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Draft Analysis of Heavy-Duty Diesel Vehicle Idle Emission Rates

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1.0 INTRODUCTION

This report describes EPA's preliminary analysis of heavy-duty diesel vehicle emission data under engine idle operating conditions, where vehicle velocity is zero. It presents analysis and results for several pollutants and operating parameters. The pollutants include emissions of nitrogen oxide (NOx), carbon monoxide (CO), hydrocarbons (HC) and particulate matter (PM) emissions. The operating parameters include the effects of both non-discretionary idle and discretionary idle, extended idle modes, temperature and parasitic load effects (A/C, heater, refrigeration, etc.).

For purposes of this report, the term "non-discretionary" represents vehicle idle operation in which the vehicle typically encounters during normal road operation. It includes the idle operation which a vehicle experiences while waiting at a traffic signal or during a relatively short stop that lasts less than an hour. It is characterized by an engine speed which is at or near the vehicle minimum (typically 600 to 1000 RPM). For future technology vehicles it will characterize vehicle operation in which the vehicle's catalytic converter or other emission control system is operating. Throughout this report, the term non-discretionary idle will also be known as "curb idle."

The second term of "discretionary" idle operation is characterized by extending idle periods that are frequently several hours in duration, include higher engine speed settings which are made by the vehicle operator through the use of a mechanical switch or lever controlled by the operator. Discretionary idling most often occurs during long layovers between trips where the truck is used as a residence, often referred to as "hoteling." The use of accessories such as air conditioning systems or heating systems will also likely occur during discretionary idling and affect emissions. For future technology vehicles discretionary idling will include the effect of cool-down of the vehicle's catalytic converter system or other exhaust emission treatments. Throughout this report, the term discretionary idle will also be known as "extended idle" or "hoteling."

EPA has done only limited testing to investigate the emission effects of idle emissions from heavy-duty diesel vehicles. Instead, this report is primarily the product of a literature search of available test results from heavy-duty diesels. As such, it combines the data and observations from a variety of recent studies.

This document is structured into three primary sections and an Appendix section. Section 1.0 is this introduction. Section 2.0 briefly describes the databases used in the analysis and development of the emission factors. Section 3.0 contains two primary sub-sections. The first sub-section describes the analysis of the non-discretionary idle data and presents the resulting curb idle emission factors. The second sub-section describes the analysis of the effects of accessory load, extended idling and other parameters on idling emissions and uses these results to generate extended, discretionary, idle emission rates.

2.0 DATA

This study did not include vehicle emission testing. Instead it is a literature review and compilation of existing idle emission data from heavy-duty diesel vehicles. It includes idle emission results currently available from eight separate test programs conducted by a variety of researchers.

2.1 **High Altitude Study** - "Idle Emissions from Heavy-Duty Diesel and Natural Gas Vehicles at High Altitude," Robert McCormick, et al, Colorado Institute for Fuels and Engine Research, Colorado School of Mines, Journal of the Air and Waste Management Association, Revised May 3, 2000.

Testing was conducted on twelve heavy-duty diesel trucks and twelve transit buses in Colorado. Ten of the trucks were Class 8 heavy-duty axle semi-tractors, one was a Class 7 truck, and one of the vehicles was a school bus. The model year range was from 1990 through 1998. A typical Denver area wintertime diesel fuel (NFRAQS) was used in all tests. Idle measurements were collected during a 20 minute time period. All testing was done at 1,609 meters above sea level (high altitude).

2.2 **CCD Study** - "Study of Exhaust Emissions from Idling Heavy-duty Diesel Trucks and Commercially Available Idle Reducing Devices," Han Lim, US EPA Office of Transportation and Air Quality, September 2002.

Testing was conducted on five trucks in May 2002. The model years ranged from 1985 through 2001. The vehicles were put through a battery of tests including a variety of discretionary and non-discretionary idling conditions.

2.3 **Clean Air Study** - "Preliminary Results for Stationary and On-Road Testing of Diesel Trucks in Tulare, California," Douglas Lambert, et al, Clean Air Technologies Inc., May 15, 2002.

Testing was conducted on 42 diesel trucks in parallel with roadside smoke opacity testing. All tests were conducted by the California Air Resources Board (CARB) at a rest area near Tulare, California in April 2002. Data collected during this study were included in the data provided by IdleAire (below) used in the analysis.

2.4 **IdleAire Study** - "NOx Emissions and Fuel Consumption of HDDVs during Extended Idle," David K. Irick, University of Tennessee, Bob Wilson, IdleAire Technologies Inc., Coordinated Research Council 12th Annual On-Road Vehicle Emission Workshop, San Diego, California, April 15-17, 2002.

A total of 63 trucks (nine in Tennessee, 12 in New York and 42 in California) were tested over a battery of idle test conditions including with and without air conditioning. Not all trucks were tested under all conditions. Only results from the testing in Tennessee and

New York are described in the IdleAire report. The Tulare, California, data are described in the Clean Air Study cited above. All analytical equipment for all testing was operated by Clean Air Technologies.

2.5 **CRC E-55 Study** - "Heavy-duty Vehicle Chassis Dynamometer Testing for Emissions Inventory, Air Quality Modeling, Source Apportionment and Air Toxics Emissions Inventory," Phase I Interim Report, CRC Project No. E-55/E-59, Mridul Gautam and Nigel N. Clark, et al, West Virginia University Research Corporation, July 2002.

Fourteen trucks were tested with idling times either 900 or 1,800 seconds long.

2.6 **NCHRP Study** - "Heavy-duty Vehicle Emissions," National Cooperative Highway Research Program Project 25-14, Cambridge Systematics, Inc., with Battelle, Sierra Research and West Virginia University. October 2002.

The idling portion of continuous sampling during transient testing was used to determine idling emission rates on two trucks.

2.7 **Metropolitan New York Study** - "Internal Report - Idle Emissions from Heavy-Duty Diesel Trucks in the New Your Metropolitan Area," Tang and Munn, New York State Dept of Environmental Conservation, November 9, 2001.

A total of 33 heavy-duty diesel trucks were tested in this study. The model years ranged from 1984 through 1999. One hundred seconds of idling were added at the end of the WVU five mile transient test driving cycle.

2.8 **UC Davis Study** - "Potential Benefits of Utilizing Fuel Cell Auxiliary Power Units in Lieu of Heavy-Duty Truck Engine Idling," Broderick, Dwyer, et al. Institute of Transportation Studies, University of California - Davis.

A Class 8 Freightliner Century with a 1999 engine was testing using EPA's on-road emissions testing trailer based in Research Triangle Park, North Carolina. Both short (10 minute) and longer (five hour) measurements were made during idling. Some testing was also done on three older trucks. This data was obtained too late to be included in the analysis data used for this report.

2.9 **Oak Ridge Study -** "Particulate Matter and Aldehyde Emissions from Idling Heavy-Duty Diesel Trucks," John M.E. Storey, John F. Thomas, Samuel A. Lewis, Sr., Thang Q. Dam, K. Dean Edwards. Oak Ridge National Laboratory. Gerald L. DeVault, Y-12 National Security Complex. Dominic J. Retrossa, Aberdeen Test Center. Five heavy-duty trucks were tested for particulate and NOx emissions under a variety of conditions. These are the same trucks used in the CCD study.

A full set of all of the individual vehicle results used in this analysis with a description of the vehicles tested will be made available electronically along with this report.

3.0 ANALYSIS

For purposes of this report, heavy-duty diesel engine idle emissions are modeled by determining the curb idle emission factor and adjusting it to account for a range of observed idling operational behavior. The development of the curb (or non-discretionary idle mode) idle mode emission factors are discussed in Section 3.1. The adjustment factors to account for extended idling periods, engine idle speed, and use of accessories such as air conditioning (A/C) and heaters are discussed in Section 3.2. All of the adjustments are multiplicative factors that are applied to the curb idle emission factors. The general form of the equation is shown in Equation 3-1.

$$\text{Idle EF} = \text{Curb\_Idle EF} * \text{IdleTimeAdj} * \text{IdleSpeedAdj} * \text{AccessoryAdj} \qquad \text{Eqn 3-1}$$

Technically, curb idle and other idle conditions are separate operating modes with unique engine operating parameters. However, the limited available samples at all modes suggest that statistical characterization of the differences in these modes can provide a more consistent estimate of the idle emission rates in each mode rather than independent estimates based on small samples.

3.1 Development of Non-Discretionary Idle Emission Factors

Test data from the test programs were processed and combined into a comprehensive data set. Only those vehicles with results from idle operation similar to which the vehicle typically encounters during normal road operation were included in this part of the analysis. Some trucks and buses received repeat tests. In these cases, the individual test results were combined into a vehicle average emission result. The resulting data set contains 109 trucks and 13 buses.

The goal of the analysis was to produce average non-discretionary idling emission factors in terms of grams per hour for each of four pollutants (NOx, PM, HC, and CO). Once determined, these idle emission factors will be used as the basis for the calculation of discretionary idle emissions.

The data set also contained information on vehicle class type, altitude, engine build year and odometer readings. From an engineering perspective, these parameters may affect emissions. The thinner air of a high altitude region may lead to higher PM and CO emissions and possibly lower NOx emissions as a result of less oxygen in the combustion process. Smaller and newer vehicles may generally have less emissions than older and larger vehicles. Regression or T-Test analysis was performed on the data sample to determine which of these parameters have a significant statistical relationship with the observed emission levels.

3.1.1 NOx Emission Factors for Non-Discretionary Idle Operation

The NOx emission analysis explored several factors that include the effect of vehicle class, the effect of altitude, the effect of engine model year, the effect of engine size and the effect of age as measured by the odometer reading. Only vehicle class (truck versus bus) and model year have statistically significant effects. The results suggest that buses have higher non-discretionary idle NOx emissions than trucks, and that the older (pre-1988 model year) trucks have lower rates than the subsequent 1988 through 2006 model year trucks. Other possible parameters were also tested using various statistical tests, but were found to be statistically insignificant (95% confidence interval).

Since the results were somewhat surprising, it should be noted that the sample sizes for buses and for model years prior to 1988 are rather small. Also, not all of the data points have engine size and odometer information to use in the analysis. When additional data becomes available, it is recommended that some attention be devoted to further exploring whether transit buses have truly different curb idle emission rates than trucks, and further explore potential age and mileage effects on curb idle NOx emissions.

3.1.1.1 NOx Effect of Vehicle Class (Truck versus Bus)

The first parameter to be analyzed was the effect of vehicle class on NOx emissions. This analysis consisted of comparing the mean NOx emission results from the sample of trucks and the sample of cars. A standard single sample T-Test was performed, and the results are shown in Tables A-1 and A-2 in Appendix A of this document. The sample of 114 trucks shows a mean idle NOx emission level of 82.6 g/hr NOx, and the sample of 13 buses shows an emission level of 118.9 g/hr. Levene's test of equal variances shows that equal variances cannot be assumed at a 95% confidence level. However, the T-Test result when equal variances are not assumed shows a statistically valid relationship with a 2-tailed significant of 0.005 and a T statistic of -3.331. These are clearly less than the required 0.05 (95% CI) level, and lead to the conclusion that trucks and buses have different mean curb idle NOx emissions.

The difference between trucks and buses seen in Tables A-1 and A-2 may be the result of the confounding effects of high and low altitude on curb idle NOx emissions. To confirm and eliminate these altitude effects, the high altitude vehicles were analyzed separately. A one sample T-Test was done on eleven trucks and thirteen buses and the results are shown in Table A-3 and Table A-4. For high altitude trucks, the mean curb idle NOx emission level was 84.0 g/hr and the bus mean was 118.9 g/hr. The test was statistically significant at a 95% confidence level. This confirms that even among the high altitude vehicles, truck and buses have different curb idle NOx emissions.

3.1.1.2 NOx Effect of Altitude

All of the buses in the sample are high altitude tests. A T-Test of using altitude was also done on the sample of trucks from both high and low altitude (buses were excluded) to determine if altitude is a factor in curb idle emission rates. The statistical results of this test are shown in Tables A-5 and A-6 in Appendix A. Here 103 low altitude trucks were tested against eleven high altitude ones. The results show statistically similar means of 82.4 g/hr and 84.0 g/hr NOx. These two samples cannot be considered different at a 95% confidence level (significance is 0.769). This suggests that vehicle class is a more important determinant than altitude for NOx idle emissions.

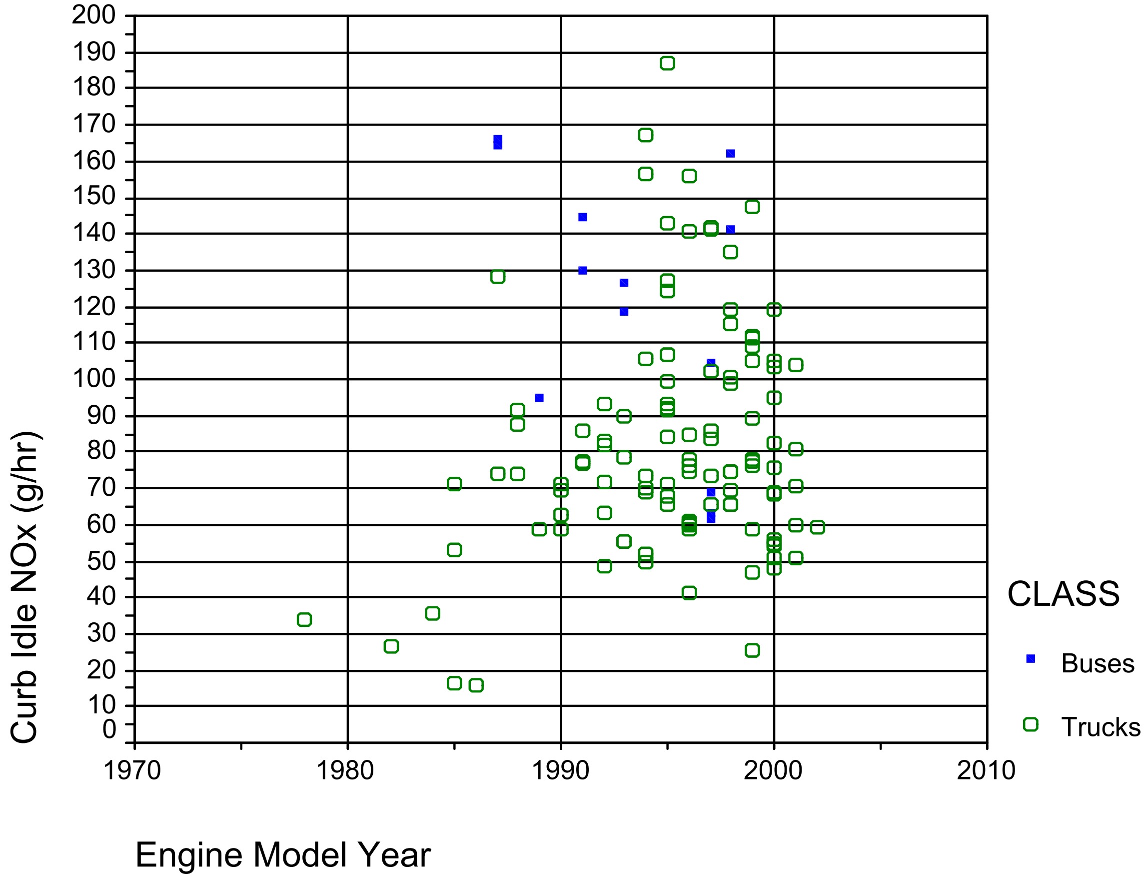
3.1.1.3 NOx Effect of Engine Model Year

A scatter plot of the curb idle NOx emissions versus engine model year for the trucks in the sample is shown in Figure 3-1. We might expect that idle emissions should be decreasing as a function of engine model year since emission standards have gradually been made more stringent with successive years. However, a regression of the idle NOx emissions versus model year (Table A-10 in Appendix A) showed no statistically significant relationship (r2 value is 0.01 and the significance is 0.260 - these are low values that indicate little correlation). Also, with the exception of the pre-1987 model years, the NOx curb idle emissions versus engine model year shows no general relationship.

The idle NOx emissions for the older vehicles in the sample are significantly lower than the newer vehicles in the sample. The sample was divided into two strata, using the 1987 model year as the dividing point. The pre-1988 model years have a mean idle NOx emission level of 50.5 g/hr, and the 1988 and later sample has a mean of 85.3 g/hr NOx. A statistical T-Test (see Tables A-7 and A-8 in Appendix A) shows a statistically difference between the two sample at a greater than 95% confidence level (signification = 0.023). The 1987/1988 model year split corresponds to a more stringent NOx emission standards for heavy-duty diesels were put into effect in the 1988 model year. Engine improvements, such as higher injection pressures, all tend to increase engine efficiency and, correspondingly, increase NOx. Newer vehicles also tend to have more accessories, which increase overall engine load and introduce transient loads at idle.

As a result of this analysis, separate idle NOx emission factors were developed for pre-1988 and for 1988 and later model year vehicles. However, since the sample sizes are quite small (only nine pre-1987 model years), it is recommended that this be an area for future research.

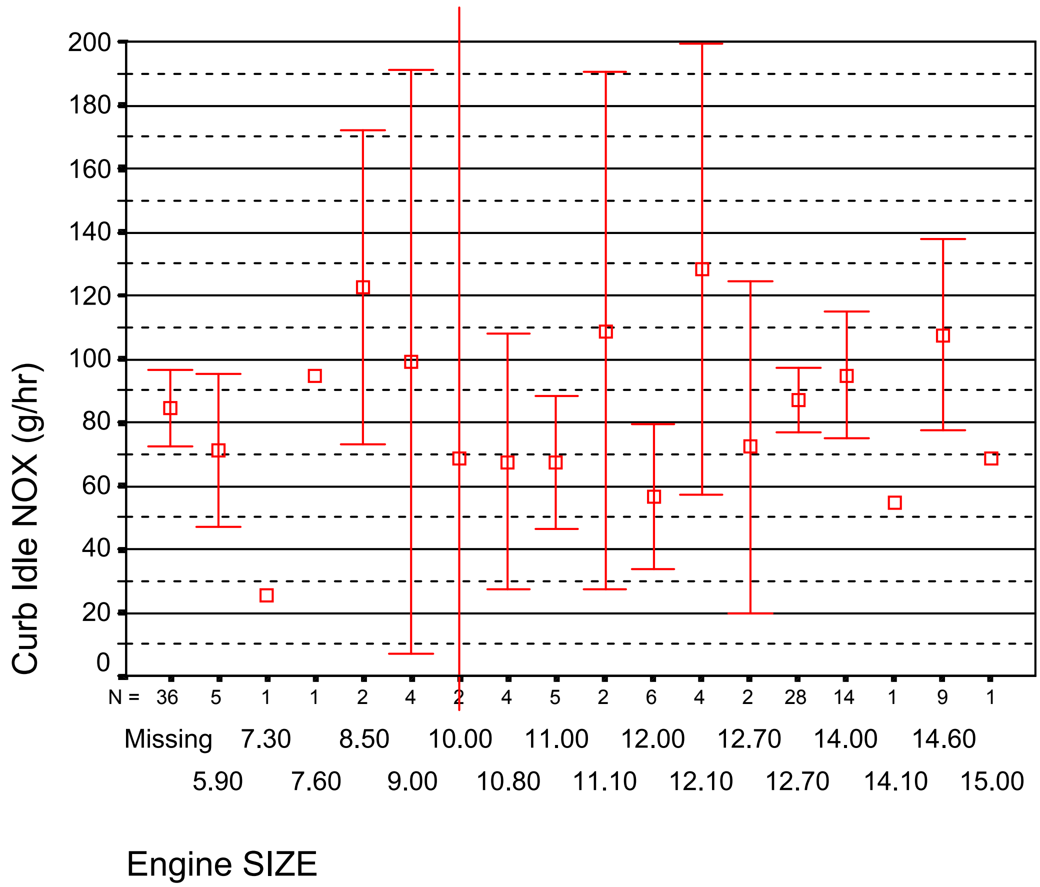
Figure 3-1   NOx Curb Idle Emissions Versus Engine Model Year



3.1.1.4 NOx Effect of Engine Size

Theoretically, the larger engines should emit more NOx per hour than a smaller one given a relatively constant exhaust concentration at idle and no after-treatment. This idea was explored in a statistical analysis of curb idle NOx emissions versus engine size in liters of displacement. Regression analysis of NOx curb idle emissions and engine size was done and the results are shown in Table A-9. The results show a small correlation coefficient ® squared of 0.028) with no statistical significance (0.114). A graph of average NOx curb idle emissions versus the engine size category is shown in Figure 3-2. The wide error bands (95% confidence intervals) around the means, the small sample size at the lower engine sizes and general up and down nature of the mean values indicate no obvious relationship between engine size and NOx emissions in this sample.

Figure 3-2 Mean Curb Idle NOx Emissions Versus Engine Size



3.1.1.5 <u>NOx Effect of Test Program</u>

The idle NOx emission results were also analyzed versus test program to see if any large statistical differences could be observed between the test programs. Large differences between the results from different programs might indicate testing or design biases between the programs that lead to erroneous conclusions. A list of the test programs is shown in Table A-11a and the mean idle NOx emission results for each test program are show in Table A-11b. The CRC E-55 program (5) is somewhat different with a mean curb idle NOx of 68.0 g/hr versus means from the other programs which are generally in the 80 g/hr range. Program 6 (NCHRP) is considerably different with a mean of 46.9 g/hr, however this program contains results from only two vehicles. A statistical ANOVA analysis (Table A-11c) shows that only program 1 and 5 are statistically different from each other at a 95% confidence level (significance = 0.035). Program #1 was a high altitude program and that it contained buses (Program #5 was from a low altitude area and did not include buses). The general conclusion from this statistical test is the differences that do exist between the samples are reasonable and may be explained by differences in sampling.

3.1.1.6 Pre-2007 Non-Discretionary Idle NOx Emission Factors

Based on the statistical analysis of the available data, the curb idle NOx emissions for model years prior to 2007 are projected to be:

All Pre-1988 Model Year Trucks and Buses	71.32 g/hr
All 1988 and Later Trucks	84.69 g/hr
All 1988 and Later Buses	110.50 g/hr

3.1.1.7 Estimated 2007 and Later Non-Discretionary Idle NOx Emission Factors

The 2007 model year heavy duty trucks requires new stringent NOx emission standards. These are not directly aimed at idle emissions; however, the new NOx catalysts and particulate traps should be effective for non-discretionary idle periods such as waiting at a traffic light for a minute or even during a limited idle period up to an hour in length. After this point, it is reasonable to assume that the catalyst will be ineffective due to cool down and that idle emissions will begin to increase.

Since no data are available on 2007 and later engines are prototypes the idle NOx emission factors will be developed using the ratio of the certification standards in the 1991 through 1998 time frame (this represents most of the data sample) to those in 2007. The non-discretionary idle NOx emissions will be reduced accordingly.

Given certification standards of:

5.0 g/bhp-hr in 1991 - 1998 time frame for certification
0.2 g/bhp-hr in 2007+

Calculating the ratio of the standards gives:

0.2 / 5.0 = 0.04

Applying the ratio to the pre 2007 model year truck and bus emission factors produces the 2007 and later model year non-discretionary idle NOx emission factors of:

Truck: 0.04 * 84.69 g/hr = 3.39 g/hr Idle NOx

Bus: 0.04 * 110.50 g/hr = 4.42 g/hr Idle NOx

3.1.2 Particulate Matter (PM) Emission Factors for Non-Discretionary Idle Operation

3.1.2.1 Pre-2007 Non-Discretionary Idle PM Emission Factor

The PM emission analysis explored several factors that include the effect of vehicle class, the effect of altitude, and the effect of engine model year. These are the same parameters as were available for the NOx emission analysis. However, PM emission were not available from all of the studies. The High Altitude Study provided 24 vehicle tests. The IdleAire Study provided 49 vehicle tests. The CRC E-55 Study provided 14 vehicle tests. The Oak Ridge Study provided 5 vehicle tests.

The conclusion from the analysis suggests that none of the parameters have a statistically significant effect on curb idle PM emissions at a confidence level of 95 percent. As a result, this paper is proposing that an average curb idle PM emission factor be used for all heavy-duty diesel vehicle classes, altitudes and model years prior to 2007. This factor is:

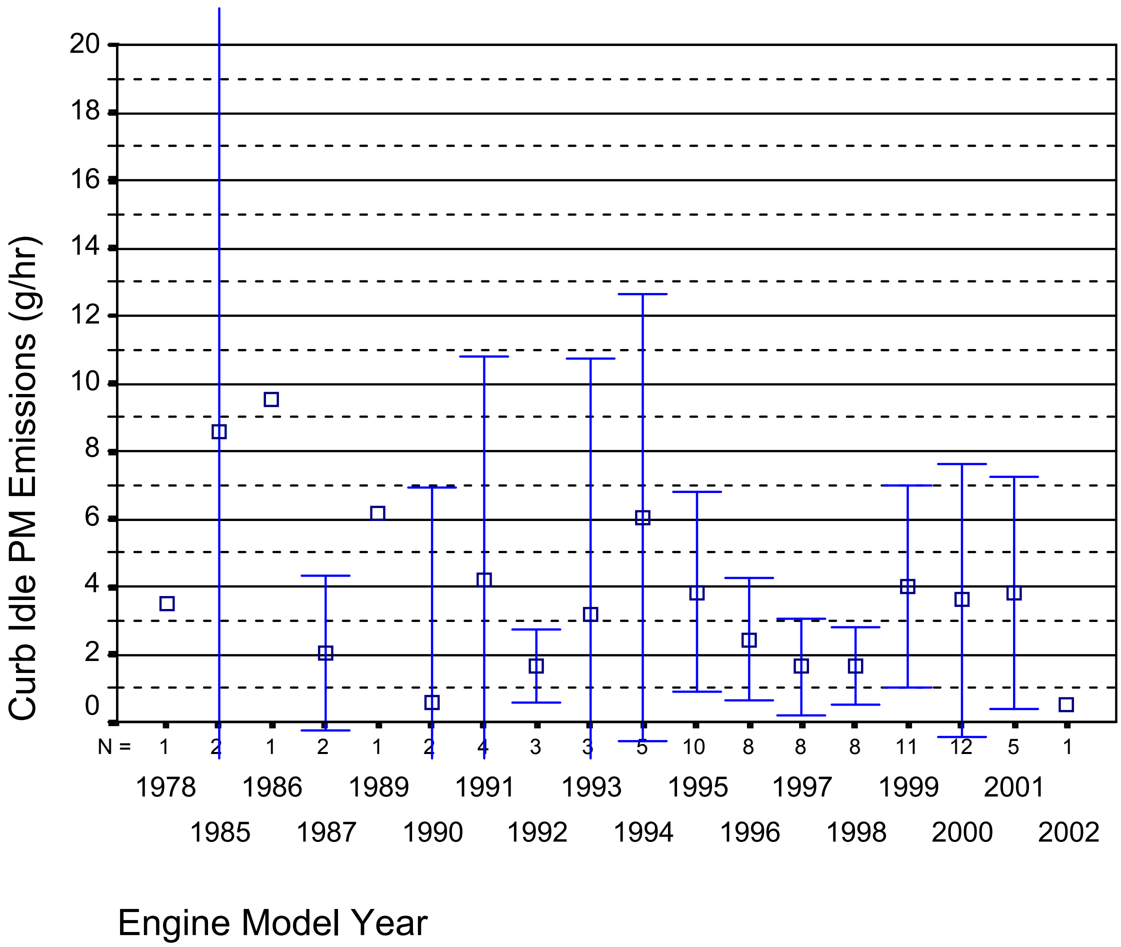
3.38 g/hr with a standard error of 0.428 g/hr

Some caution must be used in using this value, since particulate measurements are quite variable and easily affected by small differences in the measurement techniques used. The available data is not adequate to address these concerns directly.

Below and in Appendix A the emission statistics are presented that were used to determine the average curb idle PM emission factor. Table A-12 shows the mean emission factors by altitude type and class type (truck or bus). With the exception of the High Altitude Truck results, the curb idle PM emissions were fairly consistent. The eleven high altitude trucks show a mean emission factor of 1.41 g/hr and the corresponding low altitude trucks have a mean emission factor of 3.78 g/hr. This seems like a sizeable difference. However, an independent sample T-Test was done to determine if the results for trucks and buses at high altitude are statistically different at a 95% confidence level. The results in Table A-13 show a significance of 0.07; this indicates that at high altitude the vehicle classes are not significantly different at 95% CI, although nearly so. When the combined sample of trucks and buses at high altitude (2.34 g/hr) are compared with the low altitude trucks (3.78 g/hr), the difference due to altitude is not significant. Table A-14 shows the sample statistics comparing high and low altitude. Table A-15 shows the sample statistics comparing trucks and buses. Figure 3-3 graphically shows mean curb idle PM emissions versus engine model year. This figure shows considerable variance (the 95% confidence intervals are frequently larger than the mean values) of curb idle PM versus model year, but no discernable trend in the model year averages.

Figure 3-3 Curb Idle PM versus Engine Model Year

3.1.2.2 2007 and Later Non-Discretionary Idle PM Emission Factor



Since no data are available on 2007 and later model year heavy-duty real engines or prototype engines, the curb idle PM emission factors were developed by a ratio of the 2007 certification standards to those in the 1991 through 1998 time frame (this represents most of the data sample). The non-discretionary idle NOx emissions are reduced accordingly.

Given certification standards of:

0.10 g/bhp-hr in 1991 - 1998 time frame for certification
0.01 g/bhp-hr in 2007+

Calculating the ratio of the standards gives:

0.01 / 0.1 = 0.1

Applying the ratio to the pre 2007 model year truck and bus emission factors produces the 2007 and later model year non-discretionary idle PM emission factors of:

Truck: 0.1 * 3.38 g/hr = **0.34** g/hr Idle PM

3.1.3 Hydrocarbon (HC) Emission Factors for Non-Discretionary Idle Operation

3.1.3.1 HC Effect of Vehicle Class (Truck versus Bus) and Altitude

Appendix A contains the HC emission statistics that were used to determine the average curb idle HC emission factors. Table A-17 shows the mean emission factors by altitude type and class type (truck or bus). In general, the mean curb idle emission factors seem to be similar by vehicle class (truck and bus) and by high and low altitude. The accompanying T-Tests in Tables A-18 and A-19 confirm no statistically significant differences at a 95% CI exist between classes and altitudes. For example, a T-Test of HC and vehicle class shows a significance of more than 0.90 (a very low level). Likewise, a T-Test of HC and altitude (See Table A-19) shows a significance of more than 0.40 (a low level of significance).

3.1.3.2 HC Effect of Engine Size

Curb Idle HC Emissions were analyzed versus engine size using least squares regression analysis. The results are shown in Tables A-20 in Appendix A. The regression shows poor correlation between curb idle HC and engine size. The R Square value is 0.001 and the regression significance (Sig.) is 0.736.

3.1.3.3 HC Effect of Vehicle Odometer

Curb Idle HC Emissions were analyzed versus odometer using least squares regression analysis. The results are shown in Table A-21 in Appendix A. The regression shows poor correlation between curb idle HC and odometer. The R Square value is 0.008 and the regression significance (Sig.) is 0.468.

3.1.3.4 HC Effect of Model Year

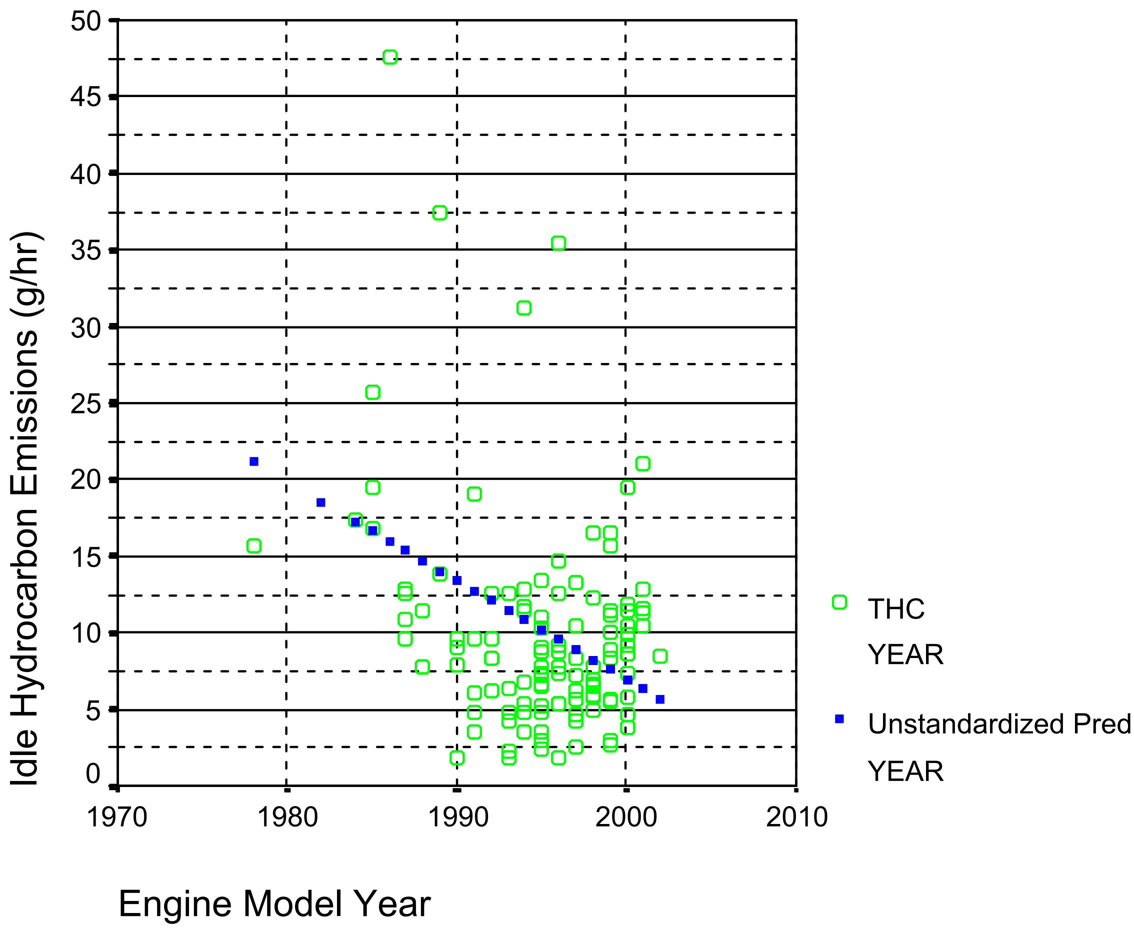
Curb Idle HC Emissions were analyzed versus model year using least squares regression analysis. The results are shown in Table A-22 in Appendix A. The regression shows modest correlation between curb idle HC and model year. The R Square value is 0.132 and the regression significance (Sig.) of 0.000 is statistically significant at more than a 95% Confidence Interval.

The Curb Idle HC Emissions and the linear regression equation of HC versus model year are shown plotted versus engine model year in Figure 3-4. The open green squares are the actual data points and the solid blue squares are the predicted values from the regression. The data shows considerable scatter and a general lack of data on the older model years. The regression fits the expected prediction of lower HC emissions with newer model years. The relatively low value 0.132 for the r-square correlation coefficient reflects the considerable scatter in the emission data.

Figure 3-4 Idle HC Emissions Versus Engine Model Year Data and Predicted Results

3.1.3.5 Pre-2007 Non-Discretionary Idle HC Emission Factor

The HC emission analysis explored several factors that include the effect of vehicle class, the effect of altitude, the effect of engine size and the effect of engine model year. These are the same parameters as were available for the NOx and PM emission analysis. The HC emission data-set contained 122 cases and included members from all of the test programs. The



conclusion from the analysis suggests that only the engine model year parameter was a statistically significant effect on curb idle HC emissions at a confidence level of 95 percent. This was determined through least squares linear regression analysis. The function shown in Equation 3-2 and 3-3 would be used to model average curb idle HC emissions for all heavy-duty diesel vehicle classes, altitudes and model years between 1978 and 2006.

Curb Idle HC (g/hr) = 1294.063 - 0.644 * Model Year   Eqn 3-2

Given:

Curb Idle HC	=	20.23 g/hr for Pre-1978 MY	Eqn 3-3
Curb Idle HC	=	2.20 g/hr for 2006 MY	Eqn 3-4
Curb Idle HC	=	0.22 g/hr for 2007 and later MY	Eqn 3-5

Where Model Year is the engine model year (i.e., 1999).

The upper curb idle HC emission factor of 20.23 g/hr given in Eqn 3-3 is the value for the 1978 model year. No earlier engine model year data were available; thus, continuation of Equation 3-2 would be extrapolation. Rather than such extrapolation, the emission factor is fixed at the 1978 model year level for all previous model years. Additional justification for this assumption is that generally the pre-1978 model years were either non-regulated or only lightly regulated for PM emissions and should be similar between model years.

All values past model year 2002 are extrapolation. This extrapolation was done through 2006 to reflect a gradual possible introduction of diesel catalyst technology. The value for the 2006 model year is shown as 2.20 g/hr in Equation 3-4.

The 2007 and later value represents a special problem to model since the new stringent PM and NOx standards are applied starting in 2007. These new regulations will likely force the complete introduction of catalytic converters and other exhaust after-treatment devices. Such devices may drive curb idle HC emissions to near zero levels. This analysis attempts to model this future event by reducing the 2006 model year level by 90%. The 90% reduction is analogous to the required PM emission reduction in the 2007 diesel rule. It has the effect of producing an average curb idle HC emission factor of 0.22 g/hr. This is considerably lower than the minimum HC value recorded by a current uncontrolled engine of 1.80 g/hr HC. However, it still might be an environmentally conservative estimate given the claims of some future technology proponents.

3.1.4 Carbon Monoxide (CO) Emission Factors for Non-Discretionary Idle Operation

3.1.4.1 CO Effect of Vehicle Class, Altitude and Model Year

A single sample T-Test was used to determine the statistical significance of altitude and least squares linear regression was used to determine the effects of engine model year.

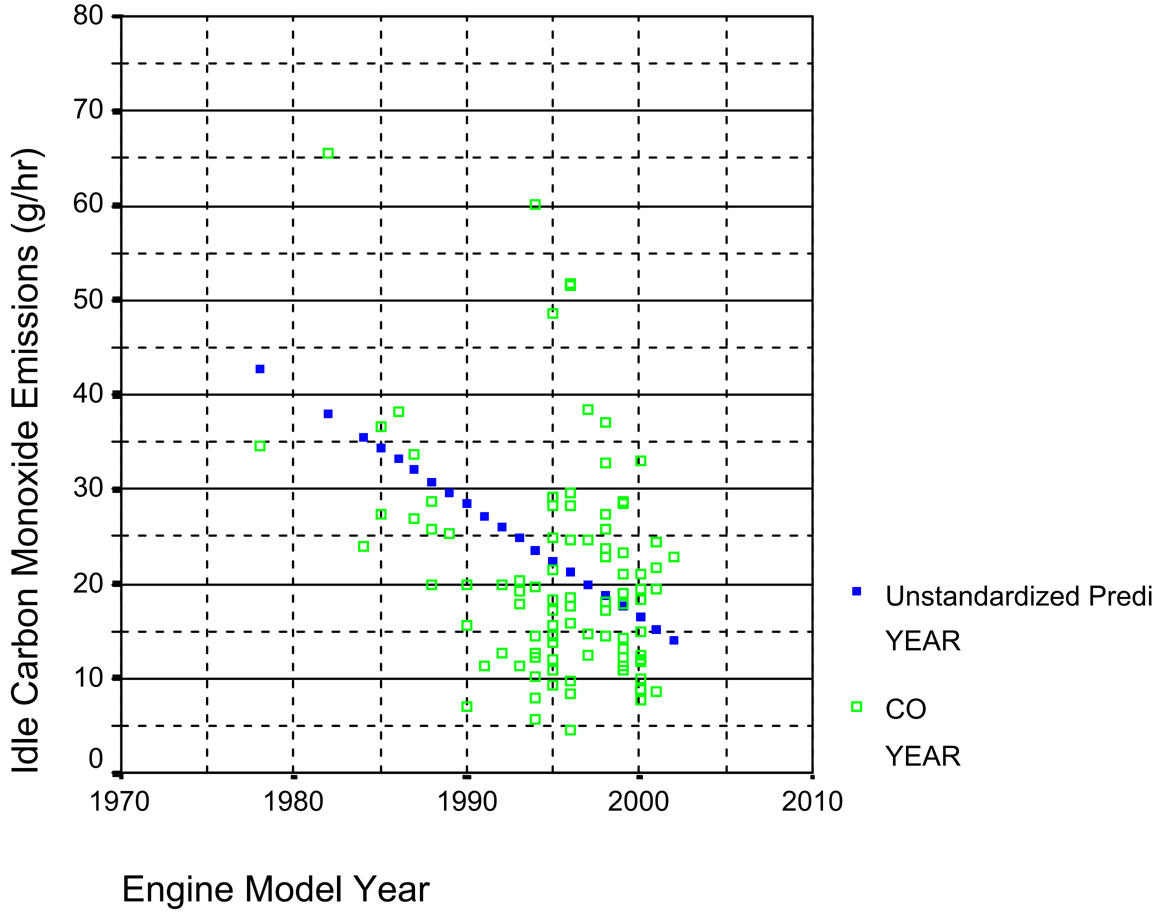
Below and in Appendix A are the emission statistics that were used to determine the average curb idle CO emission factors. Table A-23 shows the mean emission factors by altitude type and class type (truck or bus). In general, the mean curb idle emission factors seem to be similar by vehicle class (truck and bus), but vary considerably by altitude. For example, the mean high altitude CO level is 75.3 g/hr while the low altitude mean value is 22.1 g/hr. The difference between the two values makes engineering sense since the combustion air at high altitude generally has less oxygen per pound of air than low altitude. If not compensated by the engine or after-treatment devices, this oxygen deficiency would lead to higher CO emission factors at the tailpipe. The accompanying T-Tests (see Table A-24) confirm a statistically significant differences at a 95% CI exist between altitudes. For example, a T-Test of HC and vehicle class shows a significance of 0.00 (a high level of statistical significance).

A similar T-Test analysis of CO emissions versus vehicle class done on the high altitude sample of 11 trucks and 13 buses (see Table A-25) shows a low level of statistical significance (significance = 0.339). As a result, this test eliminated vehicle class as a significant parameter in the CO curb idle emission analysis.

The low altitude curb idle CO emissions were analyzed versus model year using least squares regression analysis. The results are shown in Table A-26 in Appendix A. The regression shows modest correlation between curb idle CO and model year. The R Square value is 0.142, and the regression significance (Sig.) of 0.000 is statistically significant at more than a 95% Confidence Interval.

The Curb Idle CO Emissions are shown plotted versus engine model year in Figure 3-5. The open green squares are the actual data points and the solid blue squares are the predicted values from the linear regression. The data shows considerable scatter and a general lack of data on the older model years. Nevertheless, the regression is statistically significant and it fits the expected prediction of lower CO emissions with newer model years.

Figure 3-5 Idle CO Emissions Versus Engine Model Year Data and Predicted Results



3.1.4.2 Pre-2007 Non-Discretionary Idle CO Emission Factor

The CO emission analysis explored several factors that include the effect of vehicle class, the effect of altitude, the effect of engine size and the effect of engine model year. These are the same parameters as were available for the NOx and PM emission analysis. The CO emission data-set contained 122 cases and included members from all of the test programs. The conclusion from the analysis suggests that the altitude parameter and the engine model year parameters are statistically significant effects on curb idle CO emissions at a confidence level of 95 percent. The function shown in Equations 3-6 and 3-7 are proposed for use in modeling average curb idle CO emissions for all heavy-duty diesel vehicle classes at LOW altitude and for model years between 1978 and 2006. An average CO emission factor of 75.3 g/hr (Eqn 3-10) will be used for all Pre-2007 model year high altitude vehicles.

LOW ALTITUDE

Curb Idle CO (g/hr) = 2415.728 - 1.20 * Model Year Eqn 3-6

Given:

Curb Idle CO	=	42.13 g/hr for Pre-1978 MY	Eqn 3-7
Curb Idle CO	=	8.53g/hr for 2006 MY	Eqn 3-8
Curb Idle CO	=	0.85 g/hr for 2007 and later MY	Eqn 3-9

HIGH ALTITUDE

Curb Idle CO	=	75.3 g/hr for Pre-2007 MY	Eqn 3-10
Curb Idle CO	=	0.85 g/hr for 2007 and later MY	Eqn 3-11

Where Model Year is the engine model year (i.e., 1999).

The upper curb idle CO emission factor of 42.13 g/hr is the value for the 1978 model year. No earlier engine model year data were available; thus, continuation of Equation 3-6 would be extrapolation. Rather than such extrapolation, the emission factor is fixed at the 1978 model year level.

All values past model year 2002 are extrapolation. This extrapolation was done through the 2006 model year. The value for the 2006 model year is shown as 8.53 g/hr in Equation 3-7.

The 2007 and later value represents a special problem to model since the new stringent PM and NOx standards are applied starting in 2007. These new regulations will likely force the complete introduction of catalytic converters and other exhaust after-treatment devices. Such devices may drive curb idle CO emissions to near zero levels. This analysis attempts to model this future event by reducing the 2006 model year level by 90%. The 90% reduction is analogous to the required PM emission reduction in the 2007 diesel rule. It has the effect of producing an average curb idle CO emission factor of 0.85 g/hr. This is considerably lower than the minimum CO value recorded by a current uncontrolled engine of 4.45 g/hr CO. However, it still might be an environmentally conservative estimate given the claims of some future technology proponents. The same value of 0.85 g/hr was also assumed for high altitude 2007 and later model years. The assumption is that the high altitude and low altitude vehicles will be equally controlled as a result of the stringent 2007 diesel rule requirements.

3.2 Development of Discretionary Idle Emission Factors

Once the non-discretionary or curb idle emission factors are available, they become the base emissions to which multiplicative correction factors can be applied to produce load adjusted and discretionary or extended idle emission factors for estimating the emission impacts of hoteling behavior. The correction factors were determined by analyzing operating parameters such as load on the engine (e.g., AC or heat), the speed of the engine or rpm, the amount of time spent in idle operation, and impacts of upcoming EPA regulations.

LOAD

Engine load during idle is expected to significantly effect idle NOx emission rates. In simple terms, the greater the load the greater the emission. However, determining typical load at idle requires looking at the average uses of on-board truck and bus systems. Base electrical loads, such as lights, battery charger, communications, and computer need about 1-5 kW of power. Hoteling loads, such as lighting, simple HVAC, and appliances will need 3-5 kW of power. For full truck electrification which includes all of the above, plus water and oil pumps, starter, cooling fans, transmission and hydraulic system, brake compressors, and fuel and air handling systems requires 5-15 kW of power. According to the American Trucking Association (ATA), typical engine load during extended idling operation is in the range of 10 to 30 brake horsepower (The Maintenance Council of the American Trucking Associations, *The Fleet Manager's Guide to Fuel Economy*, 1998).

RPM

Truck manufacturers generally recommend higher (than curb idle) engine idle speeds when extended idling is expected. Here are a few examples found in operating manuals.

- Caterpillar: "If extended idle time is required, control the engine RPM to 1000 RPM or above 1000 RPM." (Operation and Maintenance Manual, SEBU7186-04, May 2001, page 83. This is the manual for C-10, C-12, 3406E, C-15, and C-16 Truck Engines).

- Detroit Diesel: "When prolonged idling is necessary, maintain at least 850 RPM spring/summer and 1200 RPM fall/winter." (Operations Guide 6 SE 484 0106, page 8)

- International: "Maintain a minimum of 1250 idle RPM by use of the Hand Throttle." (Bulletin TSI 96-12-29, "Cold Weather Operation of International Engines." Guidelines for cold weather operation)

- Cummins: "Operating engines at idle RPM (650 to 1000) in cold ambient temperatures wastes fuel, accelerates wear and can result in serious engine damage. . . . If the operator insists on prolonged idling, it is recommended that the engine be idled at an RPM which is adequate to maintain coolant temperatures above 140 °F (60 °C). In 0 °F ambient (-18 °C), the engine may have to be idled above 1200 RPM." (Company Bulletin 3379009-03)

A recent IdleAire survey was done of 100 drivers (through truck stop interviews) and 100 fleet maintenance managers (by phone) regarding engine speeds used during extended idling. (David Irick and Bob Wilson report). The average, weighted by days of operation per year, was 964 rpm for drivers and 965 rpm for maintenance managers. Nearly 70 percent of these 100 drivers indicated they operated their trucks at 800 rpm or higher during extended idle. Nearly half the drivers indicated that they operate their engines during extended idling at 1000 rpm or higher, with about 40 percent reporting the range between 1000 and 1100 rpm. This suggests that operating in this rpm range is an established practice by a substantial proportion of drivers.

As with the driver survey, the fleet survey showed that a high percentage of drivers, 85.5 percent, use extended idling speeds greater than 800 rpm. Fleets say 76.8 percent of their trucks idle at 900 rpm or greater and 56.5 percent use an extended idling speed of 1000 rpm or greater.

There was little apparent connection between the size of the fleet and the choice of idling rpm. On average, fleets of 1000 or fewer trucks chose idling rpm of 965, identical to the overall average. The average fleet in the 1000-2999 size range chose a lower engine speed level (with a mean 871 rpm), while fleets with 3000 or more trucks reported an average idling engine speed of 988 rpm. A common theme among fleet owners is that, although most fleets have an official idle speed recommendation, it is the driver who chooses idle speed. More often than not, fleet owners observe that drivers may choose a speed higher than company recommendations to maximize driver comfort levels during extended rest periods.

In general, the fleet maintenance manager survey may be more reliable. Truck drivers are notoriously suspicious of authority and likely to offer socially acceptable answers. The fleet maintenance manager data has a more normal, bell shaped, distribution and may have less reason to bias their answers either higher or lower.

IDLE TIME

Idle duration is an important factor because of engine and future after-treatment device cool-down. During long durations (called extended idling) the engine begins from a high operating temperature (just off the road) and then cools to a stabilized cooler operating temperature as time goes on. Cool down gradually makes engine and after-treatment devices less efficient and causes more water condensation in the exhaust. Low exhaust flow rates and cool down may also affect emissions by condensing unburned fuel (HC) and collecting particulates in the exhaust system.

NEW REGULATIONS

The new emission standards beginning in 2007 do not require control of emissions during extended idling. However, it is reasonable to assume that the emission control strategies used to reduce driving emissions from these trucks will have an effect on idling emissions, but only as long as the devices remain effective once driving has ceased. It is reasonable to assume that engine-out idling emission rates will be similar in future model years, but that after-treatment devices used to reduce driving emissions will affect the resulting tailpipe idling emissions during curb idling.

Idling emissions during the first minutes of idling will likely be most affected by after-treatment devices because conversion efficiency of the after-treatment devices remains high. Extended idling or "hoteling" idling may last 8 hours per day. Because the effectiveness of after-treatment devices will decline as the time spent at idle grows, emission rates of trucks with after-treatment devices will increase as idling time increases. The overall fleet average idling emission rate from extended idling for trucks certified to the new emission standards will depend on the average length of time for extended idling, and the effect of the new standards on idling emission rates.

ELECTRONIC CONTROLS

The introduction of electronic controls allows engine designers to optimize engine performance to the operating mode. At curb idle conditions, the engine designer takes advantage of a mode where no useful work is done to adjust engine parameters to minimize emissions. However, when idle speed is increased or high load accessories (such as air conditioning) are detected, electronic controls allows the engine designer to optimize for power or fuel economy. However, the limited available samples at all modes suggest that statistical characterization of the differences in these modes can provide a more consistent estimate of the idle emission rates in each mode rather than independent estimates based on small samples.

3.2.1 Discretionary Idle NOx Emission Effects

3.2.1.1 NOx Effects of Accessory Load

The CCD study and the IdleAire study include paired test samples showing the effects of accessory load on idling NOx emissions from heavy-duty vehicles. The vehicle data from these two studies were combined. A truck was tested three times in the CCD study at 600 rpm with no load. The value reported in the table, and used in the analysis, is the average of these three values. The CCD study results are confounded by the fact that the temperature and humidity used with the heater on and the air conditioning on are different than the "no load" case. However, since the real-world use of heater and air conditioning accessories are strongly correlated to the temperature, the observed effect is appropriate for modeling those cases. A sample comparison t-test of the effects observed in the two study samples are not significantly different, which suggests that the effects of temperature on idling NOx emissions are not significant. For purposes of this analysis, all the observed effect will be assumed to be the result of the accessory loading only and not from any change in temperature. The NOx values in the CCD study were adjusted for differences in humidity using the standard Federal Test Procedure methods (CFR 86.1342-90).

A paired sample t-test was used to compare the means of the idle NOx emission tests with and without the accessory loads. The t-test indicates that the load effects of air conditioning on NOx emissions are significant (0.000) at both low and high idle speeds, while the effects of heater load are not significant. The t-test statistics are shown in Appendix B.

3.2.1.2 NOx Effects of Engine Idle Speed

The CCD study and IdleAire study results used to evaluate the effects of accessory load were also used to investigate the effects of idle speed on NOx emissions. A paired sample t-test was used to compare the means of the idle NOx emission tests at low (non-discretionary "curb) idle speeds and high (discretionary) idle speeds. The t-test indicates that the effects of discretionary idle speeds on NOx emissions are significant (from 0.000 to 0.002) at all loads. The t-test statistics are shown in Appendix C.

3.2.1.3 NOx Effects of Engine Idling Time

The CCD and the IdleAire study measured the idling NOx emissions from five heavy-duty vehicles continuously (second-by-second). All trucks were fully warm when idling began. Although data from the CCD study indicated a small (7%) decrease in NOx emissions, information from the IdleAire data contradicts this conclusion. Since both samples are extremely small, the direct effects of idle time will be assumed to be negligible for this analysis.

As discussed earlier, the new exhaust after-treatment devices used for 2007 and later model years should be effective for non-discretionary idle periods such as waiting at a traffic light or during a limited idle period. However, during extended idling periods, the effectiveness of these controls will likely fade substantially. This will make the overall average idling emission rate for the extended idling period much higher than the expected non-discretionary idling emission rate.

Since no data are available on 2007 and newer engines, the curb idle NOx emission factors developed for the estimate of non-discretionary idle NOx emissions will be used to represent idling emission rates for the first hour of idling. The idling emission rate after one hour of idling will be assumed to return to pre-controlled (pre-2007 model year) rates. Then, assuming that all extended idling periods are eight hours long, we can calculate the average idling emission rate for extended idling periods for the 2007 and newer engines:

2007 Extended Idling Rate = (1/8)*2007 Idle Rate + (7/8)*Pre-2007 Idle Rate

This method can also be used to determine idle emission rates for idling time periods which are less than the eight hours assumed here. The 2007 idle emission rate is a function of the pre-2007 idle emission rate, so the extended idle emission rate for 2007 and newer model years can be determined directly from the idle emission estimate for pre-2007 model year vehicles.

2007 Extended Idling Rate = [(1/8)* (0.2/5.0) + (7/8)] * Pre-2007 Idle Rate

These estimates are affected strongly by the assumption of total hours of discretionary idling, the effectiveness of the new technologies on idling emissions and the length of time the new technologies remain effective during extended idling. As new information is obtained about the emission performance of these vehicles, these estimates will need to be updated.

3.2.1.4 Discretionary NOx Idling Emission Factors

Table 3-1 summarizes the effect of air conditioning observed in the sample as a multiplicative adjustments to the basic idle NOx emissions measured with no load. The discretionary idling adjustments are a composite of the effects of higher idling speeds and extended idling time. The adjustments assume no interactions.

Table 3-1
Discretionary Effects of on Idle NOx Emissions

	Adjustment to Base Idle NOx Emission Rate		
Description	Speed	Air Conditioning	Composite
Non-Discretionary with A/C On	NA	23.7%	23.7%
Discretionary with No Load	55.5%	NA	55.5%
Discretionary with A/C On	32.6%	26.5%	67.7%
2007+ Discretionary with No Load	55.5%	NA	55.5%
2007+ Discretionary with A/C On	32.6%	26.5%	67.7%

Using these adjustments, the non-discretionary idle emission rates described in Section 3.1 and the travel fractions for Class 8 heavy duty diesel trucks from MOBILE6, we can calculate annual average idle emission rates for the fleet for calendar year 2004. This calculation assumes that idle times are proportional to vehicle miles traveled and that air conditioning is used for five months of the year. The results are shown in Table 3-2.

Table 3-2 Average Heavy Duty Truck Idle NOx Emission Rates By Calendar Year								
			Average Idle NOx Emission Rate in Grams per Hour					
	Travel Fraction		Non-Discretionary			Discretionary (Hoteling)		
Calendar Year	Pre-1988	1988-2004	No A/C	A/C On	Annual*	No A/C	A/C On	Annual*
2004	0.058	0.942	83.91	103.80	92.20	130.49	140.72	134.75
* Annual assumes five months of A/C use and seven months with no A/C load.								

3.2.2 Particulate Matter (PM) Emission Factors for Discretionary Idle Operation

The particulate matter measurements made on four of the five heavy duty trucks in the Oak Ridge Study were used to estimate the emission rates for PM during modes characteristic of discretionary idling, rather than adjusting the non-discretionary, curb idling emission rates for particulate matter. The IdleAire study did include 49 paired test samples showing the effects of accessory load and idle speed on idling PM emissions from heavy-duty vehicles. These effects are discussed below.

3.2.2.1 PM Effects of Accessory Load

A paired sample t-test was used to compare the means of the idle PM emission tests with and without the accessory loads in the IdleAire study. The t-test indicates that neither the load effects on PM emissions of air conditioning nor heater load are significant at either low or high idle speeds. All of the t-test statistics are shown in Table B-4 in Appendix B.

3.2.2.2 PM Effects of Engine Idle Speed

A paired sample t-test was used to compare the means of the idle PM emission tests at low (non-discretionary "curb) idle speeds and high (discretionary) idle speeds in the IdleAire study. The t-test indicates that the effects of discretionary idle speeds on PM emissions are significant only with the air conditioning on. All of the t-test statistics are shown in Table C-4 in Appendix C.

3.2.2.3 PM Effects of Idling Time

None of the studies contain the information needed to resolve the effects of extended idling time on PM emissions. Pre-2007 model year trucks will be assumed to have the same PM emission rate during all hours of operation. This is supported by results in the Oak Ridge study, where PM idling rates appear to be constant over idling time periods exceeding an hour.

For PM, it is expected that the new after-treatment devices used for 2007 and later model years should be effective for both short term non-discretionary idle periods and during extended idling periods. No adjustment to the non-discretionary PM idling emission factor is therefore needed to account for long-term, discretionary idling. This expectation is quite different than the assumptions used for the other pollutants (HC, CO and NOx).

3.2.2.4 Adjustments to PM Idling Emission Factors

Table 3-3 summarizes the effect of air conditioning load in combination with high idle speeds observed in the sample as a multiplicative adjustments to the basic idle PM emissions measured with no load. The idling adjustments are a composite of the effects of higher idling speeds and extended idling time, and are applicable to extended idling periods. The time adjustment for the 2007 and newer engines is applied to the estimate for pre-2007 model year non-discretionary idling PM emission rates and includes the effect of the new standards. The adjustments assume no interactions.

Table 3-3
Adjustments to Idle PM Emissions

	Adjustment to Base Idle PM Emission Rate		
Description	Time	Speed/Air Conditioning	Composite
Extended Idle with A/C On	NA	46.9%	46.9%
2007+ Extended Idle with No Load	-11.3%	NA	-11.3%
2007+ Extended Idle with A/C On	-11.3%	46.9%	30.3%

3.2.2.5 Discretionary PM Idling Emission Factors

In the case of particulate matter emissions, it was felt that an adjustment of the base curb idle PM emission rate would not be appropriate for use in modeling the effects of extended idling (hoteling). Instead, the particulate matter measurements made on four of the five heavy duty trucks in the Oak Ridge Study were used to estimate the emission rates for PM during modes characteristic of discretionary idling, rather than adjusting the non-discretionary, curb idling emission rates for PM.

Table D-1 in Appendix D shows the PM measurements on the five trucks in the study during the different seasonal operating modes with corresponding engine loading. All results shown are for the high idling speed case, which is typical of hoteling behavior. The 1992 Ford truck has unusually high PM emissions and was dropped from the averages shown in Table D-2. Each seasonal average was weighted by the number of months associated with the season (3 months for winter, 4 months for spring and fall and 5 months for summer. The resulting seasonally weighted average PM emissions are shown in Table 3-4. This number is slightly larger than the PM emission factor estimated for non-discretionary idling in Section 3.1.2.1.

For 2007 model year and later trucks, the emission rate for pre-2007 trucks was adjusted using the ratio of the standards, as described in Section 3.1.2.2 and the results are shown in Table 3-4. This result is slightly lower than the estimate for non-discretionary idle PM emissions estimated in Section 3.1.2.2.

Table 3-4
Annual Average Discretionary (Hoteling) Idle PM Emissions

Truck Model Year	PM Emission Factor (g/hr)
2006 and earlier	3.68
2007 and later	0.33

3.2.2 Discretionary Idle HC Emission Effects

3.2.2.1 HC Effects of Accessory Load

The CCD study has not yet been summarized for HC emissions. However. the IdleAire study include paired test samples showing the effects of accessory load on idling HC emissions from heavy-duty vehicles. A paired sample t-test was used to compare the means of the idle HC emission tests with and without the accessory loads. The t-test indicates that neither the load effects on HC emissions of air conditioning nor heater load are significant at either low or high idle speeds. All of the t-test statistics are shown in Appendix B.

3.2.2.2 HC Effects of Engine Idle Speed

The IdleAire study results used to evaluate the effects of accessory load were also used to investigate the effects of idle speed on HC emissions. A paired sample t-test was used to compare the means of the idle HC emission tests at low (non-discretionary "curb) idle speeds and high (discretionary) idle speeds. The t-test indicates that the effects of discretionary idle speeds on HC emissions are significant at all loads. All of the t-test statistics are shown in Appendix C.

3.2.2.3 HC Effects of Engine Idling Time

The CCD study has not yet been summarized for HC emissions. None of the other studies contains the information needed to resolve the effects of idling time on HC emissions.

As discussed earlier, the new exhaust after-treatment devices used for 2007 and later model years should be effective for non-discretionary idle periods such as waiting at a traffic light or during a limited idle period. However, during extended idling periods, the effectiveness of these controls will fade substantially. This will make the overall average idling emission rate for the extended idling period much higher than the expected non-discretionary idling emission rate.

Since no data are available on 2007 and newer engines, the curb idle HC emission factors developed for the estimate of non-discretionary idle HC emissions will be used to represent idling emission rates for the first hour of idling. The idling emission rate after one hour of idling will be assumed to return to pre-controlled (pre-2007 model year) rates. Then, assuming that all extended idling periods are eight hours long, we can calculate the average idling emission rate for extended idling periods for the 2007 and newer engines:

2007 Extended Idling Rate = (1/8)*2007 Idle Rate + (7/8)*Pre-2007 Idle Rate

This method can also be used to determine idle emission rates for idling time periods which are less than the eight hours assumed here. The 2007 idle emission rate is assumed to be 10% of the pre-2007 idle emission rate, so the extended idle emission rate for 2007 and newer model years can be determined directly from the idle emission estimate for pre-2007 model year vehicles.

2007 Extended Idling Rate = [(1/8)* (0.10) + (7/8)] * Pre-2007 Idle Rate

As new information is obtained about the emission performance of these vehicles, these estimates will need to be updated.

3.2.2.4 <u>Discretionary HC Idling Emission Factors</u>

Table 3-5 summarizes the effect of discretionary (extended) idling observed in the sample as a multiplicative adjustments to the basic idle HC emissions measured with no load. The discretionary idling adjustments are a composite of the effects of higher idling speeds and extended idling time. The time adjustment for the 2007 and newer engines is applied to the estimate for pre-2007 model year non-discretionary idling HC emission rates and includes the effect of the new standards. The adjustments assume no interactions.

Table 3-5
Discretionary Effects of on Idle HC Emissions

	Adjustment to Base Idle HC Emission Rate		
Description	Speed	Time	Composite
Discretionary	82.6%	NA	82.6%
2007+ Discretionary	82.6%		

3.2.3 Discretionary Idle CO Emission Effects

3.2.3.1 CO Effects of Accessory Load

The CCD study has not yet been summarized for CO emissions. However. the IdleAire study include paired test samples showing the effects of accessory load on idling CO emissions from heavy-duty vehicles. A paired sample t-test was used to compare the means of the idle CO emission tests with and without the accessory loads. The t-test indicates that only the load effects on CO emissions of air conditioning are significant, and only at low idle speeds. All of the t-test statistics are shown in Appendix B.

3.2.3.2 CO Effects of Engine Idle Speed

The IdleAire study results used to evaluate the effects of accessory load were also used to investigate the effects of idle speed on CO emissions. A paired sample t-test was used to compare the means of the idle CO emission tests at low (non-discretionary "curb) idle speeds and high (discretionary) idle speeds. The t-test indicates that the effects of discretionary idle speeds on CO emissions are significant at all loads. All of the t-test statistics are shown in Appendix C.

3.2.3.3 CO Effects of Engine Idling Time

The CCD study has not yet been summarized for CO emissions. None of the other studies contains the information needed to resolve the effects of idling time on CO emissions.

As discussed earlier, the new exhaust after-treatment devices used for 2007 and later model years should be effective for non-discretionary idle periods such as waiting at a traffic light or during a limited idle period. However, during extended idling periods, the effectiveness of these controls will fade substantially. This will make the overall average idling emission rate for the extended idling period much higher than the expected non-discretionary idling emission rate.

Since no data are available on 2007 and newer engines, the curb idle CO emission factors developed for the estimate of non-discretionary idle CO emissions will be used to represent idling emission rates for the first hour of idling. The idling emission rate after one hour of idling will be assumed to return to pre-controlled (pre-2007 model year) rates. Then, assuming that all extended idling periods are eight hours long, we can calculate the average idling emission rate for extended idling periods for the 2007 and newer engines:

2007 Extended Idling Rate = (1/8)*2007 Idle Rate + (7/8)*Pre-2007 Idle Rate

This method can also be used to determine idle emission rates for idling time periods which are less than the eight hours assumed here. The 2007 idle emission rate is assumed to be 10% of the pre-2007 idle emission rate, so the extended idle emission rate for 2007 and newer model years can be determined directly from the idle emission estimate for pre-2007 model year vehicles.

2007 Extended Idling Rate = [(1/8)* (0.10) + (7/8)] * Pre-2007 Idle Rate

As new information is obtained about the emission performance of these vehicles, these estimates will need to be updated.

3.2.3.4 Discretionary CO Idling Emission Factors

Table 3-6 summarizes the effect of discretionary (extended) idling and the effect of air conditioning load at low idle speeds observed in the sample as a multiplicative adjustments to the basic idle CO emissions measured with no load. The discretionary idling adjustments are a composite of the effects of higher idling speeds and extended idling time. The time adjustment for the 2007 and newer engines is applied to the estimate for pre-2007 model year non-discretionary idling CO emission rates and includes the effect of the new standards. The adjustments assume no interactions.

Table 3-6
Discretionary Effects of on Idle CO Emissions

	Adjustment to Base Idle CO Emission Rate			
Description	Speed	Time	Air Conditioning	Composite
Non-discretionary with A/C On	NA	NA	13.4%	13.4%
Discretionary	217.2%	NA	NA	217.2%
2007+ Discretionary	217.2%		NA	

Appendix A
Non-Discretionary Idle Analysis Sample and Statistics

Table A-1
Average Curb Idle NOx Emissions by Vehicle Class

Class	Mean	N	Std. Deviation	Median
Truck	114	82.585212	32.298661	3.025047
Bus	13	118.910769	37.775149	10.476941

Table A-2
T-Test Statistics for Curb Idle NOx by Vehicle Class

Levene's Test for Equality of Variances			Independent Samples t-test for Equality of Means						
	F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed	1.059	.305	-3.776	125	.000	-36.325558	9.620520	-55.365761	-17.285355
Equal variances not assumed			-3.331	14.074	.005	-36.325558	10.904917	-59.702773	-12.948342

Table A-3
Average High Altitude Curb Idle NOx Emissions by Vehicle Class

Class	Mean	N	Std. Deviation	Median
Truck	11	84.038182	24.324821	7.334209
Bus	13	118.910769	37.775149	10.476941

Table A-4
T-Test Statistics for High Altitude Curb Idle NOx by Vehicle Class

Levene's Test for Equality of Variances			Independent Samples t-test for Equality of Means						
	F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed	3.696	.068	-2.630	22	.015	-34.872587	13.257826	-62.367636	-7.377538
Equal variances not assumed			-2.727	20.683	.013	-34.872587	12.788938	-61.493510	-8.251665

Table A-5 Average Truck Only Curb Idle NOx Emissions by Altitude				
Altitude	Mean	N	Std. Deviation	Median
Low	103	82.430040	33.127697	3.264169
High	11	84.038182	24.324821	7.334209

Table A-6 T-Test Statistics for Truck Only Curb Idle NOx by Altitude									
Levene's Test for Equality of Variances			Independent Samples t-test for Equality of Means						
	F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed	2.065	.153	-.156	112	.876	-1.608142	10.289751	-21.995963	18.779680
Equal variances not assumed			-.200	14.299	.844	-1.608142	8.027791	-18.792332	15.576049

Table A-7 Average Truck Only Curb Idle NOx Emissions by Model Year Group				
Model Year	Mean	N	Std. Deviation	Median
Pre-1988	9	50.475000	36.277026	12.092342
1988 and Newer	105	85.337515	30.583874	2.984680

Table A-8 T-Test Statistics for Truck Only Curb Idle NOx by Model Year Group									
Levene's Test for Equality of Variances			Independent Samples t-test for Equality of Means						
	F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed	.337	.563	-3.235	112	.002	-34.862515	10.775837	-56.213455	-13.511576
Equal variances not assumed			-2.799	9.002	.021	-34.862515	12.455242	-63.037336	-6.687695

Table A-9
ANOVA Statistics for Curb Idle NOx by Engine Size

		R	R Square	Adjusted R Square	Std. Error of the Estimate
		.167	.028	.017	33.883323

	Sum of Squares	df	Mean Square	F	Significance
Regression	2926.367	1	2926.367	2.549	.114
Residual	102179.084	89	1148.080		
Total	105105.451	90			

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
(Constant)	56.531	19.490		2.900	.005	17.804	95.258
Size	2.541	1.592	.167	1.597	.114	-.621	5.703

a Predictors: (Constant), Engine Size
b Dependent Variable: NOx

Table A-10
ANOVA Statistics for Curb Idle NOx by Model Year

		R	R Square	Adjusted R Square	Std. Error of the Estimate
		.101	.010	.002	34.5115302

	Sum of Squares	df	Mean Square	F	Significance
Regression	1522.991	1	1522.991	1.279	.260
Residual	148880.714	125	1191.046		
Total	150403.705	126			

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
(Constant)	-1432.999	1343.572		-1.067	.288	-4092.094	1226.097
Year	.762	.673	.101	1.131	.260	-.571	2.094

a Predictors: (Constant), Model Year
b Dependent Variable: NOx

Table A-11a
Testing Program Descriptions

Program Number	Program	Description
1	High Altitude Study	"Idle Emissions from Heavy-Duty Diesel and Natural Gas Vehicles at High Altitude," Robert McCormick, et al, Colorado Institute for Fuels and Engine Research, Colorado School of Mines, Journal of the Air and Waste Management Association, Revised May 3, 2000.
2	CCD Study	"Study of Exhaust Emissions from Idling Heavy-duty Diesel Trucks and Commercially Available Idle Reducing Devices," Han Lim, US EPA Office of Transportation and Air Quality, September 2002.
4	Clean Air Tech & IdleAire Study	"NOx Emissions and Fuel Consumption of HDDVs during Extended Idle," David K. Irick, University of Tennessee, Bob Wilson, IdleAire Technologies Inc., Coordinated Research Council 12th Annual On-Road Vehicle Emission Workshop, San Diego, California, April 15-17, 2002. Also "Preliminary Results for Stationary and On-Road Testing of Diesel Trucks in Tulare, California," Douglas Lambert, et al, Clean Air Technologies Inc., May 15, 2002.
5	CRC E-55 Study	"Heavy-duty Vehicle Chassis Dynamometer Testing for Emissions Inventory, Air Quality Modeling, Source Apportionment and Air Toxics Emissions Inventory," Phase I Interim Report, CRC Project No. E-55/E-59, Mridul Gautam and Nigel N. Clark, et al, West Virginia University Research Corporation, July 2002.
6	NCHRP Study	"Heavy-duty Vehicle Emissions," National Cooperative Highway Research Program Project 25-14, Cambridge Systematics, Inc., with Battelle, Sierra Research and West Virginia University. October 2002.
8	Metropolitan New York Study	"Internal Report - Idle Emissions from Heavy-Duty Diesel Trucks in the New Your Metropolitan Area", Tang and Munn, New York State Dept of Environmental Conservation, November 9, 2001.

Table A-11b
NOx Emissions Summarized by Testing Program

Program Number	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1.00	24	102.927500	36.2877542	7.4072068	87.604525	118.250475	25.4400	166.0200
2.00	5	98.207764	39.8360597	17.8152275	48.744763	147.670765	63.3462	141.6049
4.00	49	87.088510	31.4434295	4.4919185	78.056902	96.120117	46.8921	166.9950
5.00	14	68.033929	30.0143504	8.0216726	50.704159	85.363699	15.6950	106.7100
6.00	2	46.921667	29.1351564	20.6016667	-214.847328	308.690661	26.3200	67.5233
8.00	33	81.381818	34.3725313	5.9834897	69.193849	93.569788	25.2000	187.2000
Total	127	86.303576	34.5496773	3.0657881	80.236471	92.370680	15.6950	187.2000

Table A-11c
Multiple Comparisons of Testing Programs
Dependent Variable: NOx
Bonferroni

					95% Confidence Interval	
(I) Program	(J) Program	Mean Difference* (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
1.00	2.00	4.719736	16.3873777	1.000	-44.353838	53.793311
	4.00	15.838990	8.3053676	.883	-9.032229	40.710210
	5.00	34.893571	11.2104552	**.035**	1.322788	68.464355
	6.00	56.005833	24.5339313	.363	-17.463377	129.475043
	8.00	21.545682	8.9428496	.262	-5.234539	48.325903
2.00	1.00	-4.719736	16.3873777	1.000	-53.793311	44.353838
	4.00	11.119254	15.6500211	1.000	-35.746235	57.984743
	5.00	30.173835	17.3671625	1.000	-21.833799	82.181469
	6.00	51.286097	27.8901024	1.000	-32.233489	134.805684
	8.00	16.825946	15.9974557	1.000	-31.079970	64.731861
4.00	1.00	-15.838990	8.3053676	.883	-40.710210	9.032229
	2.00	-11.119254	15.6500211	1.000	-57.984743	35.746235
	5.00	19.054581	10.1020452	.925	-11.196962	49.306124
	6.00	40.166843	24.0476775	1.000	-31.846234	112.179920
	8.00	5.706691	7.5067682	1.000	-16.773046	28.186429
5.00	1.00	-34.893571	11.2104552	**.035**	-68.464355	-1.322788
	2.00	-30.173835	17.3671625	1.000	-82.181469	21.833799
	4.00	-19.054581	10.1020452	.925	-49.306124	11.196962
	6.00	21.112262	25.1989279	1.000	-54.348345	96.572868
	8.00	-13.347890	10.6323443	1.000	-45.187464	18.491685
6.00	1.00	-56.005833	24.5339313	.363	-129.475043	17.463377
	2.00	-51.286097	27.8901024	1.000	-134.805684	32.233489
	4.00	-40.166843	24.0476775	1.000	-112.179920	31.846234
	5.00	-21.112262	25.1989279	1.000	-96.572868	54.348345
	8.00	-34.460152	24.2752182	1.000	-107.154621	38.234318
8.00	1.00	-21.545682	8.9428496	.262	-48.325903	5.234539
	2.00	-16.825946	15.9974557	1.000	-64.731861	31.079970
	4.00	-5.706691	7.5067682	1.000	-28.186429	16.773046
	5.00	13.347890	10.6323443	1.000	-18.491685	45.187464
	6.00	34.460152	24.2752182	1.000	-38.234318	107.154621

* The mean difference is significant at the 0.05 level.

Table A-12 Average Curb Idle PM Emissions by Altitude and Vehicle Class					
Altitude	Class	Mean	N	Std. Deviation	Median
Low	Truck	3.778967	63	4.428443	2.230947
	All	3.778967	63	4.428443	2.230947
High	Truck	1.418182	11	0.367201	1.380000
	Bus	3.110769	13	2.916523	2.220000
	All	2.335000	24	2.288833	1.410000
Total	Truck	3.428039	74	4.170067	1.996531
	Bus	3.110769	13	2.916523	2.220000
	All	3.380631	87	3.995079	2.017305

Table A-13 T-Test Statistics for High Altitude Curb Idle PM by Vehicle Class									
Levene's Test for Equality of Variances			Independent Samples t-test for Equality of Means						
	F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed	11.232	.003	-1.906	22	.070	-1.692587	.888243	-3.534692	.149517
Equal variances not assumed			-2.073	12.449	.060	-1.692587	.816440	-3.464373	7.91985E-02

Table A-14
Curb Idle PM Statistics by Altitude

ALTITUDE			Statistic	Std. Error
Low	Mean		3.778967	.557931
	95% Confidence Interval for Mean	Lower Bound	2.663678	
		Upper Bound	4.894256	
	5% Trimmed Mean		3.206624	
	Median		2.230947	
	Variance		19.611	
	Std. Deviation		4.428443	
	Minimum		.0800	
	Maximum		23.2782	
	Range		23.1982	
	Interquartile Range		3.431699	
	Skewness		2.293	.302
	Kurtosis		6.110	.595
High	Mean		2.335000	.467206
	95% Confidence Interval for Mean	Lower Bound	1.368511	
		Upper Bound	3.301489	
	5% Trimmed Mean		2.034444	
	Median		1.410000	
	Variance		5.239	
	Std. Deviation		2.288833	
	Minimum		.3600	
	Maximum		10.3800	
	Range		10.0200	
	Interquartile Range		1.575000	
	Skewness		2.425	.472
	Kurtosis		6.279	.918

Table A-15 Curb Idle PM Statistics by Vehicle Class				
CLASS			Statistic	Std. Error
Truck	Mean		3.428039	.484760
	95% Confidence Interval for Mean	Lower Bound	2.461913	
		Upper Bound	4.394165	
	5% Trimmed Mean		2.854778	
	Median		1.996531	
	Variance		17.389	
	Std. Deviation		4.170067	
	Minimum		.0800	
	Maximum		23.2782	
	Range		23.1982	
	Interquartile Range		3.222327	
	Skewness		2.552	.279
	Kurtosis		7.612	.552
Bus	Mean		3.110769	.808898
	95% Confidence Interval for Mean	Lower Bound	1.348332	
		Upper Bound	4.873207	
	5% Trimmed Mean		2.859744	
	Median		2.220000	
	Variance		8.506	
	Std. Deviation		2.916523	
	Minimum		.3600	
	Maximum		10.3800	
	Range		10.0200	
	Interquartile Range		3.810000	
	Skewness		1.514	.616
	Kurtosis		2.078	1.191

Table A-16 **Vehicle Sample Size with Available HC Emissions**						
	Cases Included		Excluded		Total	
	N	Percent	N	Percent	N	Percent
THC * Class * Altitude	122	92.4%	10	7.6%	132	100.0%

Table A-17 **Average Curb Idle HC Emissions by Vehicle Class and Altitude**				
Class	Altitude	Mean	N	Std. Deviation
Truck	Low	10.495414	98	8.393333
	High	7.690909	11	2.495281
	Total	10.212391	109	8.035518
Bus	High	10.476923	13	9.491434
	Total	10.476923	13	9.491434
Total	Low	10.495414	98	8.393333
	High	9.200000	24	7.191662
	Total	10.240578	122	8.159247

Table A-18 **T-Test Statistics for Curb Idle THC by Vehicle Class**									
Levene's Test for Equality of Variances			Independent Samples t-test for Equality of Means						
	F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed	.750	.388	-.110	120	.913	-.264533	2.403949	-5.024184	4.495119
Equal variances not assumed			-.096	14.128	.925	-.264533	2.742658	-6.141961	5.612896

Table A-19 T-Test Statistics for Curb Idle THC by Altitude									
Levene's Test for Equality of Variances			Independent Samples t-test for Equality of Means						
	F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed	.118	.732	.696	120	.488	1.295414	1.862257	-2.391725	4.982553
Equal variances not assumed			.764	39.852	.449	1.295414	1.695246	-2.131201	4.722029

Table A-20 ANOVA Statistics for Curb Idle HC by Engine Size					
		R	R Square	Adjusted R Square	Std. Error of the Estimate
		.036	.001	-.010	8.535066
	Sum of Squares	df	Mean Square	F	Significance
Regression	8.329	1	8.329	.114	.736
Residual	6337.720	87	72.847		
Total	6346.049	88			

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
(Constant)	12.184	4.910		2.481	.015	2.425	21.944
Size	-.136	.401	-.036	-.338	.736	-.933	.662

a Predictors: (Constant), Engine Size
b Dependent Variable: THC

Table A-21
ANOVA Statistics for Curb Idle HC by Odometer Mileage

		R	R Square	Adjusted R Square	Std. Error of the Estimate
		.087	.008	-.007	7.146260

	Sum of Squares	df	Mean Square	F	Significance
Regression	27.220	1	27.220	.533	.468
Residual	3574.833	70	51.069		
Total	3602.053	71			

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
(Constant)	9.270	1.449		6.397	.000	6.380	12.160
Miles	2.863E-06	.000	.087	.730	.468	.000	.000

a Predictors: (Constant), Odometer Mileage
b Dependent Variable: THC

Table A-22
ANOVA Statistics for Curb Idle HC by Model Year

		R	R Square	Adjusted R Square	Std. Error of the Estimate
		.363	.132	.125	7.633352

	Sum of Squares	df	Mean Square	F	Significance
Regression	1063.204	1	1063.204	18.247	.000
Residual	6992.167	120	58.268		
Total	8055.371	121			

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
(Constant)	1294.063	300.548		4.306	.000	699.000	1889.127
Year	-.644	.151	-.363	-4.272	.000	-.942	-.345

a Predictors: (Constant), Model Year
b Dependent Variable: THC

Table A-23 Average Curb Idle CO Emissions by Vehicle Class and Altitude				
Class	Altitude	Mean	N	Std. Deviation
Truck	Low	22.101692	98	15.182583
	High	68.078182	11	31.830396
	Total	26.741521	109	22.235472
Bus	High	81.383077	13	34.330353
	Total	81.383077	13	34.330353
Total	Low	22.101692	98	15.182583
	High	75.285000	24	33.185489
	Total	32.563982	122	29.065045

Table A-24 T-Test Statistics for Truck Only Curb Idle CO by Altitude									
Levene's Test for Equality of Variances			Independent Samples t-test for Equality of Means						
	F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed	40.902	.000	-11.714	120	.000	53.183308	4.540246	-62.172678	-44.193937
Equal variances not assumed			-7.657	25.403	.000	53.183308	6.945407	-67.476156	-38.890460

Table A-25
T-Test Statistics for High Altitude Curb Idle CO by Vehicle Class

Levene's Test for Equality of Variances			Independent Samples t-test for Equality of Means						
	F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed			-.978	22	.339	-13.304895	13.608256	-41.526691	14.916900
Equal variances not assumed			-.984	21.785	.336	-13.304895	13.519105	-41.357821	14.748031

Table A-26
ANOVA Statistics for Curb Idle CO by Model Year

		R	R Square	Adjusted R Square	Std. Error of the Estimate
		.377	.142	.133	14.133510

	Sum of Squares	df	Mean Square	F	Significance
Regression	3182.964	1	3182.964	15.934	.000
Residual	19176.587	96	199.756		
Total	22359.551	97			

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
(Constant)	2415.728	599.642		4.029	.000	1225.449	3606.007
Year	-1.200	.301	-.377	-3.992	.000	-1.796	-0.603

a Predictors: (Constant), Model Year
b Dependent Variable: CO

Appendix B
Engine Load Analysis Statistics

Table B-1 Idle HC Emissions Versus Engine Load (g/hr) T-Test Paired Samples Statistics					
Pair	Description	Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Curb idle with No Load	11.55440	10	4.123644	1.304011
Pair 1	Curb idle with Heater On	11.26400	10	3.651550	1.154722
Pair 2	Curb idle with No Load	10.73851	18	3.896791	0.918482
Pair 2	Curb idle with A/C On	11.22044	18	3.080620	0.726109
Pair 3	High idle with No Load	17.45338	34	8.815857	1.511907
Pair 3	High idle with A/C On	16.67390	34	8.191705	1.404866
Paired Sample Correlations		Correlation		Significance	
Pair 1	Curb Idle with Heater On	10	0.781	0.008	
Pair 2	Curb Idle with A/C On	18	0.758	0.000	
Pair 3	High Idle with A/C On	34	0.931	0.000	
Paired Differences		Mean	df	Std. Deviation	Std. Error Mean
Pair 1	Curb Idle with Heater On	-0.2904	9	2.609318	0.825139
Pair 2	Curb Idle with A/C On	-0.48193	17	2.547206	0.600382
Pair 3	High Idle with A/C On	-0.77948	33	3.219075	0.552067
Paired Differences		95% Confidence Interval of the Difference			
		Lower	Upper	t	Sig. (2-tailed)
Pair 1	Curb Idle with Heater On	-2.156994	1.57619	-0.352	0.733
Pair 2	Curb Idle with A/C On	-1.74862	0.784769	-0.803	0.433
Pair 3	High Idle with A/C On	-1.90267	0.343705	-1.412	0.167

Table B-2 Idle CO Emissions Versus Engine Load (g/hr) T-Test Paired Samples Statistics					
Pair	Description	Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Curb idle with No Load	28.01	10	12.58176	3.978702
Pair 1	Curb idle with Heater On	30.184	10	14.6011	4.617274
Pair 2	Curb idle with No Load	26.2485	18	11.27232	2.656911
Pair 2	Curb idle with A/C On	29.77747	18	13.41937	3.162975
Pair 3	High idle with No Load	54.63609	34	41.07124	7.043659
Pair 3	High idle with A/C On	53.24851	34	37.30385	6.397557
Paired Sample Correlations		Correlation		Significance	
Pair 1	Curb Idle with Heater On	10	0.984	0.000	
Pair 2	Curb Idle with A/C On	18	0.947	0.000	
Pair 3	High Idle with A/C On	34	0.986	0.000	
Paired Differences		Mean	df	Std. Deviation	Std. Error Mean
Pair 1	Curb Idle with Heater On	2.174	9	3.142922	0.993879
Pair 2	Curb Idle with A/C On	3.52896	17	4.545774	1.071449
Pair 3	High Idle with A/C On	-1.38758	33	7.518805	1.289464
Paired Differences		95% Confidence Interval of the Difference			
		Lower	Upper	t	Sig. (2-tailed)
Pair 1	Curb Idle with Heater On	-0.074311	4.42231	2.187	0.056
Pair 2	Curb Idle with A/C On	1.2684	5.78952	3.294	0.004
Pair 3	High Idle with A/C On	-4.01102	1.235855	-1.076	0.290

Table B-3
Idle NOx Emissions Versus Engine Load (g/hr)
T-Test Paired Samples Statistics

Pair	Description	Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Curb idle with No Load	127.754	13	36.296	10.067
Pair 1	Curb idle with Heater On	122.458	13	36.373	10.088
Pair 2	Curb idle with No Load	125.430	22	32.433	6.915
Pair 2	Curb idle with A/C On	155.199	22	38.982	8.311
Pair 3	High idle with No Load	150.600	5	64.682	28.927
Pair 3	High idle with Heater On	156.800	5	80.260	35.893
Pair 4	High idle with No Load	126.468	39	52.893	8.470
Pair 4	High idle with A/C On	159.960	39	77.232	12.367
Paired Sample Correlations		Correlation		Significance	
Pair 1	Curb Idle with Heater On	13	0.566	0.044	
Pair 2	Curb Idle with A/C On	22	0.835	0.000	
Pair 3	High Idle with Heater On	5	0.801	0.104	
Pair 4	High Idle with A/C On	39	0.855	0.000	
Paired Differences		Mean	df	Std. Deviation	Std. Error Mean
Pair 1	Curb Idle with Heater On	-5.296	12	33.843	9.386
Pair 2	Curb Idle with A/C On	29.769	21	21.449	4.573
Pair 3	High Idle with Heater On	6.200	4	48.080	21.502
Pair 4	High Idle with A/C On	33.492	38	42.121	6.745
Paired Differences		95% Confidence Interval of the Difference			
		Lower	Upper	t	Sig. (2-tailed)
Pair 1	Curb Idle with Heater On	-25.747	15.154	-0.564	0.583
Pair 2	Curb Idle with A/C On	20.259	39.279	6.510	0.000
Pair 3	High Idle with Heater On	-53.499	65.899	0.288	0.787
Pair 4	High Idle with A/C On	19.838	47.147	4.966	0.000

Table B-4 Idle PM Emissions Versus Engine Load (g/hr) T-Test Paired Samples Statistics					
Pair	Description	Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Curb idle with No Load	6.588975	10	5.060315	1.600212
Pair 1	Curb idle with Heater On	5.661299	10	3.289959	1.040376
Pair 2	Curb idle with No Load	6.846186	11	4.875843	1.470122
Pair 2	Curb idle with A/C On	6.333916	11	3.516132	1.060154
Pair 3	High idle with No Load	4.513723	34	6.044245	1.03658
Pair 3	High idle with A/C On	4.475141	34	6.336543	1.086708
Paired Sample Correlations		Correlation		Significance	
Pair 1	Curb Idle with Heater On	10	0.829	0.003	
Pair 2	Curb Idle with A/C On	11	0.887	0.000	
Pair 3	High Idle with A/C On	34	0.987	0.000	
Paired Differences		Mean	df	Std. Deviation	Std. Error Mean
Pair 1	Curb Idle with Heater On	-0.927676	9	2.973875	0.940422
Pair 2	Curb Idle with A/C On	-0.512271	10	2.391163	0.720963
Pair 3	High Idle with A/C On	0.03858	33	1.049061	0.179912
Paired Differences		95% Confidence Interval of the Difference			
		Lower	Upper	t	Sig. (2-tailed)
Pair 1	Curb Idle with Heater On	-3.055058	1.19971	-0.986	0.350
Pair 2	Curb Idle with A/C On	-2.118676	1.09413	-0.711	0.494
Pair 3	High Idle with A/C On	-0.327453	0.40462	0.214	0.832

Appendix C
Engine Idle Speed Analysis Statistics

Table C-1
Idle HC Emissions Versus Idle Speed (g/hr)
T-Test Paired Samples Statistics

Pair	Description	Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Curb idle with No Load	9.555759	34	4.395221	0.753774
Pair 1	High idle with No Load	17.45338	34	8.815857	1.511907
Pair 2	Curb idle with Heater On	11.264	10	3.65155	1.154722
Pair 2	High idle with Heater On	20.0038	10	7.443559	2.35386
Pair 3	Curb idle with A/C On	11.22044	18	3.08062	0.726109
Pair 3	High idle with A/C On	17.44223	18	7.567212	1.783609

Paired Sample Correlations		Correlation		Significance
Pair 1	Speed with No Load	34	0.714	0.000
Pair 2	Speed with Heater On	10	0.732	0.016
Pair 3	Speed with A/C On	18	0.687	0.002

Paired Differences		Mean	df	Std. Deviation	Std. Error Mean
Pair 1	Speed with No Load	7.897625	33	6.460725	1.108005
Pair 2	Speed with Heater On	8.739800	9	5.379976	1.701298
Pair 3	Speed with A/C On	6.221792	17	5.893289	1.389061

Paired Differences		95% Confidence Interval of the Difference			
		Lower	Upper	t	Sig. (2-tailed)
Pair 1	Speed with No Load	5.643372	10.15188	7.128	0.000
Pair 2	Speed with Heater On	4.891197	12.58840	5.137	0.001
Pair 3	Speed with A/C On	3.291129	9.152456	4.479	0.000

Table C-2
Idle CO Emissions Versus Idle Speed (g/hr)
T-Test Paired Samples Statistics

Pair	Description	Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Curb idle with No Load	17.22332	34	8.772249	1.504428
Pair 1	High idle with No Load	54.63609	34	41.07124	7.043659
Pair 2	Curb idle with Heater On	30.184	10	14.6011	4.617274
Pair 2	High idle with Heater On	73.742	10	29.07419	9.194065
Pair 3	Curb idle with A/C On	29.77747	18	13.41937	3.162975
Pair 3	High idle with A/C On	67.15153	18	38.21423	9.00718

Paired Sample Correlations		Correlation		Significance
Pair 1	Speed with No Load	34	0.630	0.000
Pair 2	Speed with Heater On	10	0.751	0.012
Pair 3	Speed with A/C On	18	0.724	0.001

Paired Differences		Mean	df	Std. Deviation	Std. Error Mean
Pair 1	Speed with No Load	37.41277	33	36.194	6.20722
Pair 2	Speed with Heater On	43.558	9	20.51483	6.48736
Pair 3	Speed with A/C On	37.37407	17	29.96987	7.063967

Paired Differences		95% Confidence Interval of the Difference			
		Lower	Upper	t	Sig. (2-tailed)
Pair 1	Speed with No Load	24.78409	50.04146	6.027	0.000
Pair 2	Speed with Heater On	28.88257	58.23343	6.714	0.000
Pair 3	Speed with A/C On	22.4704	52.27773	5.291	0.000

Table C-3
Idle NOx Emissions Versus Idle Speed (g/hr)
T-Test Paired Samples Statistics

Pair	Description	Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Curb idle with No Load	81.12896	38	33.21055	5.387463
Pair 1	High idle with No Load	126.1909	38	53.57418	8.690879
Pair 2	Curb idle with Heater On	120.6394	14	35.60214	9.515073
Pair 2	High idle with Heater On	160.8317	14	48.30586	12.91028
Pair 3	Curb idle with A/C On	154.5816	23	38.20029	7.965311
Pair 3	High idle with A/C On	204.9348	23	58.08001	12.11052

Paired Sample Correlations		Correlation		Significance
Pair 1	Speed with No Load	38	0.711	0.000
Pair 2	Speed with Heater On	14	0.628	0.016
Pair 3	Speed with A/C On	23	0.492	0.017

Paired Differences		Mean	df	Std. Deviation	Std. Error Mean
Pair 1	Speed with No Load	45.06191	37	37.98222	6.161529
Pair 2	Speed with Heater On	40.19236	13	37.94282	10.14065
Pair 3	Speed with A/C On	50.35326	22	51.47647	10.73359

Paired Differences		95% Confidence Interval of the Difference			
		Lower	Upper	t	Sig. (2-tailed)
Pair 1	Speed with No Load	32.57747	57.54635	7.313	0.000
Pair 2	Speed with Heater On	18.28482	62.09989	3.963	0.002
Pair 3	Speed with A/C On	28.09316	72.61335	4.691	0.000

Table C-4
Idle PM Emissions Versus Idle Speed (g/hr)
T-Test Paired Samples Statistics

Pair	Description	Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Curb idle with No Load	3.536667	34	4.831247	0.828552
Pair 1	High idle with No Load	4.513723	34	6.044245	1.03658
Pair 2	Curb idle with Heater On	5.661299	10	3.289959	1.040376
Pair 2	High idle with Heater On	8.196625	10	5.722588	1.809641
Pair 3	Curb idle with A/C On	6.333916	11	3.516132	1.060154
Pair 3	High idle with A/C On	9.301994	11	6.954408	2.096833

Paired Sample Correlations		Correlation		Significance
Pair 1	Speed with No Load	34	0.353	0.040
Pair 2	Speed with Heater On	10	0.628	0.052
Pair 3	Speed with A/C On	11	0.876	0.000

Paired Differences		Mean	df	Std. Deviation	Std. Error Mean
Pair 1	Speed with No Load	0.977056	33	6.264895	1.074421
Pair 2	Speed with Heater On	2.535326	9	4.463751	1.411562
Pair 3	Speed with A/C On	2.968078	10	4.229222	1.275159

Paired Differences		95% Confidence Interval of the Difference			
		Lower	Upper	t	Sig. (2-tailed)
Pair 1	Speed with No Load	-1.20887	3.162981	0.909	0.370
Pair 2	Speed with Heater On	-0.65785	5.728501	1.796	0.106
Pair 3	Speed with A/C On	0.126848	5.809309	2.328	0.042

Appendix D
Discretionary Idling Particulate Matter Statistics

Table D-1
Oak Ridge Study Idle PM Emissions Measurements

Vehicle Description	Temperature (F)	Load Type	PM (g/hr)
1998 Freightliner with Cummins N14	0	Heater on	5.603
1998 Freightliner with Cummins N14	65	No load	3.136
1998 Freightliner with Cummins N14	90	A/C on	2.946
1992 Ford with Caterpillar 3406	0	Heater on	6.885
1992 Ford with Caterpillar 3406	65	No load	20.386
1992 Ford with Caterpillar 3406	90	A/C on	20.574
1999 Volvo truck, DDC series 60	0	Heater on	4.790
1999 Volvo truck, DDC series 60	65	No load	3.904
1999 Volvo truck, DDC series 60	90	A/C on	5.061
Freightliner, DDC Series 60	0	Heater on	8.208
Freightliner, DDC Series 60	65	No load	2.480
Freightliner, DDC Series 60	90	A/C on	3.312
Exact97 International Caterpillar	0	Heater on	3.347
Exact97 International Caterpillar	65	No load	2.200
Exact97 International Caterpillar	90	A/C on	1.439

Table D-1
Oak Ridge Study Idle PM Emissions Measurements
(Excluding the 1992 Ford)

Temperature (F)	N	Mean	Minimum	Maximum	Std. Deviation	Weighting
0	4	5.487167	3.34689	8.20828	2.039957	0.250
65	4	2.930185	2.20022	3.90439	0.758637	0.333
90	4	3.18931	1.43929	5.06079	1.487654	0.417
Total	12	3.868887	1.43929	8.20828	1.826509	1.000
					Wgt. Std. Error	
Seasonal Weighting		3.677399			0.42709	