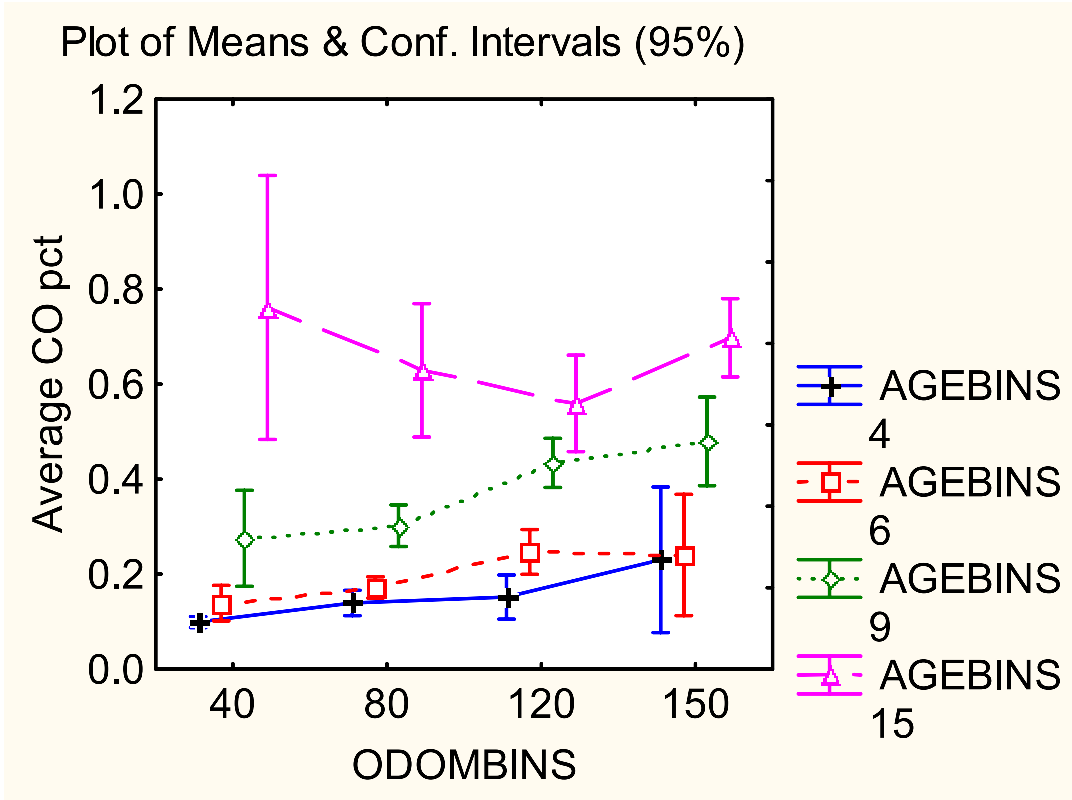
Variation of NO with Age BIN

- NO ppm at Missouri Site 3 in 2000 with VSP between 2.5 and 22.5 kW/t and Odometer Readings within 3 months of the Remote Sensing Measurement,
- Minimum Measurements per AGE x ODOM Bin = 43



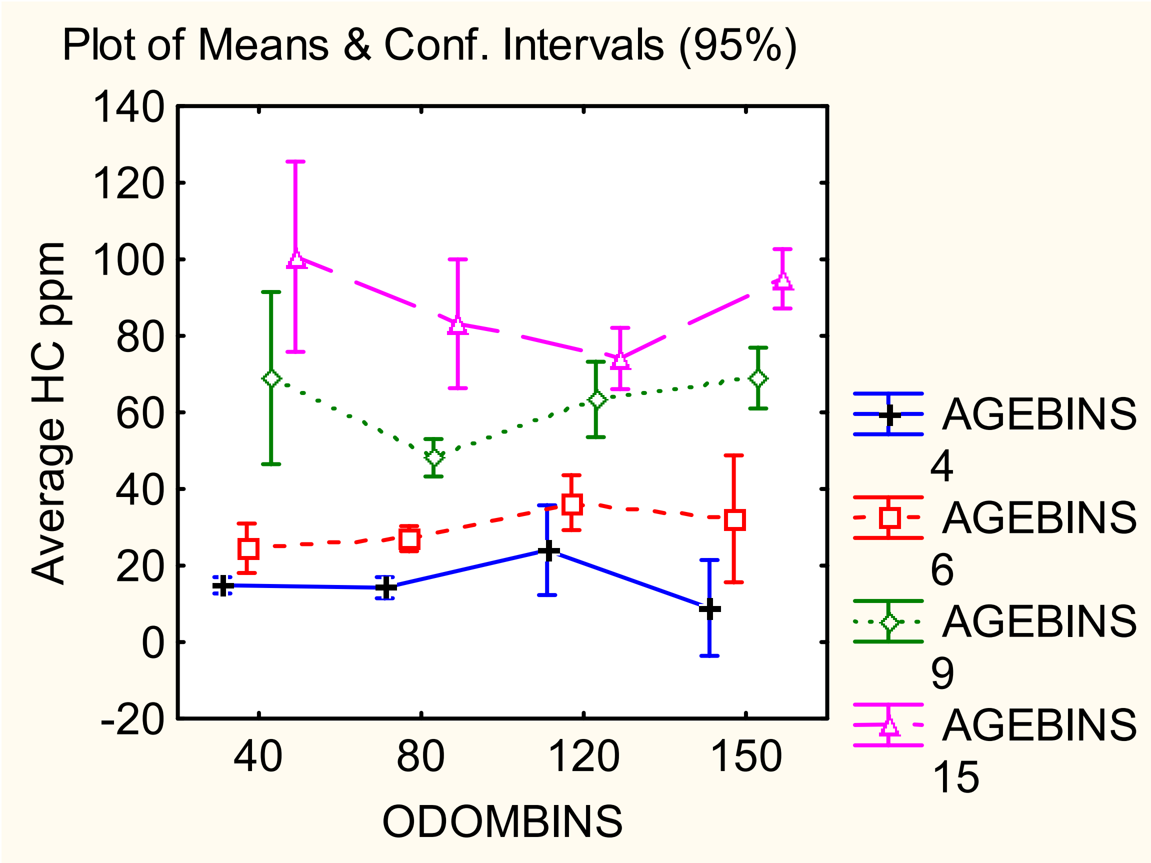
Variation of CO with Odometer BIN

- CO pct at Missouri Site 3 in 2000 with VSP between 2.5 and 22.5 kW/t and Odometer Readings within 3 months of the Remote Sensing Measurement,
- Minimum Measurements per AGE x ODOM Bin = 43



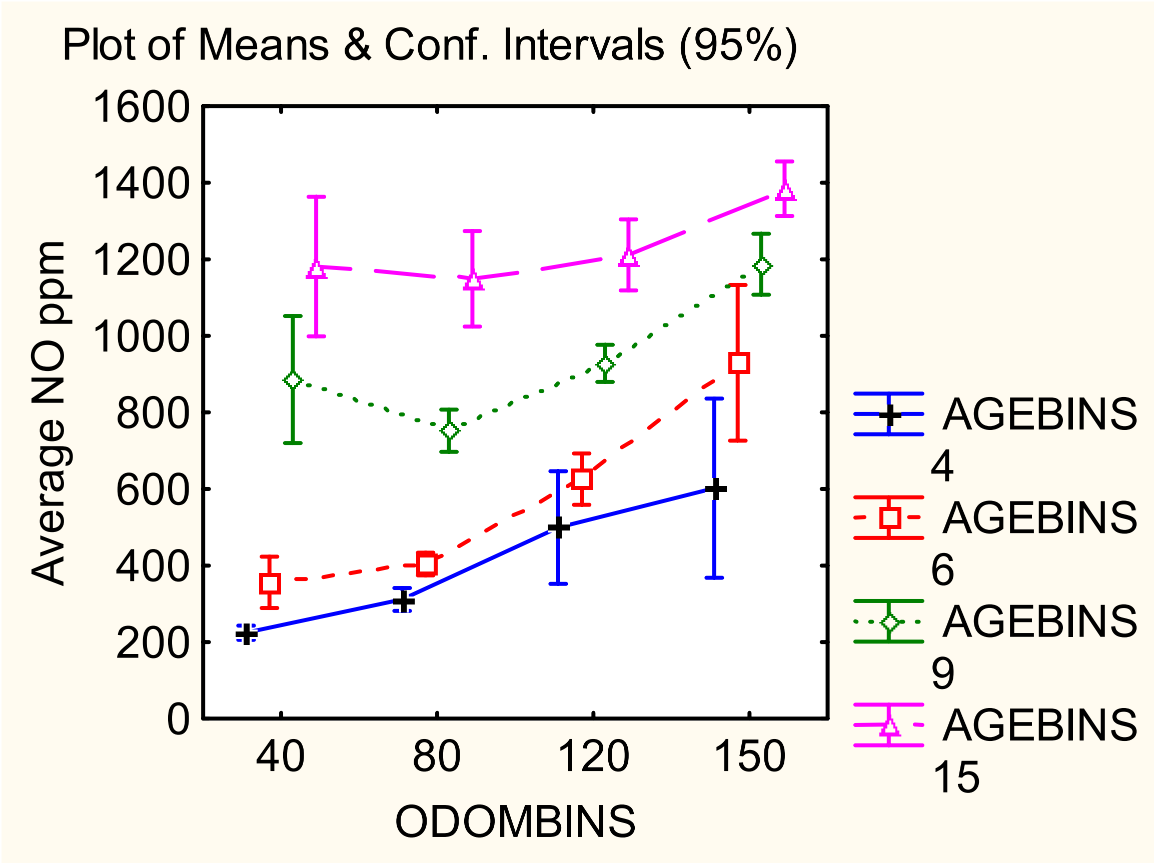
Variation of HC with Odometer BIN

- HC ppm at Missouri Site 3 in 2000 with VSP between 2.5 and 22.5 kW/t and Odometer Readings within 3 months of the Remote Sensing Measurement,
- Minimum Measurements per AGE x ODOM Bin = 43



Variation of NO with Odometer BIN

- NO ppm at Missouri Site 3 in 2000 with VSP between 2.5 and 22.5 kW/t and Odometer Readings within 3 months of the Remote Sensing Measurement,
- Minimum Measurements per AGE x ODOM Bin = 43

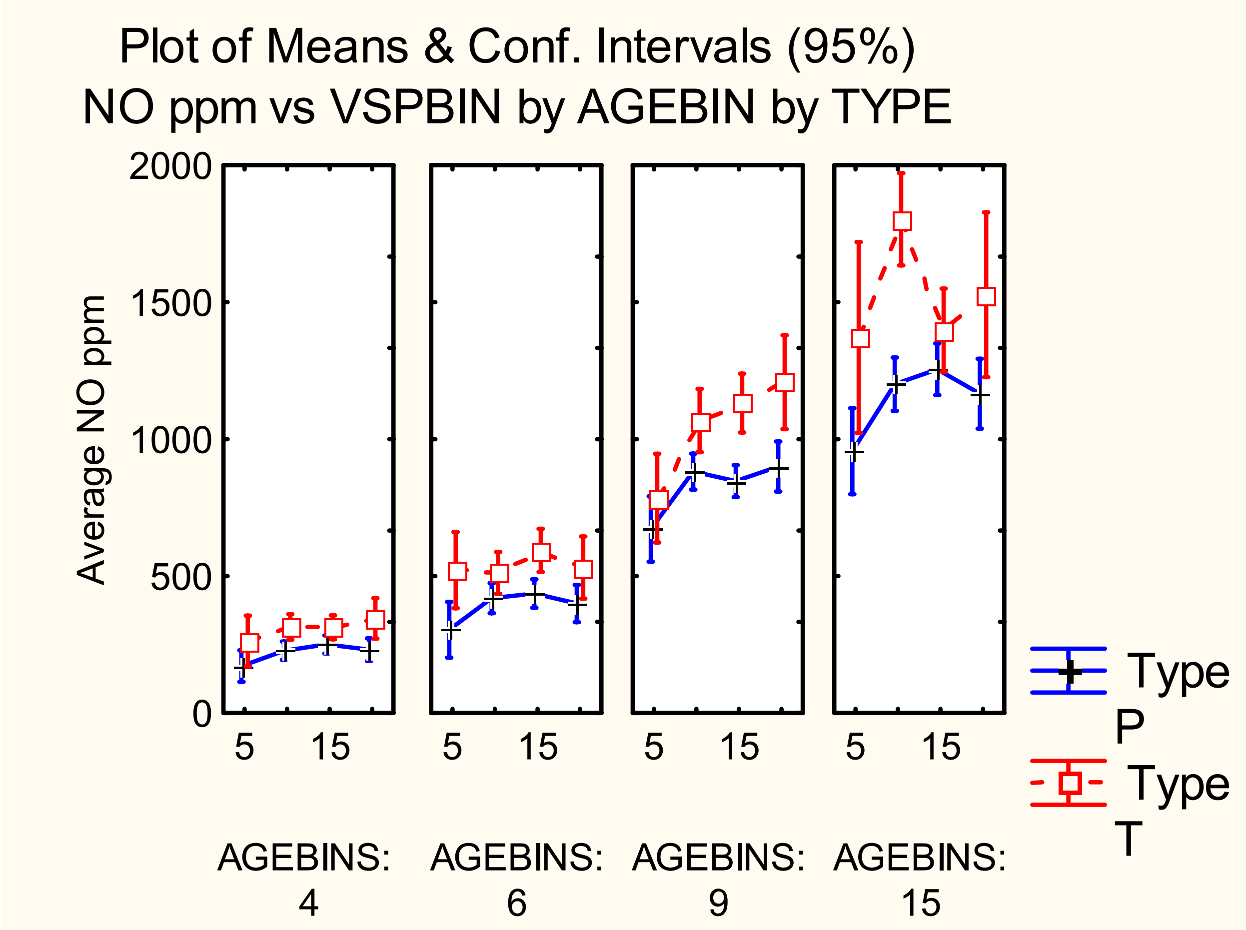


Variation of concentrations with VSP

- The following slides show the variation of concentrations with VSP over the range 2.5 to 22.5 kW/t in the four 5 kW/t VSP BINS by AGE and TYPE.
  - NO concentrations increase with VSP.
    - The effect is more noticeable in older vehicles.
    - Some older vehicles go into enrichment during the 20 kW/t VSP BIN, reducing NO concentrations from the 15 kW/t VSP BIN.
  - VSP has little effect on HC and CO concentrations for newer vehicles at the scale of the graphs.
  - Older vehicles behave as expected, with higher HC and CO concentrations at lower and higher VSP.

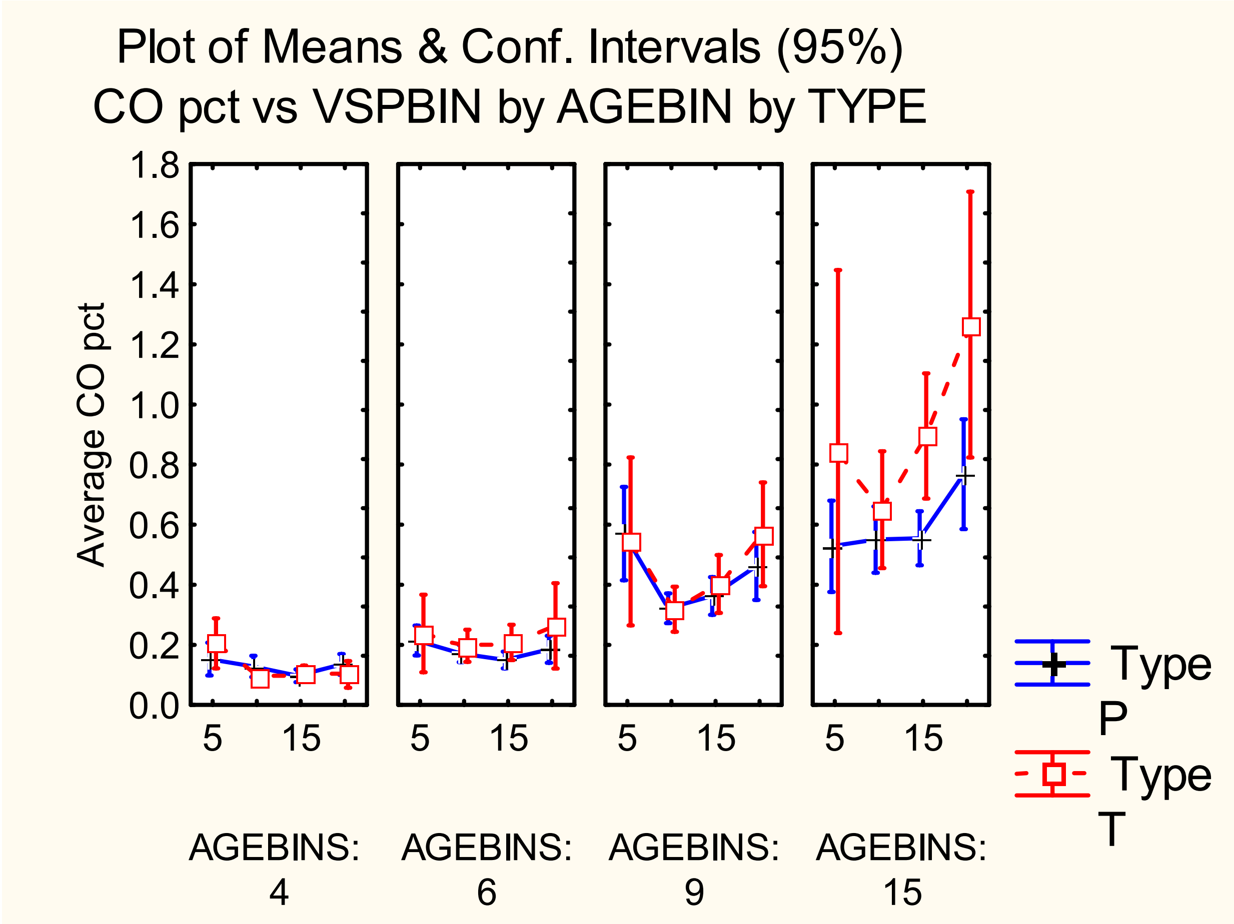
NO ppm vs VSPBIN by AGEBIN by TYPE

- NO ppm at Missouri Site 3 in 2000 with VSP between 2.5 and 22.5 kW/t and Odometer Readings within 3 months of the Remote Sensing Measurement,
- Minimum Measurements per AGE x VSP x TYPE Bin = 39



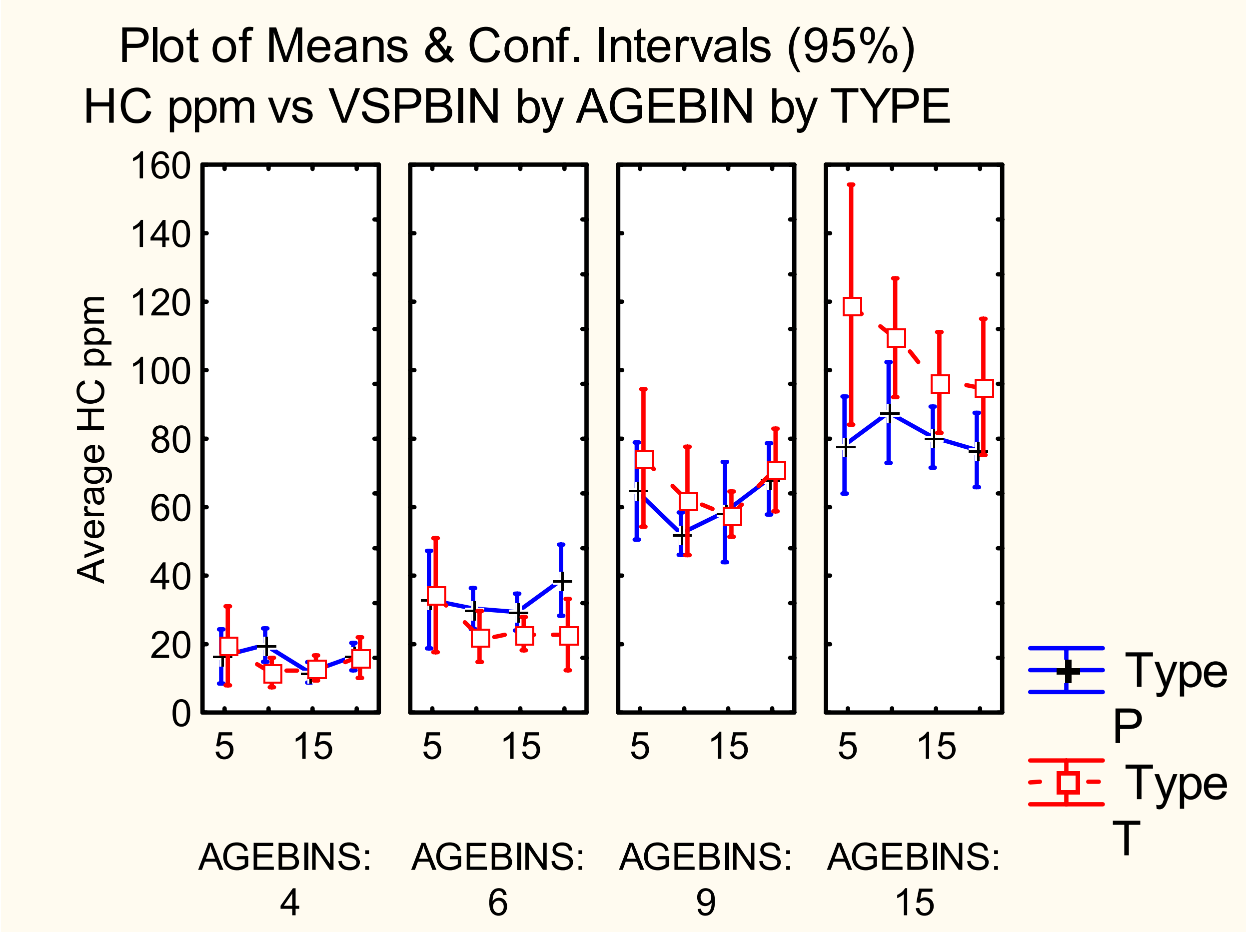
CO pct vs VSPBIN by AGEBIN by TYPE

- CO pct at Missouri Site 3 in 2000 with VSP between 2.5 and 22.5 kW/t and Odometer Readings within 3 months of the Remote Sensing Measurement,
- Minimum Measurements per AGE x VSP x TYPE Bin = 39



HC ppm vs VSPBIN by AGEBIN by TYPE

- HC ppm at Missouri Site 3 in 2000 with VSP between 2.5 and 22.5 kW/t and Odometer Readings within 3 months of the Remote Sensing Measurement,
- Minimum Measurements per AGE x VSP x TYPE Bin = 39



Further Analysis

- Further analysis should be performed to better define how remote sensing data should be included in MOVES.
  - Include more Missouri remote sensing sites. The additional data is available and would allow:
    - More independent variables to be examined, such as engine size.
    - Extending the VSP range.
    - Limiting vehicle age or type.
    - Seeing if the geographical distribution of high emitters is concentrated in time and space in the St. Louis area.
    - Checking the sensitivity of individual remote sensing sites to various parameters such as vehicle age or VSP distribution.
  - Compare Missouri remote sensing with Missouri IM240 results on the same vehicles. Compare large remote sensing databases in other states with their inspection maintenance emissions data on the same vehicles.
  - Include both model year and age for data sets with at least four years of measurement to see the impact of vehicle technology on emissions.
  - Test second-by-second dynamometer data set for fuel rate correlations based on parameters that could be measured at roadside (multiple speed measurements, multiple acceleration measurements, road grade) and vehicle look-up variables (engine size, vehicle weight, etc.)

Conclusions

- EPA Reports EPA420-R-02-027 and EPA420-P-02-008 should be revised.
- Further analysis should be done to define a protocol for how remote sensing data should be incorporated into MOVES.
  - Past programs have generated, and on-going clean-screening programs will continue to generate, large quantities of high quality remote sensing data that should be used in MOVES development.

Other Comments on EPA420-R-02-027

- What acceleration value was used in the VSP equation? Equation (2-1) in the NCSU report adjusts acceleration for gravity. But the VSP equation already corrects for gravity using road grade.
- Page 8. The 1.65 factor to adjust NDIR HC to FID HC is smaller than 2.0 reported by Singer and Harley.
- Page 10. Odometer reading was omitted from the data set. The validation vehicle sets are based on very few vehicles.