

Data Collection of Heavy-Duty Drayage Trucks in Houston-Galveston Port Area

Data Collection of Heavy-Duty Drayage Trucks in Houston-Galveston Port Area

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

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Acronyms

| | |
|-----------------|---|
| A/C | Alternating Current |
| ASD | Assessment and Standards Division |
| BSFC | Brake-Specific Fuel Consumption |
| CO | Carbon Monoxide Emissions |
| CO ₂ | Carbon Dioxide Emissions |
| CSV | Comma-Separated Variable file |
| DLC | Diagnostic Link Connector |
| EAM | Emissions and Activity Measurements |
| ECU | Electronic Control Unit |
| EFM | Sensors' Exhaust Flow Meter |
| EPA | United States Environmental Protection Agency |
| ERG | Eastern Research Group |
| FEAT | Fuel Efficiency Automobile Test |
| FID | Flame Ionization Detector |
| g | grams |
| GPS | Global Positioning System |
| H-GAC | The Houston-Galveston Area Council |
| HC | Hydrocarbon |
| HP | Horsepower |
| IOO | Independent Owner / Operator |
| hr | hour |
| kW | Kilowatt |
| LOD | Laboratory Operations Division |
| MPS | Micro-Proportional Sampling System |
| MSOD | Mobile Source Observation Database |
| MOVES | Motor Vehicle Emission Simulator Model |
| NDIR | Non-dispersive infrared |
| NH ₃ | Ammonia |
| NO _x | Oxides of Nitrogen |
| OTAQ | Office of Transportation and Air Quality |
| OTR | Over-the-road (long-haul truck) |
| PAMS | Portable Activity Measurement System (aka datalogger) |
| PEMS | Portable Emissions Measurement System |
| PHA | The Port of Houston Authority |
| PM | Particulate Matter |
| QA | Quality Assurance |
| QAPP | Quality Assurance Project Plan |
| QC | Quality Control |
| QMP | Quality Management Plan |
| RSD | Remote Sensing Device |
| RPM | Revolutions Per Minute |
| SAE | Society of Automotive Engineers |
| SAS | Statistical Analysis Software |
| SCFM | Standard Cubic Feet per Minute |

| | |
|-----------------|---|
| SIP | State Implementation Plan |
| SO ₂ | Sulfur Dioxide |
| SOP | Standard Operating Procedure |
| TCEQ | The Texas Commission on Environmental Quality |
| THC | Total Hydrocarbons |
| TxDOT | Texas Department of Transportation |
| VSP | Vehicle Specific Power |

Acknowledgments

The Port of Houston Drayage Study was a multi-year effort resulting from collaboration between the U.S. Environmental Protection Agency (EPA), the Texas Commission on Environmental Quality (TCEQ), the Houston-Galveston Area Council (H-GAC), and the Port of Houston Authority (PHA). Many people were responsible for the success of this project. ERG would like to recognize the commitment and contributions from Shelley Whitworth and Patricia Franco Lawhorn of the H-GAC, Mary McGarry-Barber of the TCEQ, and Ken Gathright of the PHA. From EPA's ASD division, Carl Fulper, Robert Giannelli, Connie Hart, Cheryl Caffrey, David Hawkins, John Koupal, Michael Christianson, Prashanth Gururaja and Jim Warila all provided significant contributions, both in project design and analysis and also with fieldwork deployment. Carl Fulper's dedication and overall direction was instrumental, as was Bob Giannelli's support in diagnosing, maintaining and repairing the complex equipment used in the study. A number of EPA LOD personnel also provided significant contributions, including Robert Caldwell, Charles Schenk, Ethan Schauer, Dale Van Earp, Craig Swan and Brian Ratkos. The efficiency and expertise of the LOD team was evident and critical, in particular with the planning, complex fabrication, cutting, welding, equipment setup and other work necessary for each unique installation. ERG's subcontractors on this project, Sensors, Inc. and the University of Denver, also provided mission-critical support during the study. In particular, Louis Moret and Chris Darby of Sensors both proved (once again) invaluable during the field deployment, and Chris Darby's detailed analysis of PEMS data after fieldwork was complete helped ensure the highest quality data was available from this study. Gary Bishop, Don Stedman and Brent Schuchmann from the University of Denver demonstrated their expertise as they efficiently conducted the RSD sampling effort which preceded the PEMS deployment. Recruiting support by Patricia Lawhorn, Shelley Whitworth, Ken Gathright, and Diane Preusse (ERG) provided an abundance of trucking companies to support the study, and field support from ERG staff including Alan Stanard, Scott Fincher, Gopi Manne, Sandeep Kishan and Mike Sabisch all helped keep things running smoothly on the ground and during subsequent analysis, validation and reporting.

Executive Summary

This work was conducted by EPA, ERG and Sensors, in coordination with the Texas Commission on Environmental Quality (TCEQ), the Houston-Galveston Area Council (H-GAC), and the Port of Houston Authority (PHA). The objective of this work assignment was to collect emissions and activity data on drayage trucks for incorporation of this source category into the EPA Motor Vehicle Emission Simulator (MOVES) emission model used for state implementation plan modeling,

University of Denver personnel performed one of the initial steps in this study by using a remote sensing device (RSD) to make NO_x emission measurements of drayage trucks at the Port of Houston. This part of the study was conducted for EPA in order to both begin characterizing drayage truck emissions and to provide a group of trucks to sample from for further exhaust testing. Staff recorded these RSD measurements along with each truck's model year so that ERG could then develop a stratified sampling plan for selecting drayage trucks to be tested. Trucks were selected from a sample pool of 1877 trucks which had received an RSD test, and these trucks (and their associated companies) were identified using port terminal gate data merged with TxDOT registration data. Both fleet and independently owned and operated trucks were recruited to participate in the program, and company and driver incentives were offered to encourage participation.

Twelve companies that operate trucks that routinely service terminals in the Port of Houston ultimately contacted ERG to inquire about the program, and of those, six companies participated in the program. Portable emission measurement system (PEMS) and portable activity measurement system (PAMS) testing was conducted in three phases between December 6, 2009 and March 17, 2010. Twenty-three PAMS instrumentations were performed during the study and were approximately one week in duration and forty-six one-day PEMS tests were performed on 37 trucks (some trucks were tested multiple times). PAMS tests consisted of collecting 1 Hz date/time, truck speed, location, engine RPM, and engine datastream data (when available). Two types of PEMS tests were performed, gaseous-only tests (of which 24 were performed) and gaseous / PM tests (of which 22 were performed). Gaseous testing involved 1 Hz collection of THC, CO, CO₂ and NO_x emissions and exhaust mass flow rate, and gaseous / PM testing involved collecting all gaseous and exhaust data along with micro-proportionally-sampled PM mass emissions collected on gravimetric filters. Activity data and other system and environmental parameters were also collected during the PEMS tests.

Once fieldwork was complete, study data was processed, analyzed, validated (problems identified, flagged, and corrected as appropriate) and eventually processed for input into the EPA Office of Transportation and Air Quality's (OTAQ's) Mobile Source Observation Database (MSOD). Gaseous and PM mass-based emissions have been calculated on a fuel basis (grams per gallon), time basis (grams per second), distance basis (grams/mile) and work basis (grams per brake-horsepower hour). Work based emissions have been calculated using engine control unit load data (and lug curves, as needed). Similarly, activity data has been further characterized in terms of brake-specific load. Emissions and activity results have been calculated and are presented both within and outside of port terminals, and have been further broken down on a vehicle-specific-power (VSP) basis as is used in MOVES modeling. These results are available in Section 7 of the report. As can be seen in Section 7, higher idle operation was seen within port boundaries than outside of port boundaries, both for PEMS and PAMS testing. Similarly, average speeds were lower within ports than outside of ports. Both work-based and distance-based emissions were higher within ports than outside of ports. Analysis of PAMS results similarly showed significantly lower speeds and loads for in-port activity vs. non-port activity. Hence, dominance in lower MOVES operating mode bins is seen for port activity when compared to non-port activity. It should be noted that non-port activity only includes local operations and does not include over-the-road (interstate) operations. Inclusion of interstate operation in these results would likely increase the differences seen in MOVES operating mode bins between port and non-port activities.

This study was a significant undertaking and involved a high level of planning, staffing and resources. This report describes methods and procedures for preparing for and performing the field study, and also processing and validating the data. A summary of the data collected is provided, but additional work needs to be done to better understand the true emission values and uncertainty limits of this data and to further characterize port emission and activity profiles using the data collected in this study. In addition, future studies to better understand emissions from other port activities such as emissions from marine vessels, emissions from cranes and gantries, emissions from dedicated port vehicles (aka yard mules), emissions from railcars and other miscellaneous port emission sources are necessary in order to understand the overall emissions contribution from all port activities.

1.0 Introduction

The objective of this work assignment was to collect data on drayage trucks for incorporation of this source category into the EPA Motor Vehicle Emission Simulator (MOVES) emission model used for state implementation plan modeling. Drayage trucks are heavy-duty trucks that are used to transport containers, bulk and break-bulk goods to and from port terminals and intermodal rail yards to other locations. This work only involved diesel-powered trucks, which is the fuel type powering almost all drayage trucks in the study area. This work was a continuation of Work Assignment 2-7 of Contract EP-C-06-080, during which remote sensing device (RSD) testing was performed to gather drayage truck emissions data for use in developing sampling criteria for this study. After development of the truck sampling criteria, recruiting and equipment preparation took place and portable emission measurement systems (PEMS) and portable activity measurement systems (PAMS) were then used to gather emissions and activity data from trucks selected for participation in this study.

This work was conducted by ERG and EPA in coordination with the Texas Commission on Environmental Quality (TCEQ), the Houston-Galveston Area Council (H-GAC), and the Port of Houston Authority (PHA). TCEQ and H-GAC developed a partnership with the EPA to work together on improving mobile source emission inventory estimates used in the SIP process. Emphasis was placed on the Houston area, with particular focus on drayage trucks due to their possibly significant emission contribution resulting from port activities.

The emissions measurements that were performed during this study were 40 CFR 1065-compliant onboard PEMS measurements of gaseous and aggregate particulate matter (PM) exhaust emissions. Each test was conducted over a typical workday. For the activity measurements, Isaac dataloggers were used to collect date, time, location (GPS), engine speed and ECU datastream data (for SAE J1708 and J1939-controlled engines) over a period of approximately one week.

Once fieldwork was complete, study data was processed, analyzed, quality assured (problems identified, flagged, and corrected as appropriate) and eventually processed for input into the EPA Office of Transportation and Air Quality's (OTAQ's) Mobile Source Observation Database (MSOD).

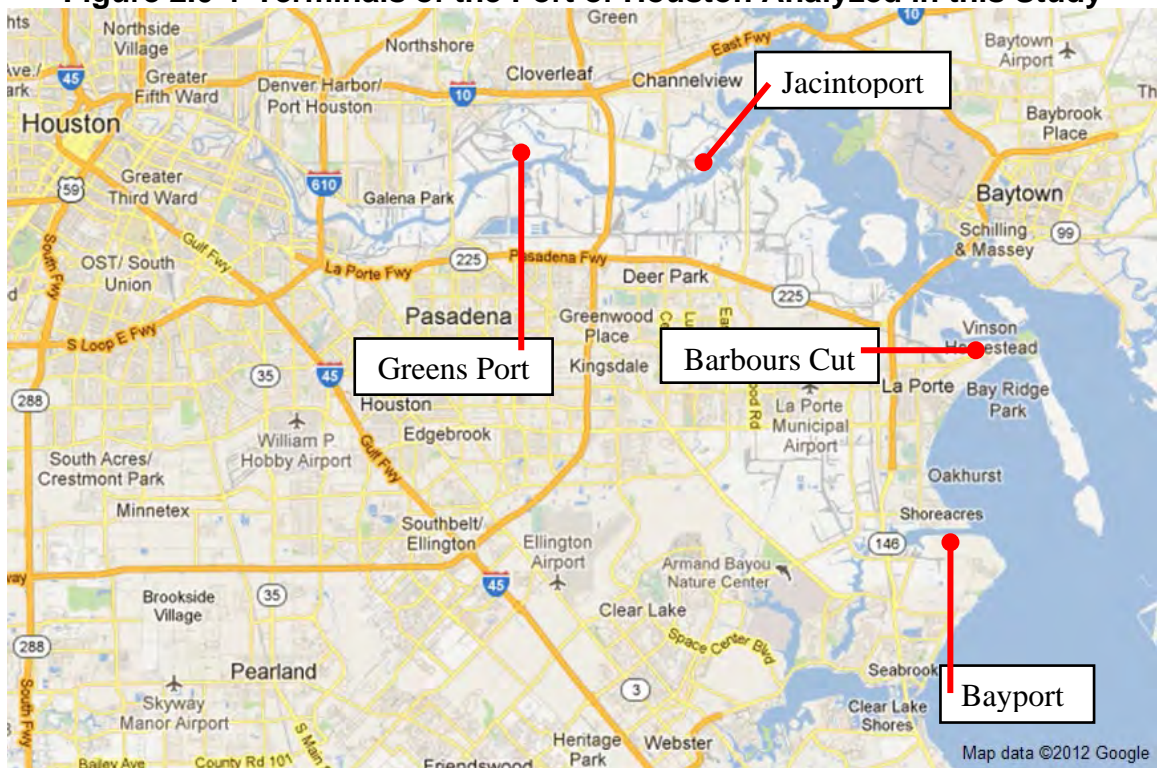
Information regarding the sample design, study preparation and execution and data processing and QC are presented in this report, along with complete study results. Analysis, interpretation of the results and implications are not presented here but will be the focus of future work.

2.0 Background

Drayage trucks operate in large numbers, with activity focused at a limited number of locations in an urban area, such as port terminals and intermodal facilities. These trucks are heavy duty trucks that are usually diesel-powered and are used to transport containers, bulk, and break-bulk goods to and from ports and intermodal rail yards to other locations.

These trucks conduct the majority of their travel on short-haul runs, repeatedly moving containers across fixed urban routes. Drayage truck activity in the Houston area is largely focused at the Port of Houston, particularly at the Barbours Cut Container Terminal, but also with activity at the Bayport Container Terminal, the Jacintoport General Cargo Terminal and Greens Port Industrial Park Terminal. A map of the locations of these four port terminals is shown in Figure 2.0-1.

Figure 2.0-1 Terminals of the Port of Houston Analyzed in this Study



Emissions from on-road drayage truck operations may be estimated using the default short-haul combination truck source type within the MOVES model. However, the activity and emissions occurring off-network within the port itself, which consists of

significantly more idle and low speed operation than on road (non-port) activity is not included in the MOVES model used in the SIP process.

To address this, EPA conducted this study to collect information required in order to create a new source category within the MOVES model for drayage activities. Toward this goal, EPA developed a partnership with TCEQ and H-GAC for collecting the information needed to improve the inventory in the SIP process. The focus of this partnership was placed on the Houston area because of the large emission inventory that exists due to all of the drayage truck operations that take place in and around the port terminals. In this study, references are made to “in-port” and “non-port” driving modes. In-port operation refers to vehicle operation within the secured and gated boundaries of the port terminals. All port terminals studied in this project were a part of the Port of Houston.

For this study, ERG and EPA, in partnership with TCEQ and H-GAC, collected information necessary to add drayage trucks as a source category in the MOVES model. The PEMS and PAMS devices were used to gather emissions and activity data. A secondary objective was for this study to serve as a template for local areas to expand default MOVES source categories to better reflect local conditions. This report describes the preparation for and execution of the data collection study and presents results from and lessons learned during the study.

3.0 Study Design

This section describes the key elements of the study design including the preliminary work performed in preparation for conducting this study. A comprehensive workplan and quality assurance project plan (QAPP) were developed outlining all steps in the study and a remote-sensing study was conducted under a prior work assignment in order to gather emissions information to be used in developing the truck sampling plan used in this study. Details of the sampling plan which is based on the remote sensing data are presented in Section 3.2. Section 3.3 contains a description of the strategy used for recruiting candidate trucks specified in the sampling plan.

3.1 Workplan and Quality Assurance Project Plan (QAPP) Development

Several iterations of the workplan and QAPP were developed during this study. SOPs, included by reference as appendices to the QAPP, were also created for all facets of fieldwork and were revised as needed throughout the study.

3.1.1 Development of the Workplan

With the goal of characterizing emissions and activity from drayage trucks operating in and around the Port of Houston, EPA and the ERG team developed a workplan that outlined the study design to collect emissions data on approximately 32 trucks and activity data on approximately 24 trucks during the study. This workplan was revised as needed throughout the study as work requirements changed.

3.1.2 Development of the QAPP

As part of the proposal effort for this contract, ERG tailored the corporate Quality Management Plan (QMP) into a guidance document which provides corporate quality guidelines for work under this contract. In addition, a QAPP was developed as part of this work assignment to provide project-specific guidelines covering all facets of the study. This QAPP was drafted prior to the commencement of project activities, and was revised during the project. As specified in the work assignment, the QAPP was based on the following two guidance documents:

- Requirements for Quality Assurance Project Plans. EPA QA/R-5. EPA/240/B-01/003. USEPA Office of Environmental Information. Washington, D.C. (Available at <http://www.epa.gov/quality/qs-docs/r5-final.pdf>).
- Guidance for Quality Assurance Project Plans. EPA QA/G-5. EPA/240/R-02/009. USEPA Office of Environmental Information. Washington, D.C. (Available at <http://www.epa.gov/quality/qs-docs/g5-final.pdf>).

The QAPP conforms to requirements specified in Task 2 of the performance work statement, and describes the following measures:

- standard procedures for calibration of all portable measurement instruments
- standard schedules for regular calibration of portable measurement instruments, and the maintenance of permanent and retrievable records of all calibrations
- procedures or decision rules for verifying proper operation of a portable measurement system when reviewing records of calibrations, spans, or zeroes
- maintenance of operating logs for all portable measurement systems
- standard operating procedures for equipment used to perform calibrations
- standard operating procedures for portable measurement instruments (PEMS/PAMS)
- procedures for sampling and recruitment of respondents
- procedures for data transfer, entry and management
- procedures for regular transfer of all data generated within this project to the Work Assignment Manager for review and audit
- procedures for the protection of respondent confidentiality and,
- data tracking and chain of custody procedures

A copy of the QAPP is provided in Appendix A of this report.

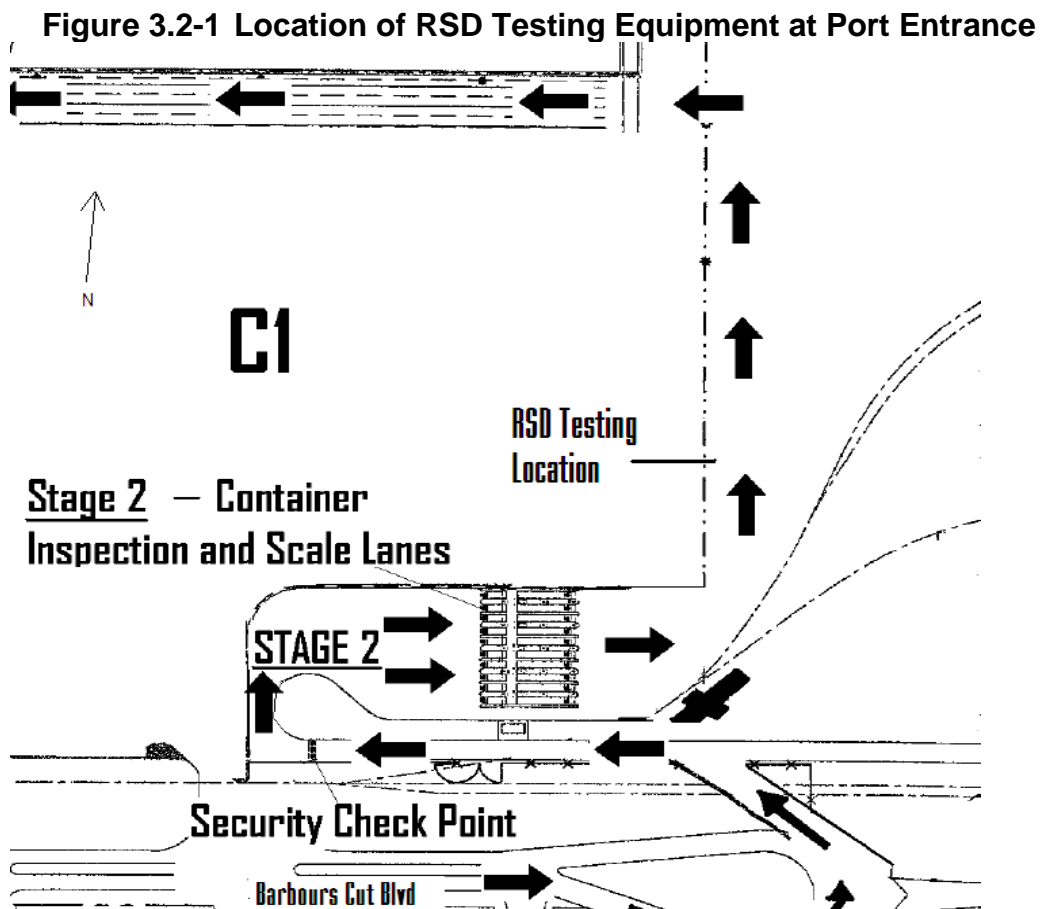
3.2 RSD Testing and Vehicle Sampling Plan Development

Remote sensing device (RSD) testing was performed by University of Denver personnel operating with ERG under a previous work assignment (WA 2-7 of this contract) in order to gather preliminary emissions information on the fleet which operates at the Barbours Cut Terminal. This RSD emissions information was used in developing the PEMS sampling plan for the study. Descriptions of RSD testing performed and the sampling plan which was developed follow.

3.2.1 RSD Testing and Development of the PEMS Sampling Plan

Under Work Assignment 2-7 of this contract, RSD testing was conducted From July 21 through July 31, 2009 at the Port of Houston's Barbours Cut Terminal to measure emissions of diesel drayage trucks as they entered the gate at the port. Gary Bishop from the University of

Denver set up the Fuel Efficiency Automobile Test (FEAT) RSD instrument to take measurements at the top of the exhaust stacks of each vehicle. Barriers were used to funnel trucks through a narrow chute so that the RSD instrument would take measurements on one vehicle at a time. Figure 3.2-1 shows the location of the RSD instrumentation just beyond the entrance of the Barbours Cut Terminal. Approximately 4500 HC, CO, NO_x¹, SO₂, NH₃ and opacity RSD measurements were collected for approximately 2000 trucks with Texas license plates over the 2-week test period. The instantaneous speed and acceleration of each vehicle were measured at the same time as the RSD beam block. As is customary, a video photo was taken of each truck's license plate.



The following RSD instruments were used to measure diesel exhaust from heavy duty diesel drayage trucks as they entered the Barbours Cut terminal.

FEAT 3002 developed by University of Denver

¹ In relation to RSD measurements described in this section, we make no distinction between NO_x and NO. We refer to these generically as NO_x.

- NDIR Component – Measures CO, CO2, HC, and percent opacity
- 2 UV Spectrometers – Measure NO, NO2, SO2, and NH3

ESP 4600 by ESP, Inc

- NDIR Component – Measures CO, CO2, HC,
- Dispersive UV Spectrometer – Measures NO, and Smoke factor

The measurement system required the use of scaffolding to position the RSD instrument and detector at a suitable height so that the system could “see” the drayage truck’s exhaust plume with its light detector. Figure 3.2-2 shows the RSD equipment immediately before a truck passes through the beam.

Figure 3.2-2 RSD Test Equipment



Emissions data was collected over a 9 day period for as many vehicles that entered or exited the port as possible in order to obtain an understanding of the gaseous and particulate emissions for trucks operating in and at the port. License plate information for each truck, which was photographically captured during the RSD test, was then transcribed and used to merge the

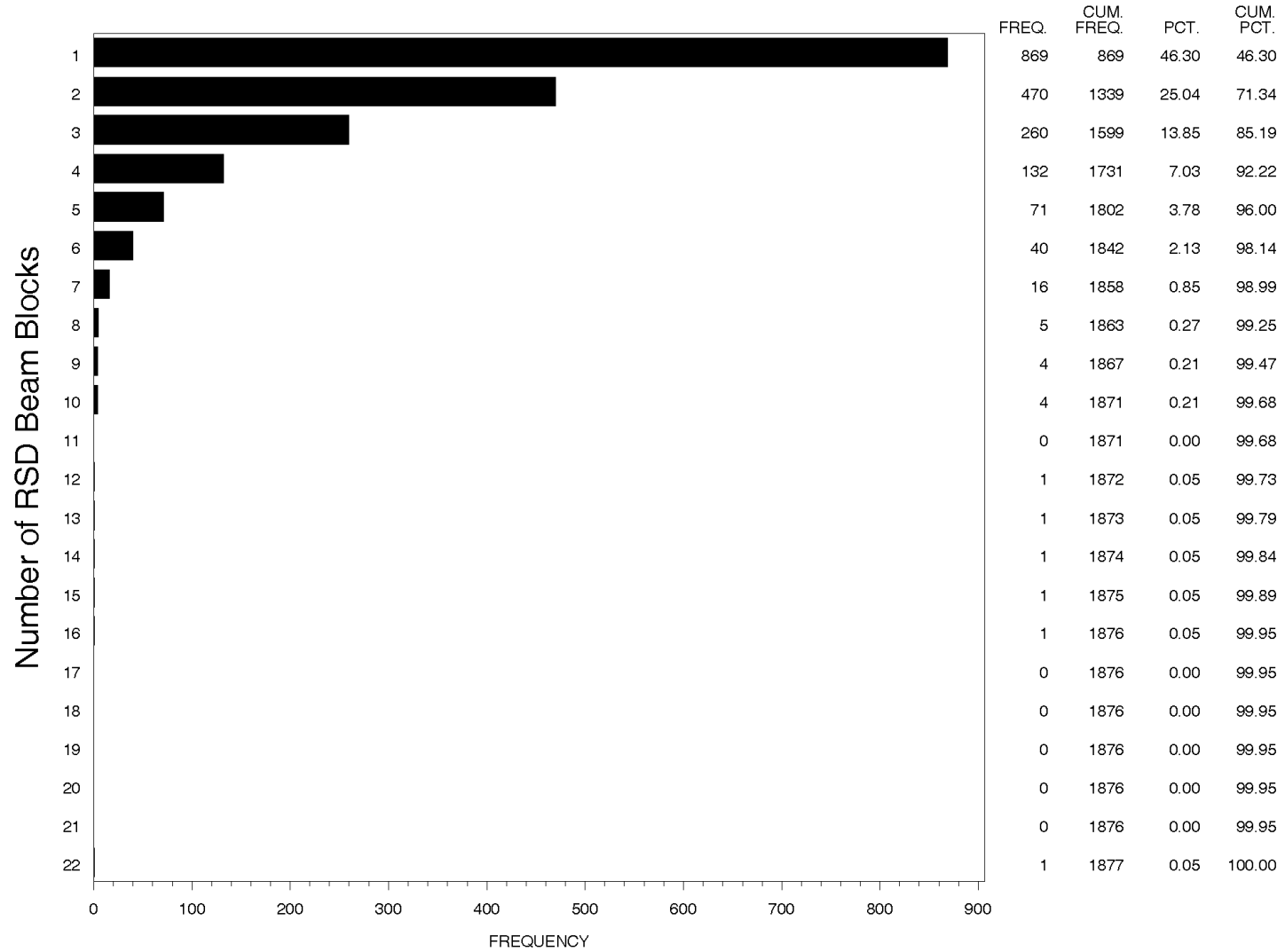
RSD data with the Texas Department of Transportation's (TxDOT's) heavy-duty vehicle registration data, which included information such as each vehicle's weight, model year, manufacturer, etc. In addition, data from the Barbour's Cut Terminal entry database was also procured and merged (via license plate), providing information on each truck's trailer chassis and container's ownership and weight as the truck was driven into the port.

Using this merged dataset, ERG developed a sampling strategy including sampling strata and participation targets, based on the anticipation that there would be six weeks of PEMS and four weeks of PAMS testing. The RSD emissions data within the dataset were grouped into emission level "bins" for the measured vehicle population. These RSD emission level bins were used as a stratification variable for selecting test vehicles, accounting for anticipated vehicle and operator variability and possible participation bias. The database was also analyzed to identify companies (also known as establishments in project terms) with the highest volume of traffic at the port in order to maximize vehicle selection opportunities within the those companies. These companies with high volumes of port traffic in many different emission level bins were known as "targeted establishments".

3.2.2 PEMS Sampling Plan Development

As previously described, data from each RSD beam block (measurement episode) was merged by transcribed license plate with Texas registration records, yielding the model year of each truck that was registered in Texas. After matching RSD emissions measurements with Texas registration data, there were successful registration matches for 4,032 of the RSD beam blocks on 1,877 vehicles. Vehicles were selected from these 1,877 vehicles for PEMS installations. Some vehicles had more than one RSD beam block. The distribution of the number of beam blocks per vehicle is shown in Figure 3.2-3.

Figure 3.2-3 Distribution of the Number of RSD Beam Blocks Per Vehicle in the Sample



3.2.2.1 Use of Model Years as a Stratification Variable

The distribution of model years of the RSD beam blocks for the 1,877 vehicles in the sample is shown in Figure 3.2-4. EPA chose five groups to stratify the model years. The model year strata and the counts of sample vehicles in each stratum are shown in Table 3.2-1.

Table 3.2-1 Count of Sample Vehicles in Each Model Year Bin

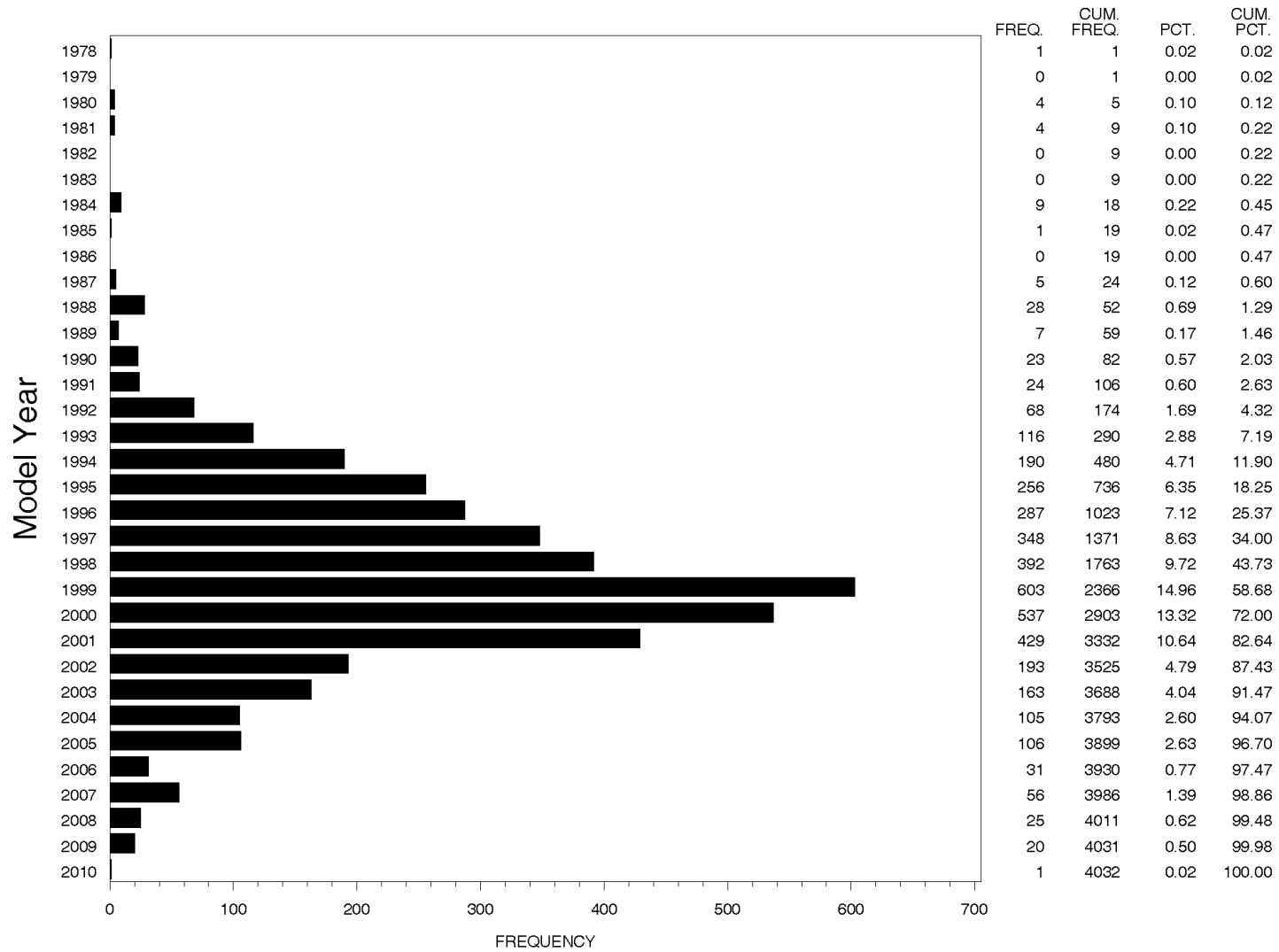
| Model Year Bin | Vehicle Count |
|-----------------------|----------------------|
| 1978-1993 | 122 |
| 1994-1997 | 494 |
| 1998-2003 | 1065 |
| 2004-2006 | 131 |
| 2007-2010 | 65 |

3.2.2.2 Use of RSD Emissions as a Stratification Variable

The two most important emissions for diesel engines are NO_x and particulate matter (PM). The RSD instrument measures instantaneous (0.5s) NO_x (as grams NO_x per gram fuel) and opacity for each beam block. Initial regressions of the effect of vehicle identity on opacity showed no significant difference among the 1,877 vehicles. On the other hand, vehicle identity had a strong influence on NO_x. Therefore, since NO_x is an important diesel emission and since the initial regressions indicated strong differences among the vehicles, we chose to stratify the sample set on RSD NO_x emissions, as well as model year group.

Figure 3.2-5 shows the distribution of measured RSD NO_x values for the dataset. Clearly, the distribution is positively skewed. However, before dividing the NO_x emissions into strata, it needed to be determined if, in addition to vehicle identity, NO_x was significantly influenced by vehicle speed, vehicle acceleration, vehicle specific power (VSP), or vehicle weight. If NO_x was significantly influenced by one or more of these independent variables, then a correction would be needed for those effects so that the NO_x emissions of the vehicles in the sample would all be on the same measurement condition basis. The intent of this correction would be to make sure that the vehicles were only stratified based on their NO_x emissions, not by the other factors such as speed or VSP, which could possibly affect the measured NO_x results and, therefore, stratification.

Figure 3.2-4 Distribution of Drayage Vehicle Model Years in the Sample



Ordinary least squares regression of the measured NOx values against vehicle identity (using license plate as a categorical variable), speed, acceleration, VSP, and weight can be used to determine which independent variables are important to NOx. However, for the regression results to be reliable, the errors of the NOx measurements need to be approximately homogeneous and approximately normal.²

The homogeneity of the NOx variance can be evaluated by looking at the variances (or standard deviations) for individual vehicles in the sample that received more than a single beam block. Figures 3.2-6 through 3.2-11 show plots of the standard deviation of the NOx readings vs. the mean of the NOx readings for vehicles with 2, 3, 4, 5, 6, and 7 replicate RSD readings³, respectively. All six plots use the same horizontal and vertical scales. Each point on a plot represents the results for a single drayage vehicle in the dataset.

Figures 3.2-6 through 3.2-11 indicate that the standard deviation of the NOx readings tends to be proportional to the mean NOx readings. This means that the NOx readings have an inhomogeneous variance. For the purposes of performing regressions, we would like the NOx variance to be more homogeneous, that is, more nearly constant at all levels of mean NOx values.

Now, consider Figures 3.2-12 through 3.2-17, which are for the same observations as Figures 3.2-6 through 3.2-11. For these new plots we have raised all NOx readings to the 0.2 power and then calculated the standard deviation and mean of the power-transformed values for

² Ordinary least squares is based on the assumption that the error variance is homogeneous, that is, the same under different conditions. Certain probability calculations discussed later are facilitated if, in addition, the response variable (NOx or a transformation thereof) is approximately normal. These probability calculations pertain to the use of the NOx values to identify strata to use as the basis of the stratified experimental design. Below, we discuss the determination of a transformation that achieved these objectives (homogeneous variance, normality of the transformed NOx values).

Another standard assumption of ordinary least squares is that the errors in the response variable be normally distributed. Again, the transformed NOx value is the response variable here. This assumption affects hypothesis tests to determine which of the variables listed above, vehicle identity, speed, acceleration, VSP, and weight, are significantly related to NOx. Briefly, certain effects of using a very large sample size (4,032) mitigate the concern about this normal assumption. While we do not want to digress into the full mathematical details, the effects of the large sample size to which we refer are loosely related to the central limit theorem. Further, the hypothesis tests are just a mechanism for identifying important variables and do not constitute the final results of the study. Thus, the normality of the errors in the y-variable is not a critical issue that merits a lot of attention in this particular study.

³ Plots for more than 7 replicates are not shown because so few vehicles had more than 7 replicates that a trend is not clear.

each vehicle⁴. Again, all six plots use the same horizontal and vertical scales, and each point on a plot represents the results for a single drayage vehicle in the dataset.

The plots in Figures 3.2-12 through 3.2-17 show that the standard deviations of the transformed NOx values are relatively independent of the mean of the transformed NOx values. The vertical scatter of the standard deviation in these plots is a consequence of random statistical fluctuations in the standard deviation of the NOx readings. The vertical scatter in each plot can be described by a transformation of the chi-square distribution.⁵

These results indicate that the 0.2-power transformation is appropriate for homogenizing the variance of the RSD NOx values in this dataset. Accordingly, regressions to determine the influences on NOx were performed on $\text{NOx}^{0.2}$. The regression of $\text{NOx}^{0.2}$ against just vehicle identifier (as a categorical variable) had an r^2 of 0.795 and a root mean square error⁶ of 0.1033. For the regression of $\text{NOx}^{0.2}$ against vehicle identifier plus speed, acceleration, VSP, and weight, only speed had a significant regression coefficient. The regression of $\text{NOx}^{0.2}$ against vehicle identifier plus speed had an r^2 of 0.830 and a root mean square error of 0.1002. Since the size of the speed coefficient was quite small, since adding speed to the regression caused the residual error to go down only a small amount (from 0.1033 to 0.1002), and since classifying a vehicle's RSD emissions characteristic is easier using just RSD emissions information (and not also using vehicle speed), we decided to drop speed from further consideration. In this case the influence of the independent variable (speed) is not very important even though it was statistically significant.

⁴ We chose the 0.2-power transformation because it caused the variances to be closest to homogeneous across the range of NOx values. Powers less than 0.2 were too strong, and powers greater than 0.2 were too weak.

Nevertheless, even with the 0.2-power transformation the variance is probably not exactly homogeneous.

⁵ While the full details are given in basic statistics books, the estimate of a standard deviation behaves like the square root of a chi-square-distributed variable, after accounting for certain constant factors that do not change the basic shape of the distribution.

⁶ The root mean square error is the standard deviation of the residuals left over from the regression.

Figure 3.2-6 Trend of Standard Deviation of NO_x with Mean of NO_x for Vehicles with 2 RSD Replicates

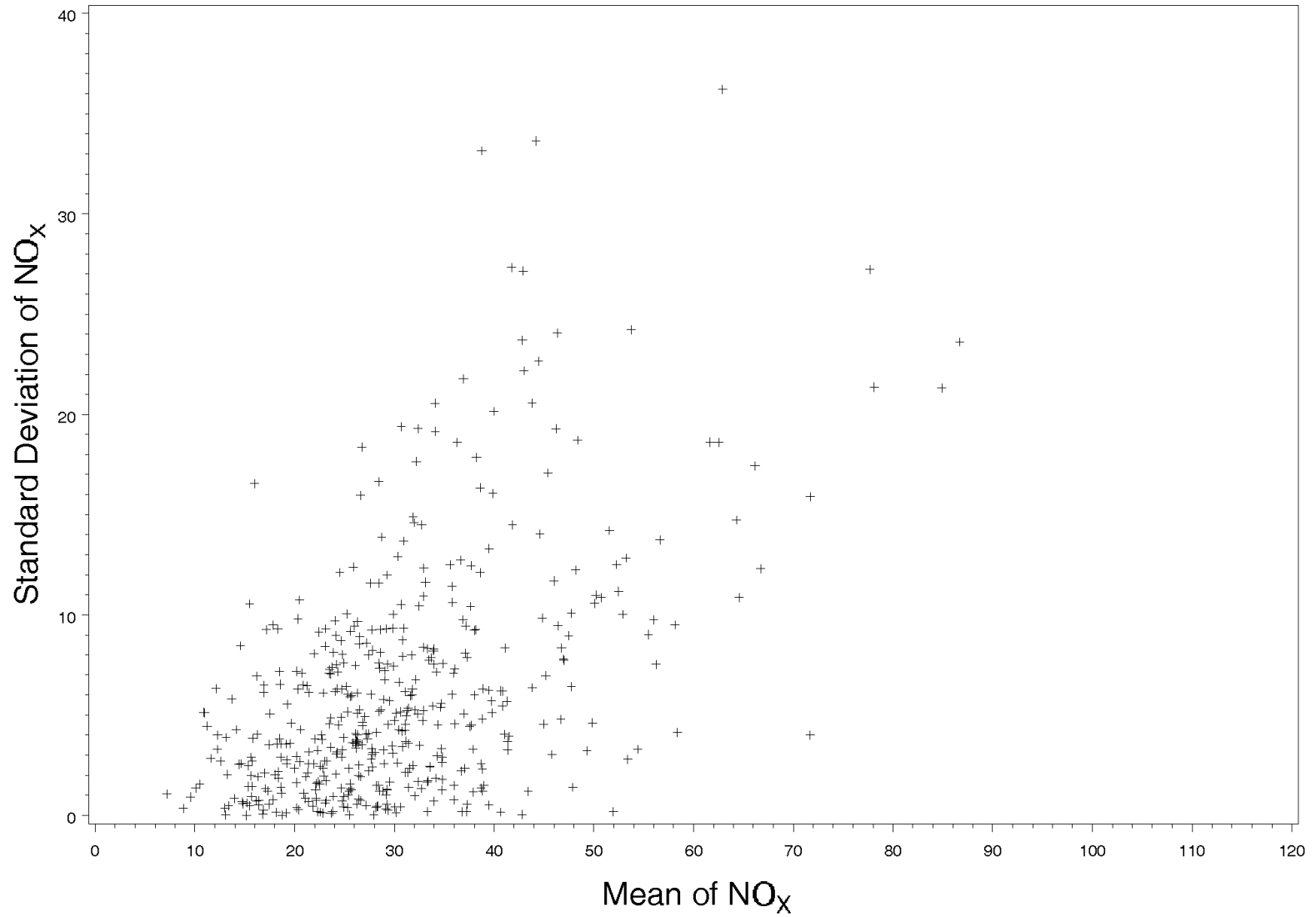


Figure 3.2-7 Trend of Standard Deviation of NO_x with Mean of NO_x for Vehicles with 3 RSD Replicates

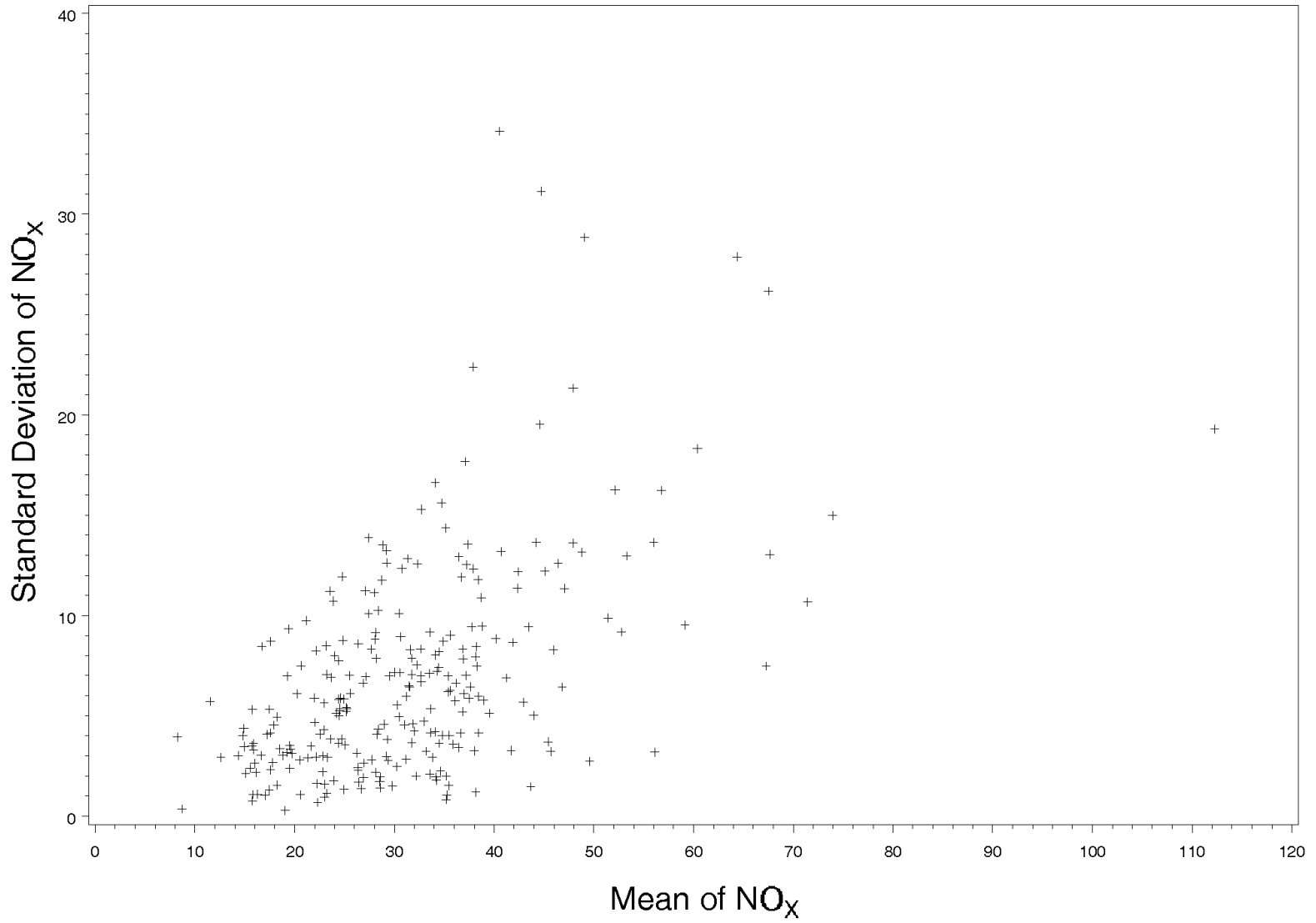


Figure 3.2-8 Trend of Standard Deviation of NO_x with Mean of NO_x for Vehicles with 4 RSD Replicates

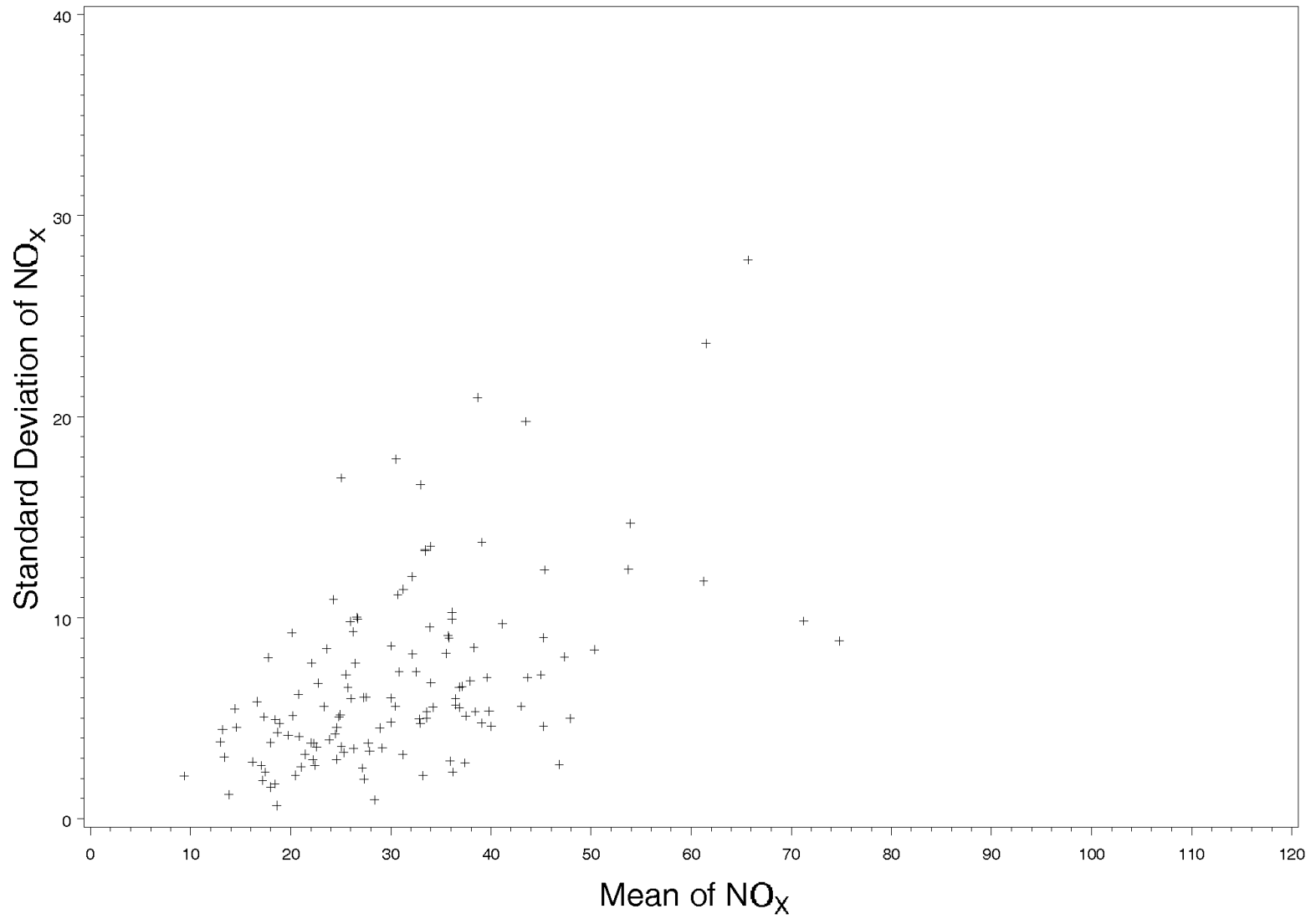


Figure 3.2-9 Trend of Standard Deviation of NO_x with Mean of NO_x for Vehicles with 5 RSD Replicates

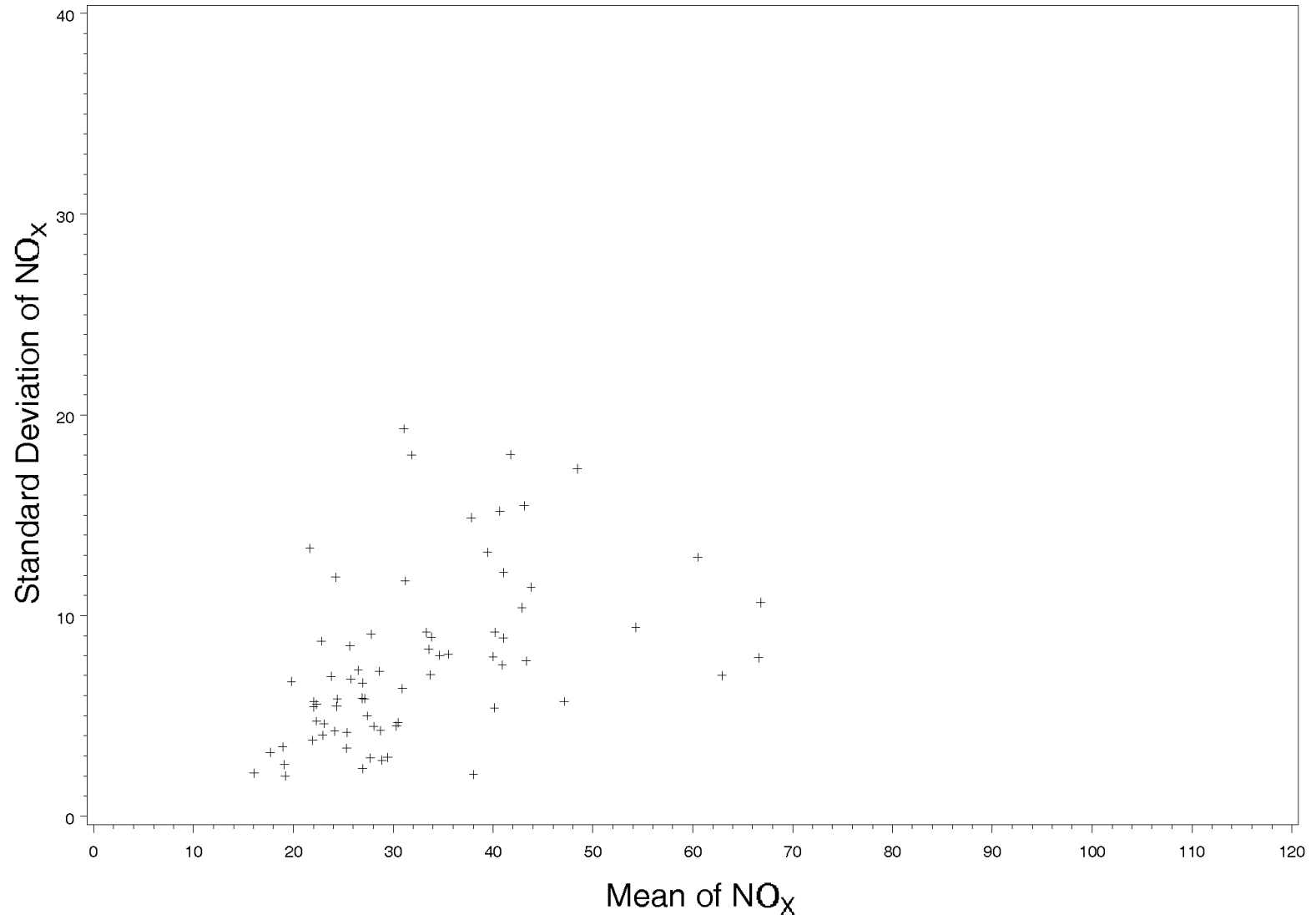


Figure 3.2-10 Trend of Standard Deviation of NO_x with Mean of NO_x for Vehicles with 6 RSD Replicates

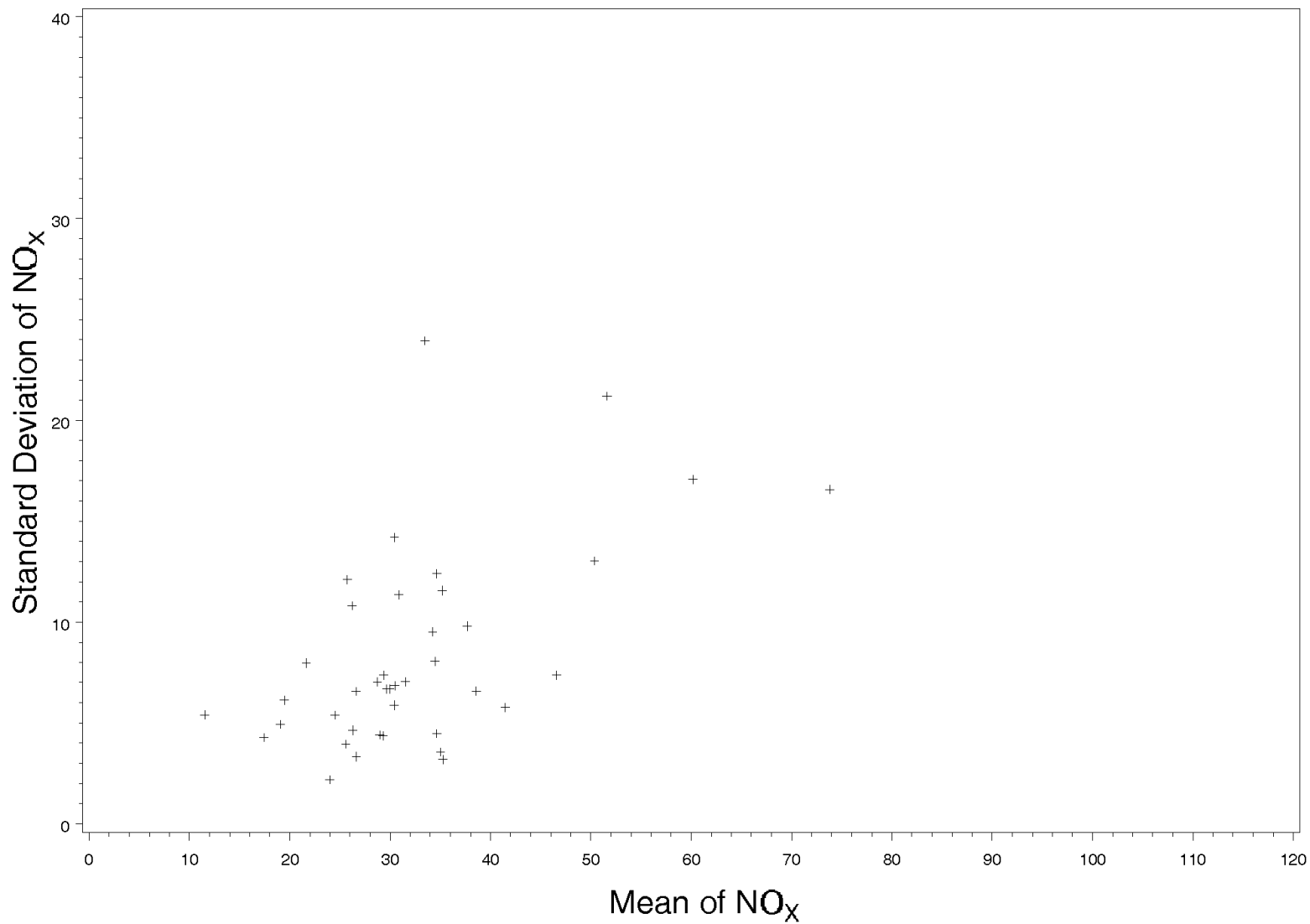


Figure 3.2-11 Trend of Standard Deviation of NO_x with Mean of NO_x for Vehicles with 7 RSD Replicates

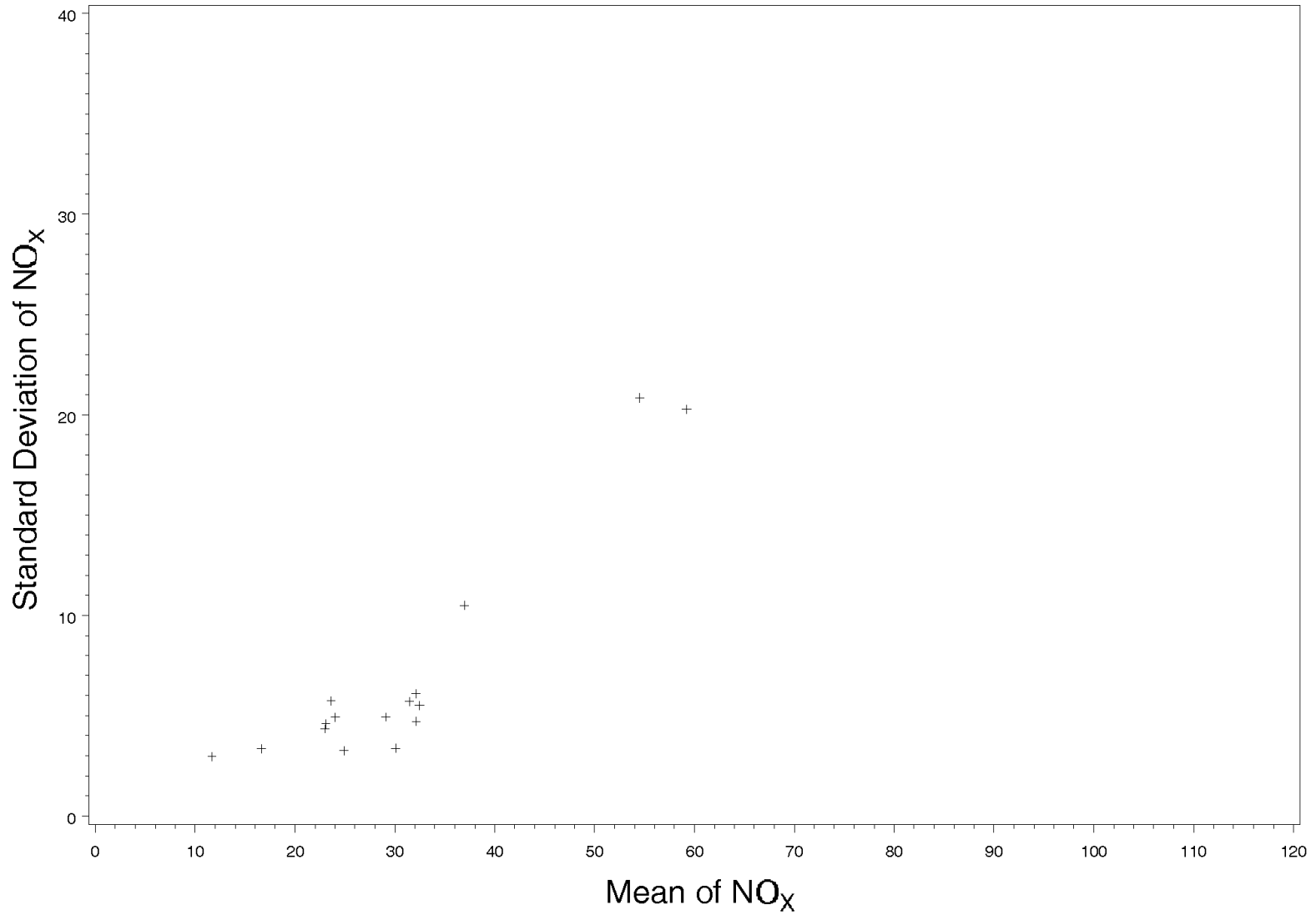


Figure 3.2-12 Trend of Standard Deviation of $\text{NO}_x^{0.2}$ with Mean of $\text{NO}_x^{0.2}$ for Vehicles with 2 Replicates

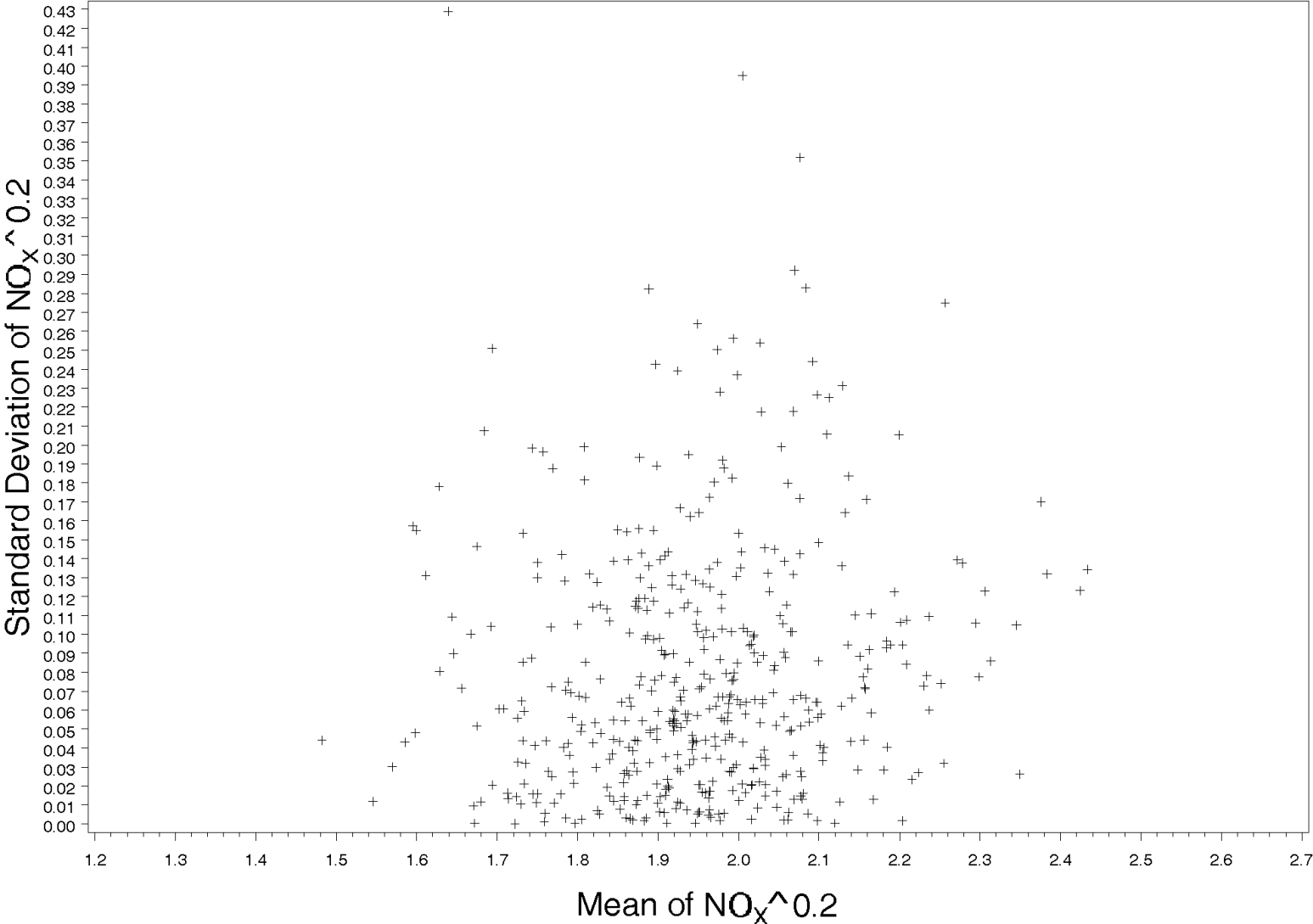


Figure 3.2-13 Trend of Standard Deviation of $\text{NO}_x^{0.2}$ with Mean of $\text{NO}_x^{0.2}$ for Vehicles with 3 Replicates

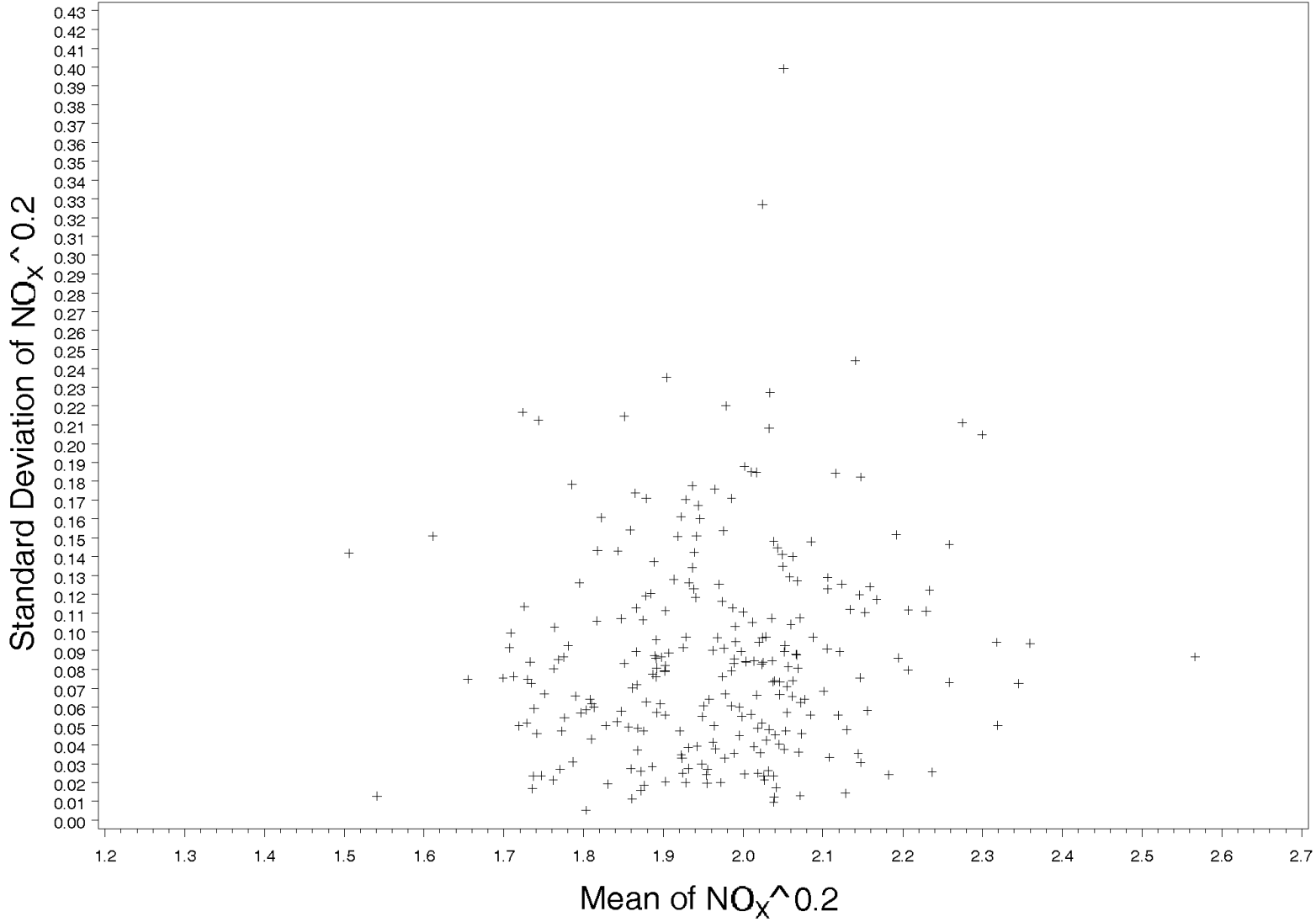


Figure 3.2-14 Trend of Standard Deviation of $\text{NO}_x^{0.2}$ with Mean of $\text{NO}_x^{0.2}$ for Vehicles with 4 Replicates

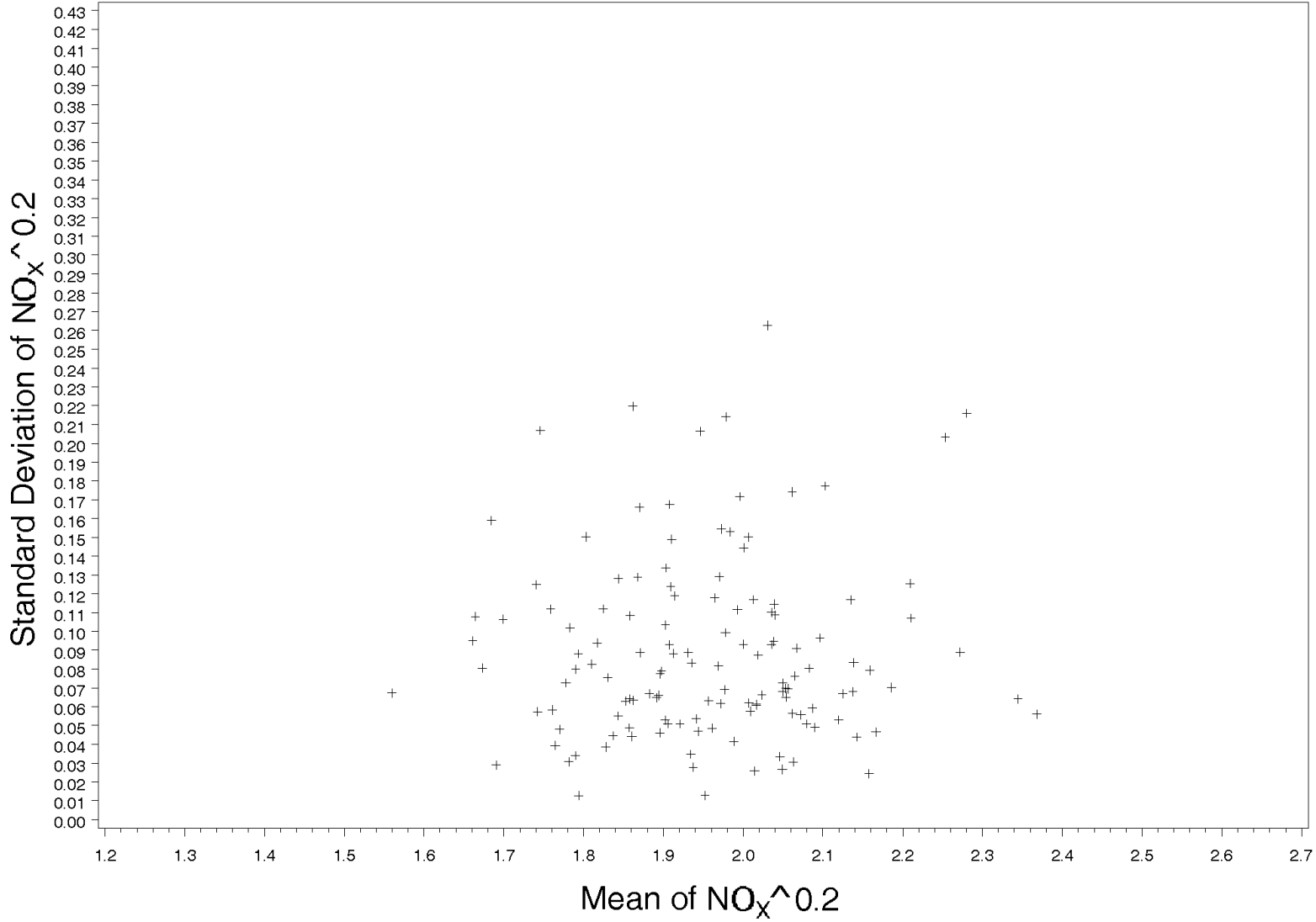


Figure 3.2-15 Trend of Standard Deviation of $\text{NO}_x^{0.2}$ with Mean of $\text{NO}_x^{0.2}$ for Vehicles with 5 Replicates

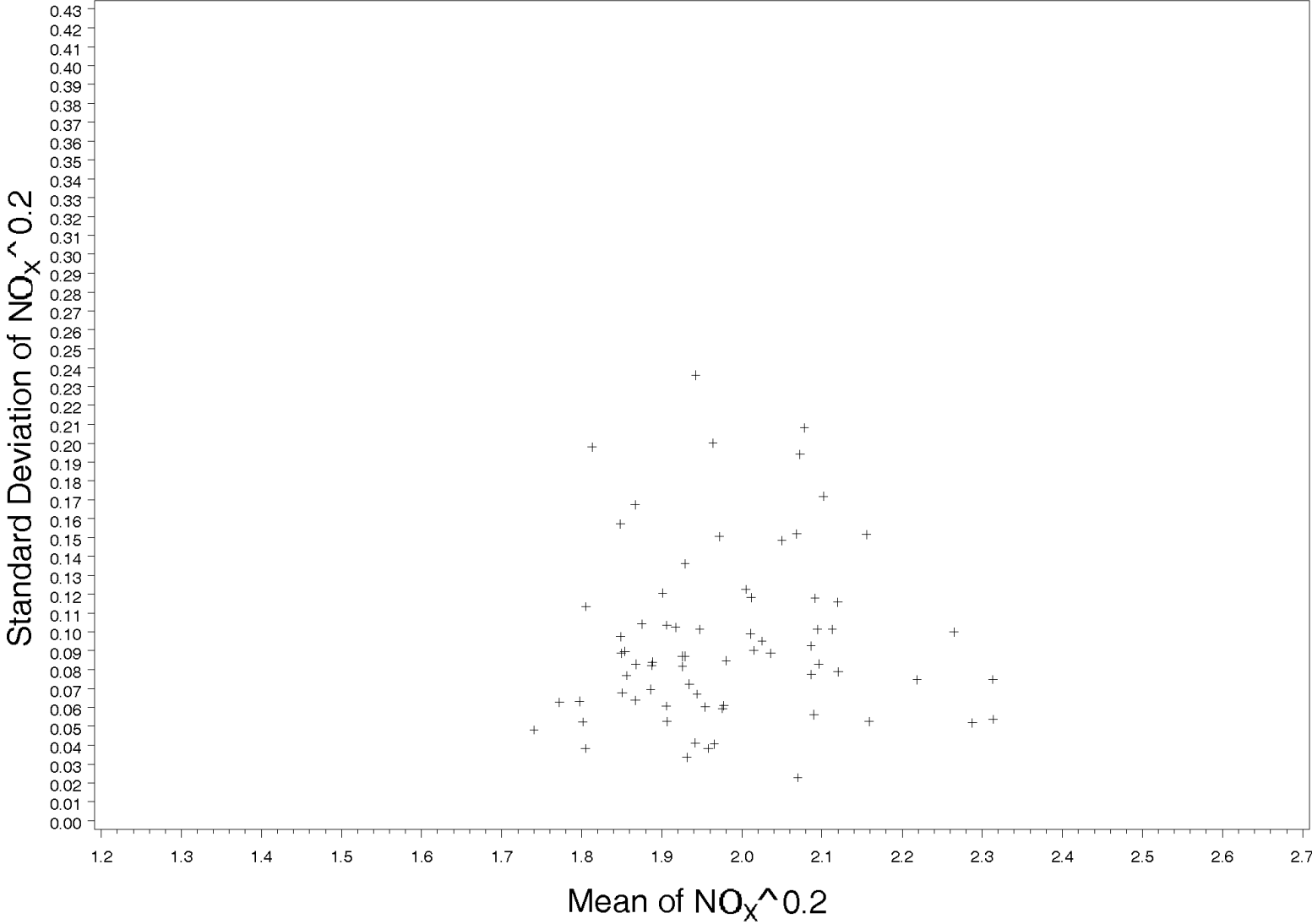


Figure 3.2-16 Trend of Standard Deviation of $\text{NO}_x^{0.2}$ with Mean of $\text{NO}_x^{0.2}$ for Vehicles with 6 Replicates

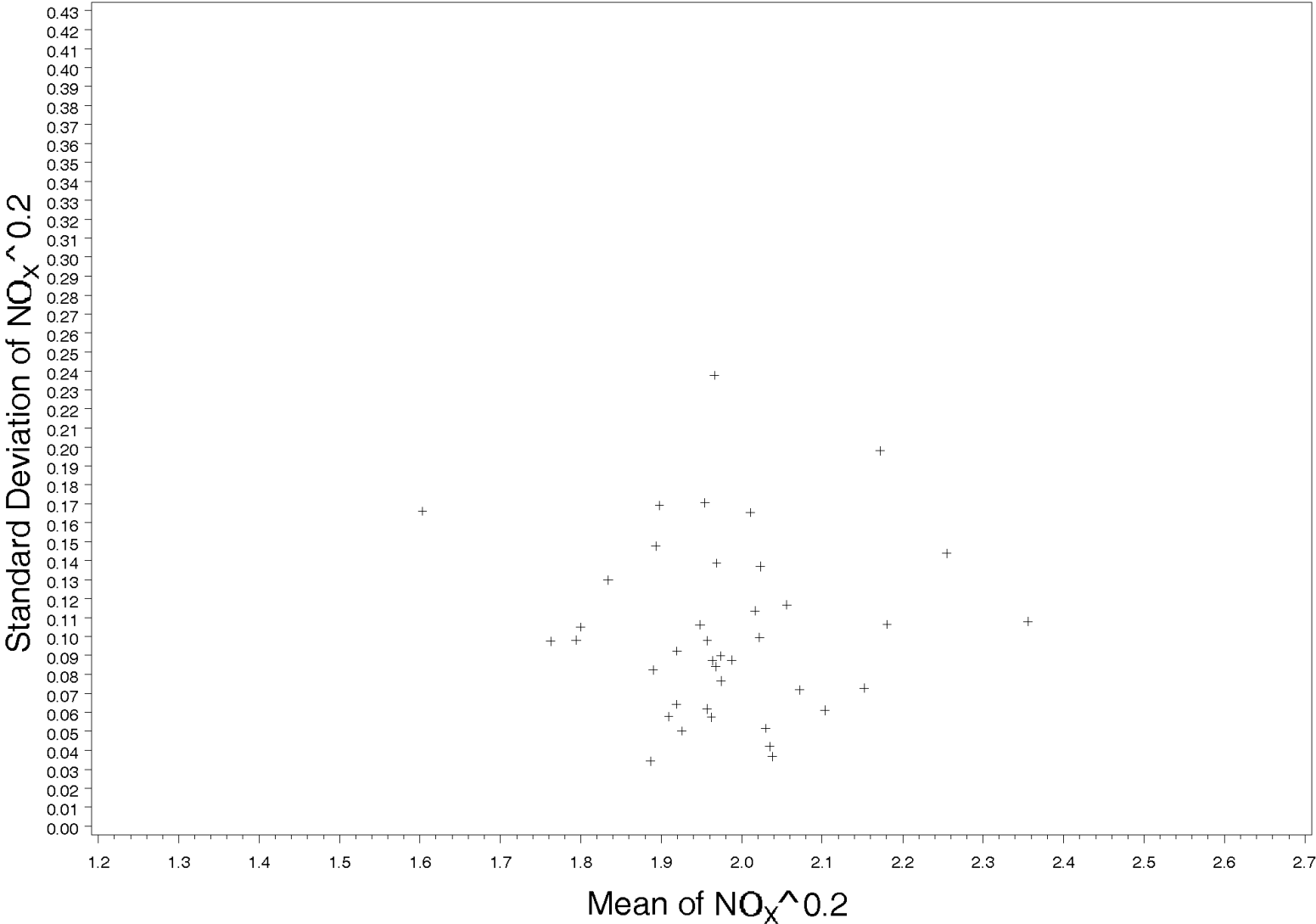
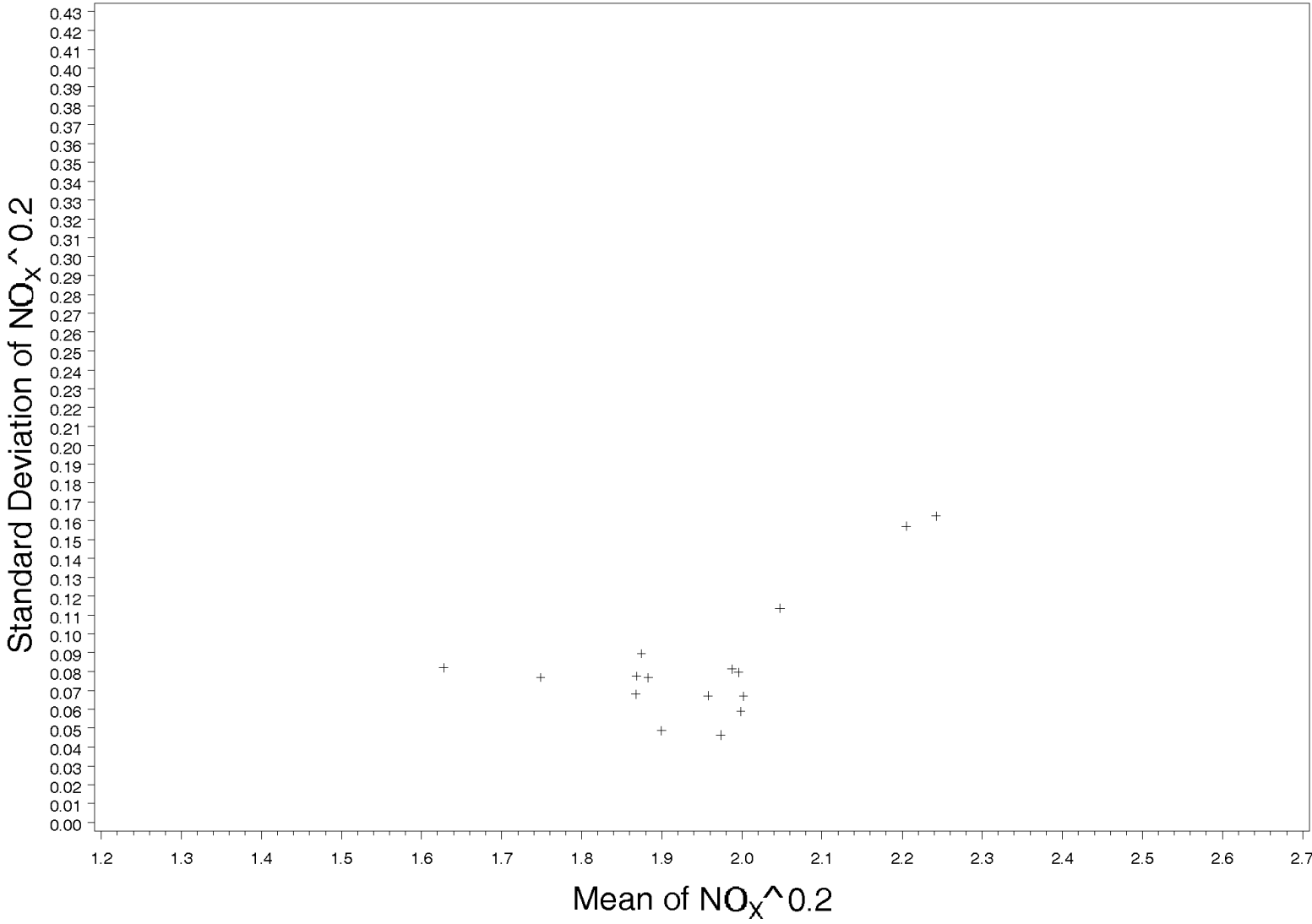


Figure 3.2-17 Trend of Standard Deviation of $\text{NO}_x^{0.2}$ with Mean of $\text{NO}_x^{0.2}$ for Vehicles with 7 Replicates



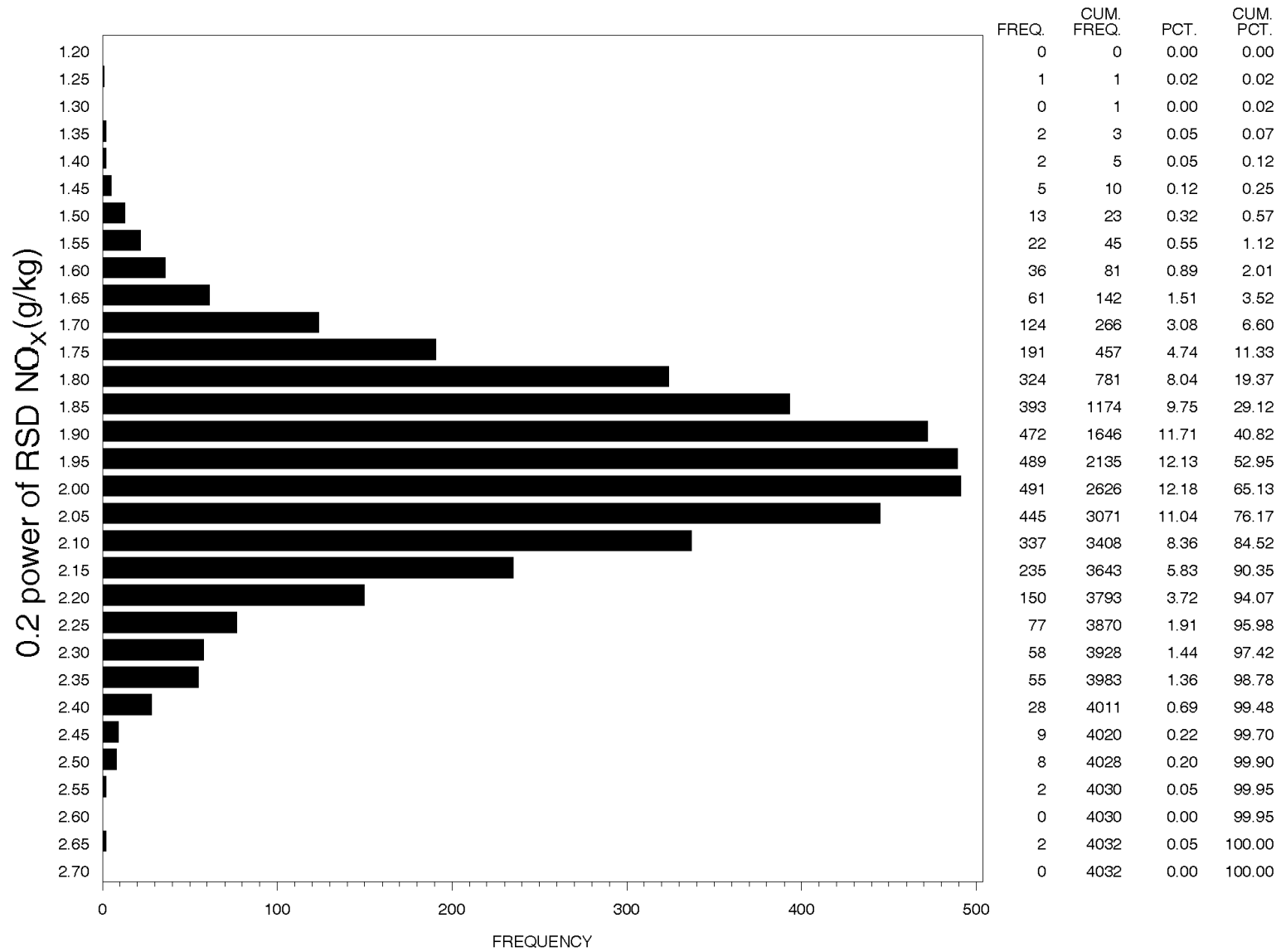
The distribution of the 4,032 $\text{NOx}^{0.2}$ values is shown in Figure 3.2-18. Comparison of Figure 3.2-18 with Figure 3.2-5 shows that the 0.2-power transformation also converts the skewed distribution of measured NOx values into a distribution that is more nearly normal.

Each vehicle in the dataset has a “true” NOx value that is characteristic of that vehicle. This “true” value is the actual average NOx concentration that would typically be emitted by the vehicle while in the operating mode that the RSD was set up to measure (ie. low speed acceleration). Some vehicles have characteristically low “true” NOx values; other vehicles have characteristically high “true” NOx values. The measured NOx values are not only a function of the “true” value, but also have contributions due to each truck’s day-to-day emissions variability and the RSD unit’s inherent measurement error. The intent of the stratification process was to stratify the vehicles according to their “true” NOx values rather than their NOx measurements. Another complicating factor is that some vehicles received only a single RSD measurement while others received up to 22 RSD measurements, as shown in Figure 3.2-3. Because of the differences in the number of RSDs received, a simple stratification by the mean RSD NOx would cause individual vehicles to be stratified in an inconsistent manner. Stratifying vehicles by the mean of the measurements would be reliable for the vehicles with many RSDs and unreliable for vehicles with a single RSD. ERG needed to find a method that could stratify the vehicles according to their “true” NOx value in a way that treated all vehicles similarly whether they received a single RSD or many RSDs.

Fortunately, because the 0.2-power transformation homogenizes (approximately) the variance of replicate RSD NOx measurements (see Figures 3.2-12 - 3.2-17) and normalizes (approximately) the distribution of the RSD NOx measurements (see Figure 3.2-18), analysis of the NOx data for the purposes of NOx stratification can overcome these two complications.

Each of the 4,032 measured $\text{NOx}^{0.2}$ values shown in Figure 3.2-18 can be thought of in terms of two sources of variation. The first source of variation characterizes the distribution of the “true” NOx values of the 1,877 vehicles in the dataset about the mean “true” NOx value for the dataset. The variance of this first source of variability is called var_{veh} . The second source of variation causes the RSD NOx measurements for an individual vehicle to scatter around the “true” NOx value for a given vehicle. The variance of this second source of variability is called var_{Meas} . The standard deviation of 0.1033 as calculated above is used to calculate the var_{Meas} value of 0.0107 ($=0.1033*0.1033$). The contributions to this second source of variability are the emissions variability of the vehicle and the variability of the RSD measurement. In order to perform the stratification, it is not necessary to separate these two contributions to the second source of variability.

Figure 3.2-18 Distribution of RSD NO_x^{0.2} Measured Values in the Sample



Since the distribution of measured $\text{NOx}^{0.2}$ values is influenced by the two sources of variation, its variance $\text{var}_{\text{Veh}+\text{Meas}}$ can be described in terms of var_{Veh} and var_{Meas} :

$$\text{var}_{\text{Veh}+\text{Meas}} = \text{var}_{\text{Veh}} + \text{var}_{\text{Meas}} \quad \text{Equation 1}$$

The equation describes how the distribution of the “true” $\text{NOx}^{0.2}$ values of the 1,877 vehicles is broadened by the variability in the NOx measurements for each vehicle to produce the slightly wider distribution of the measured NOx values for the dataset.

Thus, $\text{var}_{\text{Veh}+\text{Meas}}$ can be estimated from the distribution of measured $\text{NOx}^{0.2}$ values. But we need to be sure that the set of data on which $\text{var}_{\text{Veh}+\text{Meas}}$ is calculated has the same number of RSDs for each of the 1,877 vehicles. Otherwise, the calculated value of $\text{var}_{\text{Veh}+\text{Meas}}$ will be incorrect. Again, some vehicles have one RSD and others have up to 22 RSDs as shown in Figure 3.2-3. To include all of the 1,877 vehicles in the calculation, we used all of the RSDs for vehicles that had one RSD and a randomly selected one RSD for each vehicle that had more than one RSD. This subset of 1,877 RSD $\text{NOx}^{0.2}$ values had a mean of 1.965, a standard deviation of 0.1644, and a variance of 0.0270.⁷

Since the value of $\text{var}_{\text{Veh}+\text{Meas}}$ is 0.0270 and the value of var_{Meas} is 0.0107, then using Equation 1 the value of var_{Veh} is 0.0164 by difference. This is the variance of the “true” NOx emissions of the 1,877 vehicles in the dataset.⁸ If each of the 1,877 vehicles had a very large number of RSD measurements, the distribution of the vehicle mean $\text{NOx}^{0.2}$ values would have a standard deviation of $\text{SQRT}(0.0164)$. However, in our case of 4,032 measurements on the 1,877 vehicles, almost all vehicles have one or a few measurements. Because of this, the distribution of the mean vehicle values is broadened. Quantitatively, the standard deviation of the mean $\text{NOx}^{0.2}$ value for the distribution of mean vehicle $\text{NOx}^{0.2}$ values each having N replicates for each vehicle can be expressed in terms of var_{Veh} and var_{Meas} :

$$\text{Standard Deviation of the Mean } \text{NOx}^{0.2} = \text{SQRT} [\text{var}_{\text{Veh}} + (\text{var}_{\text{Meas}} / N)] \quad \text{Equation 2}$$

$$\begin{aligned} \text{where } \text{var}_{\text{Veh}} &= 0.0164 \\ \text{var}_{\text{Meas}} &= 0.0107 \\ N &= \text{the number of RSD } \text{NOx} \text{ replicates for the vehicle.} \end{aligned}$$

⁷ Calculation in /proj1/EPA_Drayage/StratificationPlan/rsd_variability2.sas

⁸ As an aside, the 0.2-power transformation of NOx values which approximately normalizes the variances, the determination of var_{Veh} of 0.0164, and the calculation of the sample mean $\text{NOx}^{0.2}$ value of 1.965, allows us to estimate the distribution of the “true” RSD NOx values for this set of 1,877 vehicles. Note that this distribution does not contain the influences of the RSD measurement error and vehicle NOx emissions variability that are present in the RSD measurements. The only exception to this statement is that the estimates of the parameters of the normal distribution are not absolutely free of the influence of measurement errors or random variations in vehicle emissions; because of the large sample size (1,877), this influence is small. The cumulative distribution is described by the Excel function $\text{NORMDIST}(\text{NOx}^{0.2}, 1.965, \text{SQRT}(0.0164), \text{TRUE})$, where NOx is the RSD-measured NOx in grams NOx per kilogram of fuel.

Equation 2 indicates that, as the number of replicates (N) increases, the standard deviation of the mean approaches $\text{SQRT}(0.0164)$.

The mean $\text{NOx}^{0.2}$ value and the standard deviation of the mean for a given vehicle can be used along with the mean $\text{NOx}^{0.2}$ value for the 1,877 vehicle sample (1.965) to calculate a z-value for the vehicle:

$$Z = \frac{\text{Vehicle's Mean NOx}^{0.2} - \text{Sample Mean NOx}^{0.2}}{\text{Standard Deviation of the Mean NOx}^{0.2}} \quad \text{Equation 3}$$

The z-value places the vehicle in the distribution of $\text{NOx}^{0.2}$ mean values for the 1,877 vehicles whether the vehicle in question received one RSD or many RSDs. Equation 3 properly calculates a z-value for each vehicle's mean $\text{NOx}^{0.2}$ emissions while taking into account the number of RSD replicates. Figure 3.2-19 shows the distribution of the z-values for the 1,877 vehicles in the dataset.

We want to assign each of the 1,877 vehicles to one of a few bins that are related to the general NOx level of the vehicle. Figure 3.2-19 shows that some vehicles tend to be low NOx emitters, some tend to be high NOx emitters, and most tend to be medium NOx emitters. For the purposes of characterizing the full range of NOx emitters we need to select vehicles across the range of NOx emissions. We also want to stratify the number of vehicles selected for second-by-second PEMS installations so that that data can be used to characterize low, medium, and high NOx emitters equally well. To do this stratification, we have arbitrarily chosen to use five NOx strata defined by the 2.5, 22.5, 77.5, and 97.5 percentile points in the z-value distribution. These points occur at z-values of -1.992, -0.726, +0.651, and +2.148.⁹ We name the NOx bins -2, -1, 0, +1, and +2. $\text{NOx Bin} = 0$ has the middle 55% of the z-values. $\text{NOx Bin} = -1$ has the vehicles with the next lower 20 % of the z-values and $\text{NOx Bin} = +1$ has the vehicles with the next higher 20 % of the z-values. $\text{NOx Bin} = -2$ has the vehicles with the lowest 2.5% of the z-values and $\text{NOx Bin} = +2$ has the vehicles with the highest 2.5% of the z-values.

The effect of the number of RSD replicates on the NOx bin assignments is shown in Figure 3.2-20. Each point in the plot represents one vehicle's number of RSD replicates and its mean $\text{NOx}^{0.2}$ value. As the number of replicates decreases, the lines separating the NOx bins get farther apart as the influence of var_{Meas} increases according to Equations 2 and 3. If the effect of the number of replicates had not been included in making bin assignments, many vehicles would have been incorrectly binned.

⁹ The z-values given were determined empirically from the distribution of points and differ somewhat from the theoretical, tabulated values (-1.96, -0.755, +0.755, and +1.96) for the z-distribution for the specified percentile points.

Figure 3.2-19 Distribution of Z-values for Vehicles in the Sample

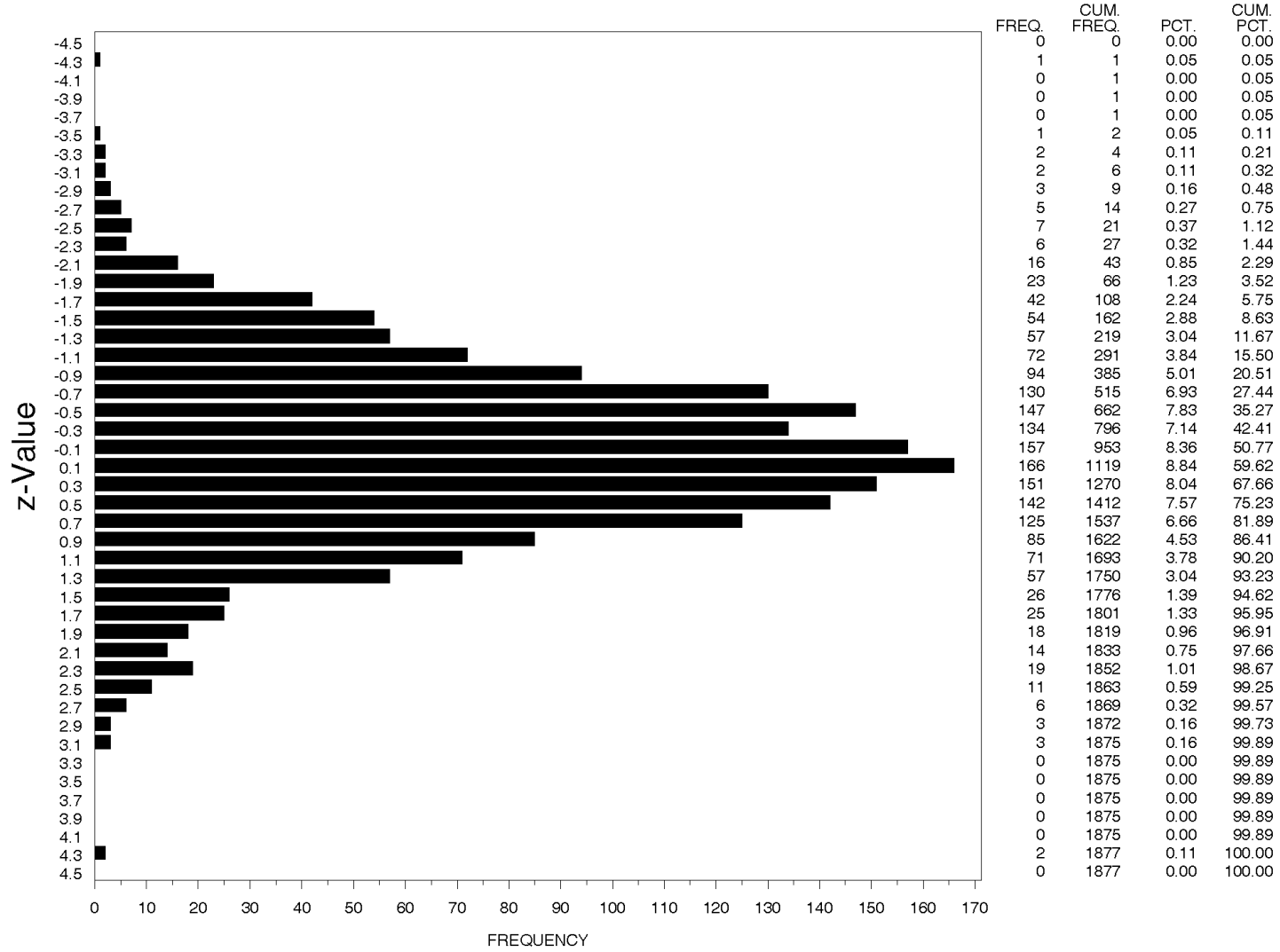
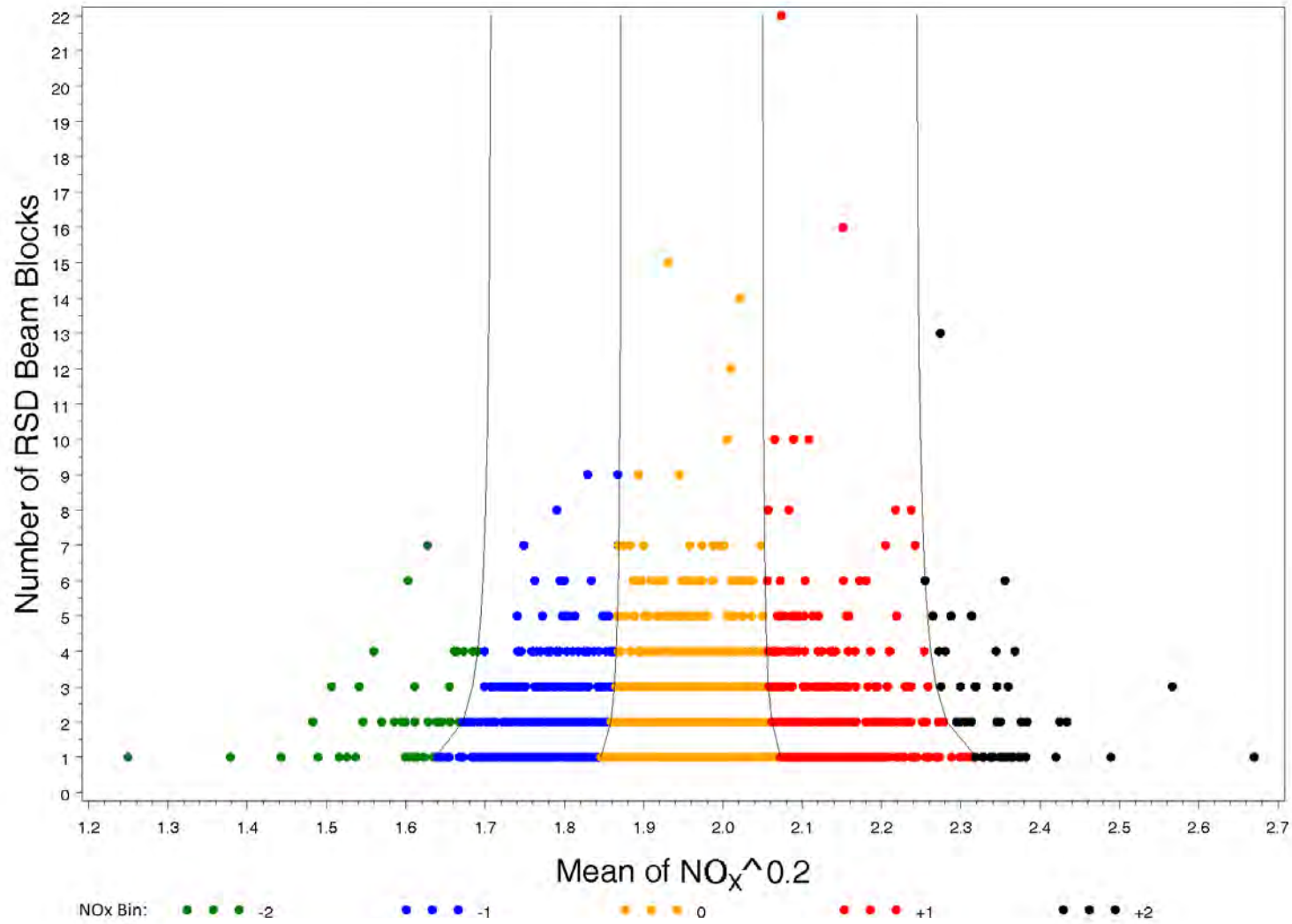


Figure 3.2-20 NOx Bin Assignment of Vehicles with Differing Numbers of RSD Replicates



3.2.2.3 Vehicle Allocation among 25 Strata Defined by Model Year Group and RSD NOx Bin

The discussions above defined five model year group strata and five RSD NOx strata. Together these make 25 overall strata. Allocation of the 1,877 vehicles in the dataset among these 25 strata is shown in Table 3.2-2. The allocation among the 5 model year group strata is shown by the totals in the right column. Allocation among the 5 NOx Bin strata is shown by the totals in the bottom row. Both of these totals show that many vehicles are assigned to the center strata and few vehicles assigned to the extreme strata.

Table 3.2-2 Allocation of the 1,877 Sampled Vehicles Among 25 Strata

| | NOx Bin | | | | | |
|------------------|-----------|------------|-------------|------------|-----------|--------------------|
| | -2 | -1 | 0 | 1 | 2 | |
| <i>1978-1993</i> | 8 | 23 | 69 | 20 | 2 | 122 |
| <i>1994-1997</i> | 1 | 34 | 259 | 175 | 25 | 494 |
| <i>1998-2003</i> | 11 | 234 | 636 | 168 | 16 | 1065 |
| <i>2004-2006</i> | 11 | 65 | 43 | 8 | 4 | 131 |
| <i>2007-2010</i> | 15 | 20 | 26 | 4 | 0 | 65 |
| | 46 | 376 | 1033 | 375 | 47 | <u>1877</u> |

EPA anticipated that PEMS needed to be installed on about 32 of the 1,877 vehicles. If 32 vehicles were selected randomly or proportionally from the 1,877 vehicles, a distribution of vehicles similar to that shown in Table 3.2-3 would result. The table shows that the selected vehicles would also be distributed among the model year strata and the NOx bin strata with large counts near the center and low counts near the extremes. Such an allocation does not provide a distribution of selected vehicles evenly across both model year group and NOx bin strata that would serve to well define the characteristics of vehicles in the extreme strata.

Table 3.2-3 Distribution of 32 Proportionally Selected Vehicles Among 25 Strata

| | NOx Bin | | | | | |
|------------------|------------|------------|-------------|------------|------------|------------------|
| | -2 | -1 | 0 | 1 | 2 | |
| <i>1978-1993</i> | 0.1 | 0.4 | 1.2 | 0.3 | 0.0 | 2.1 |
| <i>1994-1997</i> | 0.0 | 0.6 | 4.4 | 3.0 | 0.4 | 8.4 |
| <i>1998-2003</i> | 0.2 | 4.0 | 10.8 | 2.9 | 0.3 | 18.2 |
| <i>2004-2006</i> | 0.2 | 1.1 | 0.7 | 0.1 | 0.1 | 2.2 |
| <i>2007-2010</i> | 0.3 | 0.3 | 0.4 | 0.1 | 0.0 | 1.1 |
| | 0.8 | 6.4 | 17.6 | 6.4 | 0.8 | <u>32</u> |

A more desirable allocation of 32 vehicles is shown in Table 3.2-4. In this allocation, most of the 25 strata have at least one vehicle, and a few of the strata have more than one vehicle. The total row and total columns show that, while center strata still contain more vehicles than the extreme strata, vehicles are more evenly distributed among each of the 5 levels of model year group and NOx bin strata. The result is that all of the model year group and NOx bin strata have at least 4 vehicles in each stratum level. Analysis of second-by-second data from this allocation of vehicles will be better able to quantify the effects of model year group and NOx bin effects, as well as interactions between them.

Table 3.2-4 A Stratified Distribution of 32 Selected Vehicles Among 25 Strata

| | NOx Bin | | | | | |
|------------------|----------|----------|----------|----------|----------|------------------|
| | -2 | -1 | 0 | 1 | 2 | |
| <i>1978-1993</i> | 1 | 1 | 1 | 1 | 1 | 5 |
| <i>1994-1997</i> | 0 | 1 | 2 | 2 | 2 | 7 |
| <i>1998-2003</i> | 1 | 2 | 3 | 2 | 2 | 10 |
| <i>2004-2006</i> | 1 | 2 | 1 | 1 | 1 | 6 |
| <i>2007-2010</i> | 1 | 1 | 1 | 1 | 0 | 4 |
| | 4 | 7 | 8 | 7 | 6 | <u>32</u> |

3.2.2.4 Vehicle Selection and Ranking Within Each of the 25 Strata

The number of vehicles shown in Table 3.2-4 in each of the 25 strata need to be selected from each of the vehicles assigned to the 25 strata shown in Table 3.2-2. For example, Table 3.2-4 shows that 3 participants are needed from the stratum defined by Model Year Group =1998-2003 and NOx Bin = 0. Table 3.2-2 shows that that stratum contains 636 vehicles. Which of those 636 vehicles should be chosen? This question needs to be answered for each stratum.

Clearly, practical considerations are important in choosing the vehicles to solicit for PEMS installations. For example, the vehicle’s owner must be willing to participate in the study by allowing access to the vehicle. Beyond the practical considerations, two statistical issues are important for the 32 vehicles in the instrumented vehicle set:

1) **Probability that a vehicle is actually in the assigned NOx Bin** – Proper NOx bin assignment is important because we want to be reasonably certain that all 32 vehicles are in the assigned bins so that we can be certain that all levels of NOx are covered by the 32 vehicles. Because a vehicle’s RSD measurements were used to assign a vehicle to a NOx bin, if a vehicle was RSDed many times, it is more likely to actually be in the NOx bin to which it was assigned. The probability that a vehicle’s characteristic NOx measurement is actually in the assigned NOx

bin depends on the mean $\text{NOx}^{0.2}$ value, the number of RSDs that were used to calculate that mean value, and the lower and upper $\text{NOx}^{0.2}$ values that define the bin to which the vehicle was assigned.¹⁰ The probabilities range from about 50% to 100%.¹¹

2) Frequency that the vehicle will drive in the Port of Houston during the period of instrumentation – After going through the expense of instrumenting a vehicle, we want to be reasonably certain that the vehicle will drive in one of the port terminals so that the second-by-second emissions and activity data that is collected will be representative of driving in the port. We want to give higher selection priority to vehicles that were observed by RSD to drive many times in the port. The logic is that vehicles that were seen many times in the port during the RSD data collection phase will be more likely to be seen in the port during the vehicle instrumentation phase of the study. We need to be aware, however, that the methods that trucking companies use to assign vehicles to jobs may spoil the connection between past and future port activity levels of individual vehicles. Also, because selection priority was given to vehicles that appeared to service the port more frequently, care needs to be taken if the emissions results of this study are to be applied to the heavy-duty truck fleet as a whole. It is possible that duty cycle differences for drayage trucks could bias emissions results as compared to the entire on-road fleet.

To assist in soliciting trucking companies and vehicles for participation in the project, we need a prioritized list of vehicles within each of the 25 strata. Companies that have vehicles at the top of each of the 25 lists could be solicited first. Ideally, vehicles that have both a high probability of being in the NOx bin and that had received a large number of RSDs would be given high priority. Because a ranking cannot be made simultaneously on two variables, we arbitrarily ranked vehicles within each stratum by the product of the fractional probability of being in the assigned NOx bin and the square root of the number of RSDs received. While many ranking variables could be devised, this ranking variable produced rankings that appeared to have acceptable trade-offs between the probability of being in the assigned NOx bin and the number of RSDs received.

Prioritized lists for each of the 25 strata are provided in Appendix B, RSD Stratification Results. Vehicles were targeted for recruitment based on these prioritized rankings.

¹⁰ The probability that a vehicle is actually in the assigned bin is calculated in `/proj1/EPA_Drayage/StratificationPlan/rsd_variability2.sas`.

¹¹ For example, if a vehicle's mean value is very near a bin border, then the probability of being in the assigned bin will be about 50% since the vehicle might actually be in the lower bin or the upper bin. If a vehicle received many RSDs, then the probability of being in the assigned bin will be near 100% since the uncertainty in the mean value will be low.

3.2.3 PAMS Sampling Plan

The same pool of vehicles used for PEMS testing was intended for use in selecting trucks for PAMS installations (each vehicle was to be one of the 1877 RSD-screened trucks). However, since activity was not generally expected to be correlated to emissions, RSD emission measurements were not used in determining PAMS selection bins.

In order to efficiently obtain a stratified random sample of activity measurements which would yield a representative sample of fleet activity under our current sampling structure, the same model year groupings used for PEMS selections were used for PAMS selections. In order to roughly match the model year distribution of the 1877 RSD-screened vehicles, the team attempted to recruit vehicles in such a way as to yield PAMS model year bin sizes which were proportional to the percentage of trucks in each of the five model year bins shown in Table 3.2-1. An effort was also made to conduct PEMS and PAMS testing on some of the same vehicles, providing a "matched" set of emissions and activity data.

3.3 Develop Recruiting Plan

ERG worked with EPA, TCEQ, H-GAC and the Port of Houston Authority in developing the strategy and materials for recruiting for this study. Informational brochures and “frequently asked questions” sheets were developed by EPA, along with TCEQ and the H-GAC, which provided basic information about the project to potential candidates. These brochures, which were produced in English and Spanish, are shown in Appendix C.

The recruitment approach was tailored to maximize the yield from the recruited establishments. Companies which operated at the port were selected for recruitment based on their count of “high value” trucks from the list of 1877 trucks which had received RSD measurements. Value in this context pertained to the probability that a truck was within its assigned NO_x bin and also the likelihood that the truck would be driven to Barbours Cut Terminal over the instrumentation period, as described in Section 3.2.2.4. As shown in Appendix B, each truck was assigned a bin ranking based on these probabilities. Companies with the largest counts of candidate trucks were generally recruited by H-GAC, TCEQ and PHA personnel through telephone calls and emailing of the Appendix C brochures and FAQs. During the initial phone calls, a brief description of the study and incentive program was provided, and interested participants were asked to contact ERG after review of the literature and consideration

of the program. In order to increase the “callback” response rate, an additional incentive was offered to the contact in each company who initiated a phone call to ERG.

The overall study’s incentive program was as follows:

- \$100 to each individual who responded to ERG as a result of initial contact by PHA, H-GAC or TCEQ personnel
- \$1000 (one-time incentive) to each company whose fleet trucks or independent owner/operator trucks contracted to that company received one or more PEMS and/or PAMS tests
- \$500 for each truck that was successfully PEMS tested, paid to the independent owner/operator (if independently owned) or the company that owned the fleet (if it was a fleet truck)
- \$250 for each truck that was successfully PAMS tested, paid to the independent owner/operator (if independently owned) or the company that owned the fleet (if it was a fleet truck)

4.0 Study Preparation

4.1 Acquiring and Preparing PEMS and PAMS Equipment

EPA provided all equipment used in this study. Sections 4.1.1 and 4.1.2 describe preparation of the PEMS and PAMS equipment prior to the study. Section 4.2 describes mockups which were conducted prior to fieldwork in order to prepare the equipment and team for PEMS and PAMS installations. After equipment preparations and installation and operation mockups were completed, recruiting began, followed by preliminary onsite visits, as described in Sections 4.3 and 4.4.

4.1.1 PEMS Preparation

For emissions measurements, the PEMS team used SEMTECH-DS PEMS manufactured by Sensors, Inc. and provided by the EPA for use during this work assignment.

The SEMTECH-DS system collected the following information in one-second intervals, as specified in the work assignment:

- engine speed (revolutions per minute, rpm),
- oxygen concentration in the exhaust stream ($[O_2]$, percent by weight, wt%),
- carbon-dioxide concentration in the exhaust stream ($[CO_2]$, percent by weight, wt%),
- oxides of nitrogen concentration in the exhaust stream ($[NO_x]$, parts per million, ppm),
- carbon monoxide concentration in the exhaust stream ($[CO]$, percent by weight, wt%)
- total hydrocarbon concentration in the exhaust stream, ($[THC]$ parts per million, ppm)
- aggregate particulate matter by gravimetric methods (g),
- ambient temperature (EC),
- exhaust temperature (EC),
- exhaust mass flow rate (via the Sensors EFM)
- relative humidity (%), and
- barometric pressure (kilo-Pascals, kPa).
- date/time stamp.

The following derived measurements were also provided for all emissions measurements:

- exhaust flow volume (adjusted to standard temperature and pressure, cu. ft/min (scfm)),
- fuel flow volume (g/sec, gal/sec),
- carbon dioxide emission rate (g/sec, g/kg fuel),
- pollutant emission rates for NO_x , CO, THC, and PM, (g/sec, g/gal).

In addition to the above measured and derived values, information from each truck's electronic network (either SAE J1708 or SAE J1939 compliant) was collected, when available. The SEMTECH DS' default parameter lists for each protocol were used. Information was collected on a second-by-second basis within the same datafile as the emissions measurements.

Exhaust flow rate measurements were made using Sensors' five-inch diameter exhaust flowmeters (EFMs). Although flowmeters of different diameters were available, all trucks tested during the study had five inch diameter exhaust systems and sufficient exhaust flow volume for use of five-inch flowmeters.

Gravimetric filter sampling was accomplished using Sensors' micro-proportional sampling system (MPS) and their 3-chamber gravimetric filter sampler provided by EPA. Gravimetric PM samples were collected on 47mm Teflon filters housed in the gravimetric filter sampling unit which was heated to 1065 specifications. For gravimetric sampling, an air compressor and flow control unit was used to provide filtered dilution air to the MPS, and a rotary vane vacuum pump was used for drawing the filter sample. Compressed nitrogen (from a compressed gas cylinder) was used for activating gravimetric filter solenoids. A SEMTECH-DS adjacent to a 3-chamber gravimetric PM sampler is shown Figure 4.1-1.

Figure 4.1-1 SEMTECH-DS (left) and 3-Chamber Gravimetric PM Sampler (right)



A small air compressor and filtration unit was used to operate the MPS and to automatically back-purge the EFM pressure lines at specified intervals. This air compressor, mounted inside the MPS chamber, operated on A/C power provided by a Honda portable generator. Ambient air scrubbed with carbon and particulate filters was supplied by the system to allow zero-calibrations to be performed during periods of non-sampling.

Heated sample lines were used to transport exhaust sample from the exhaust flow meter to the SEMTECH-DS, and also from the MPS chamber to the gravimetric filter sampler.

Rigid and flexible stainless steel tubing was custom fabricated for each installation to allow transport of the complete exhaust flow from the truck's exhaust pipe to the EFM mounted

on the top of the MPS rack. Tubing was mounted to the outlet of the muffler, in place of the tailpipe stack, after the tailpipe stack had been removed. Joints were secured with welds, ring clamps and band clamps, as appropriate. This entire system is shown installed on a custom rack on the back of a city bus in Figure 4.1-2. Although components were mounted differently in the drayage study (the SEMTECH-DS and the 3-chamber gravimetric sampler were generally housed inside the cab in the drayage study), Figure 4.1-2 shows the layout of all components relative to one another. In this figure, the SEMTECH-DS is mounted in an environmental chamber, which was not necessary in the drayage study since the SEMTECH-DS was placed inside each truck's cab.

For trucks for which only gaseous samples were taken (no PM measurements), the exhaust flowmeter was typically mounted directly to the outlet of the exhaust muffler, and a heated sample line was then used to transport the sample from the exhaust flowmeter to the SEMTECH-DS, as shown in Figure 4.1-3. Also shown in this figure is the FID fuel cylinder (mounted on the frame platform next to the generator) and the CL-size calibration and zero gas cylinders (on the concrete) used for calibrating the SEMTECH-DS prior to (and after) each test.

Filter sampling could be controlled automatically by way of an integral timer, through user-input conditions such as elapsed times at certain operating conditions, or manually through laptop-interface control. For this study, all gravimetric filter switching was performed manually by field personnel riding along with the driver and test equipment, and was primarily based on operations (whether operations were within or outside of the port and idle vs. non-idle operation).

EPA provided multiple backups for all critical components, including the SEMTECH-DS, the 3-chamber gravimetric filter sampler, the MPS sampling system, exhaust flowmeters, heated sample lines and generators. Raw materials and hardware required for multiple daily installations were also maintained in overstock in EPA's onsite trailer. Spare parts for repairing and maintaining all equipment were also maintained on-site (in EPA's trailer) throughout the study.

Equipment was inventoried, acquired as needed and prepared for several months prior to the start of this study. A verification of performance of gaseous measurement equipment, exhaust flow measurement equipment and proportional sampling equipment with standards listed in 40 CFR 1065 was performed by Sensors and EPA staff on all equipment to be used in the study.

Figure 4.1-2 Gaseous and PM System Used in Drayage Study

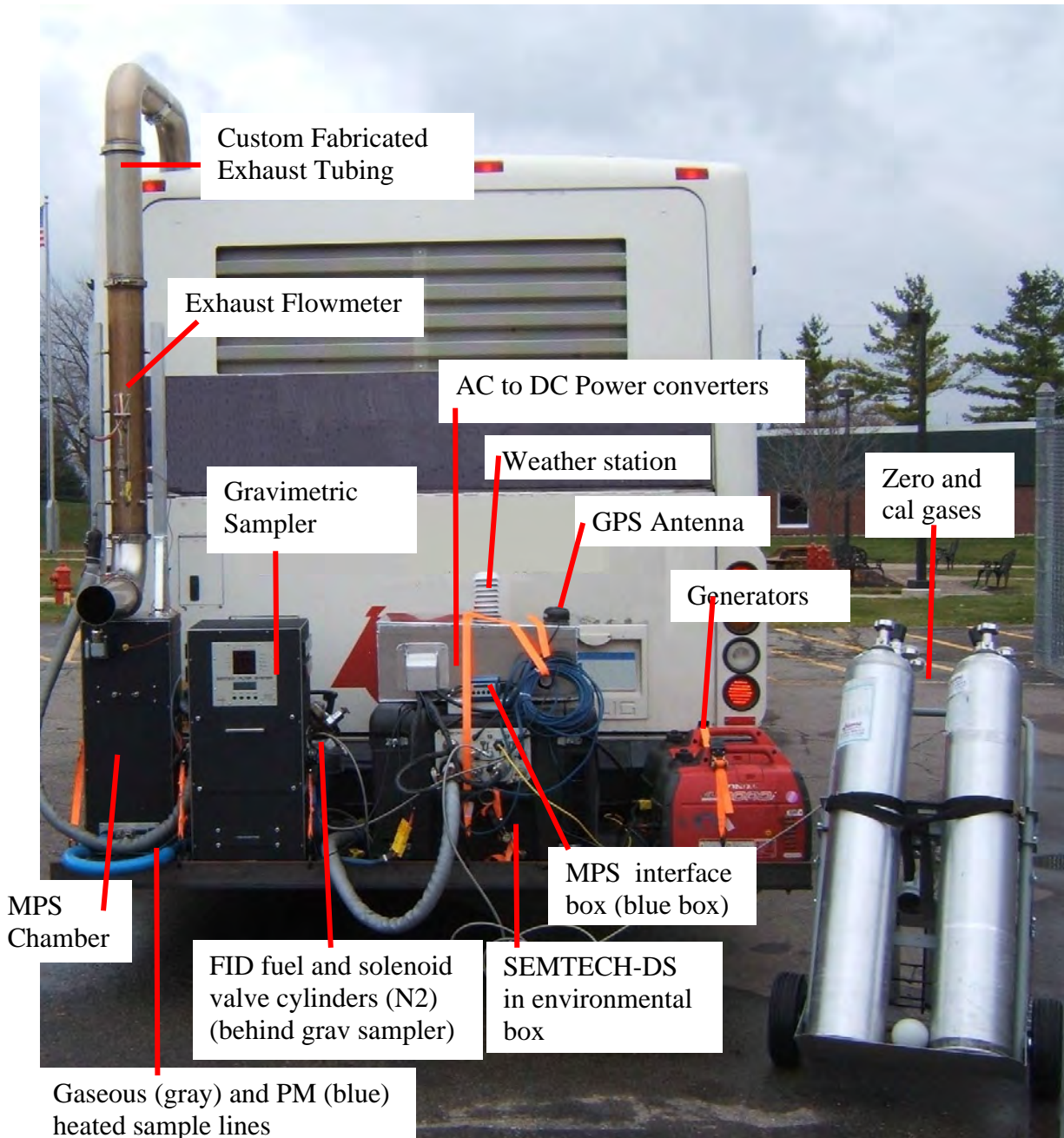


Figure 4.1-3 Gaseous-only Flowmeter Mounting on Drayage Truck



Due to space constraints, equipment for this study would have to be mounted in various locations in trucks, including inside the cab (SEMTECH, power supply and gravimetric sampler) and outside of the cab (MPS chamber, exhaust flowmeter, pressurized cylinders and generator). Consequently, equipment and materials beyond that which had been required for prior studies were needed to allow installations on drayage trucks. The space constraints of drayage truck installations also prevented the PEMS rack, which was used to house the MPS, gravimetric sampler, power supply and SEMTECH-DS as a single unit during the recently completed nonroad diesel equipment field study, from being used during this program.

EPA acquired and equipped a 24-foot Haulmark trailer for PEMS field operations support. All materials and tools necessary for PEMS and PAMS testing and equipment repairs were maintained in this trailer. Specially-designed racks and workbenches stored all equipment, tools, materials and consumables and provided working space for field personnel. A specialized rack with dedicated ventilation in the front upper deck of the trailer provided storage of various compressed gas cylinders to be used in the study.

EPA fabricated mounting hardware, including platforms for the SEMTECH-DS and gravimetric sampler and retention cylinders for the nitrogen and FID-fuel gas bottles, prior to the study. Electrical harnesses with appropriate 6-pin and 9-pin Deutsch connectors and associated communication boxes for collection of SAE J1708 and SAE J1939 data from truck ECUs were acquired. Transport tubing, elbows, adapters and clamps were acquired to accommodate all expected exhaust configurations. Hand tools, power tools such as air wrenches, an onboard air compressor, band saw, welder and other equipment were also acquired for use in the study and stored in EPA's trailer.

All consumables and hardware necessary for conducting the study, such as gravimetric filters and shipping materials, PEMS system filters, exhaust tubing and clamps, quick-release power cables and other electrical harnesses and auxiliary sensors with their associated harnesses, fuel sample bottles, calibration and audit gases and FID fuel and nitrogen gas cylinders and associated high-pressure gas transport lines were also prepared as needed.

A preliminary inventory of PEMS and PAMS equipment which was used during study preparation is provided in Appendix D.

PEMS SOPs, developed during the prior nonroad field study, were revised for the new equipment hardware and software requirements for this work assignment. A copy of the PEMS SOPs used in this study is provided in Appendix E.

4.1.2 PAMS Preparation

Prior to the start of fieldwork, ERG evaluated the PAMS available from the previous nonroad study to determine which candidates would be suitable for use in this study. The six Isaac V8 sealed dataloggers were selected for use in this study. An Isaac datalogger is shown in Figure 4.1-4.

Isaac harnesses with 6-pin and 9-pin Deutsch connectors were acquired in order to allow collection of SAE J1708 and SAE J1939 data from truck ECUs. Garmin GPS antennas were purchased both from Isaac and from Garmin to allow incorporation of GPS in the PAMS data. EPA technologists installed Isaac harness connectors on the GPS antennas purchased from Garmin to allow them to be used with the Isaac dataloggers. Additional wiring harnesses for operating the Isaac dataloggers from switched ignition power and optical RPM collection sensors were also acquired, and brackets were fabricated to allow Isaac optical sensors to be used with the Caterpillar magnetic-base RPM sensor mounts used in the prior nonroad field study.

Figure 4.1-4 Isaac datalogger used Drayage study



The functionality of all six Isaac units was verified prior to field deployment for this study. Repairs and software reconfigurations were performed as needed to ensure all units had maximum memory capacity, 3-dimensional accelerometer data collection capabilities and complete SAE J1708 and SAE J1939 ECU data collection capabilities. Configuration files were created for the three anticipated types of installations (RPM collection via optical pickup, SAE J1708 data collection and SAE J1939 data collection). Desired data parameters for both J1708 and J1939 communication protocols were defined in each of the configuration files to ensure consistent and complete data collection for each PAMS installation. These units were configured to record engine on and off status, associated date and time stamps, engine speed, location and speed (via GPS) and ECU data on a 1-Hz basis. Datalogger electrical current usage rates in active and standby mode under different installation configurations were measured in order to

ensure the drayage truck batteries would not be drained after a period of extended inactivity with the dataloggers installed.

PAMS SOPs were also developed based on the current equipment and installation procedures. A copy of these SOPs is provided in Appendix F.

4.2 PEMS and PAMS Mockups in Ann Arbor

After preliminary PEMS and PAMS equipment inventory and preparation had taken place, the ERG team assisted EPA in performing “mockup” testing of the PEMS and Isaac PAMS equipment on Class 8 trucks similar to those to be tested during the study. Three mockup sessions were performed at EPA’s National Vehicle and Fuel Emissions Laboratory in Ann Arbor, Michigan. These mockups served several purposes, including:

- Installation team members were able to increase their familiarity with the equipment configuration and software operation for this study
- Team members practiced installations on vehicles similar to those being targeted for this study, which allowed the team to determine the best procedures and locations for installations of various equipment to help optimize efficiency and safety,
- Team members were given an opportunity to confirm the PEMS equipment was of a size and configuration which would allow it to be installed in the desired locations on targeted test vehicles, and make necessary hardware changes to reduce the chances of installation problems
- The mockups allowed identification and acquisition or development of any equipment, tools, materials, or procedures which would be needed for field activities
- The mockups allowed identification of previously unforeseen technical or logistical challenges, with sufficient time for resolving these issues prior to field activities
- Team members were able to ensure all equipment was operating as expected and ensure any systematic data quality issues were resolved, and
- The mockups allowed the need for all consumables necessary for field testing to be identified in time for the consumables to be sourced and acquired

Sensors’, Inc. personnel assisted with PEMS equipment support and provided training for operation of the PEMS and PM sampling equipment to EPA and ERG staff during the mockups. Many of the PEMS and PAMS preparation tasks described in Section 4.1 were performed during the mockups.

4.3 Conduct Recruiting

Prior to the start of recruiting, ERG attended and presented an overview of the drayage study at H-GAC’s September 22, 2009 Federal Diesel Grant Program presentation held at the Port of Houston. This provided ERG and H-GAC an opportunity to inform candidates about the

upcoming study and to gauge interest and obtain feedback to be used to tailor recruiting for the study.

Several weeks prior to the beginning of fieldwork, ERG worked with the EPA and project partners to begin recruiting candidate drayage trucks. As described in Section 3.3, ERG identified the “target” trucking companies with the highest number of “high value” trucks from the sample of 1877 RSD-tested trucks. Preliminary contact information for these companies was obtained through Internet research and these company lists (with the preliminary contact information) was provided to PHA, H-GAC and TCEQ staff, who attempted to contact each company, using the preliminary contact information provided by ERG or their own contact information (i.e., acquaintances and the H-GAC Air Quality Database records). Once a successful contact was made with each company, the PHA, H-GAC or TCEQ staff member briefly explained the study and incentive program and offered to provide additional information (the recruiting materials shown in Appendix C). The company contact was asked to consider the study and contact ERG if they had interest in participating. Recruiting began several weeks prior to the start of fieldwork and was performed throughout the majority of the study. Table 4.3-1 provides a summary of recruiting performed.

Table 4.3-1 Summary of Drayage Recruiting, by Companies

| Recruiting Parameter | Count of Companies |
|--|---------------------------|
| Total number of companies from pool of 1877 RSD'd trucks | 178 |
| Companies for which recruitment attempts were made (by PHA, H-GAC, and TCEQ personnel) | 86 |
| Companies for which no recruitment attempts were made (companies with lowest number of “high value” trucks in the RSD sample pool) | 92 |
| Companies who called ERG to inquire about study participation | 12 |
| <i>Of companies who called ERG, those who agreed to testing, but didn't have any eligible trucks available</i> | 2 |
| <i>Of companies who called ERG, those who agreed to testing, but were not ultimately involved in the study because all their trucks were in full bins or because the study concluded before they were needed</i> | 2 |
| <i>Of companies who called ERG, those who ultimately refused testing</i> | 2 |
| <i>Of companies who called ERG, those who received a preliminary “onsite visit” to discuss study logistics and evaluate trucks for eligibility / testability, and ultimately participated in PEMS and PAMS testing</i> | 6 |

As indicated above, 12 companies interested in participating (or even interested in only receiving the “initial call incentive” as described in Section 3.3) contacted ERG personnel for

additional study information. ERG staff described the study, answered any questions the participant had, and attempted to schedule a visit to meet with the respondent, discuss testing logistics and assess the company's eligible trucks for "testability". As can be seen in Table 4.3-1, six companies received onsite visits, and field testing was ultimately performed at all six of these companies. An additional four of the 12 companies expressed interest in participating in the program, but did not ultimately participate either because their eligible trucks were unavailable (out of service or over-the-road long-haul trucks), were in sampling bins that were already full, or were just recruited too late in the study for testing (we completed fieldwork without the need for testing these company's trucks). Only two companies who contacted ERG ultimately refused to participate. All companies who agreed to an onsite visit did participate in testing.

4.4 Preliminary Visits to Candidate Establishments

The preliminary onsite visits were performed several days to several weeks before testing began at an establishment. ERG attempted to minimize the delay between the preliminary onsite visit and the start of testing at each company, in order to prevent participation attrition. By this point in the recruitment process, the company contact was generally familiar with the study and incentives, but usually was interested in learning more about exactly what participation entailed. ERG staff discussed PEMS and PAMS testing, including how installations were performed around working schedules, where equipment would be placed and how it was installed and secured, temporary modifications that would be made to the truck (and later reversed) and driver / company commitments. Also during this preliminary visit, logistics of the study were discussed with the company contact in further detail, addressing issues such as identification of the day-to-day contact for recruiting and testing, location to be used for installing test equipment on trucks, operation and installation schedules, a suitable location for the onsite PEMS trailer, availability of shore power (a/c power distributed from the facility where installations were taking place) for onsite operations, off-hours facility access, method of incentive disbursements (to the company or individually to each driver), insurance requirements for ride-alongs, tax issues associated with the incentives, liability issues, how best to recruit independent drivers and other issues.

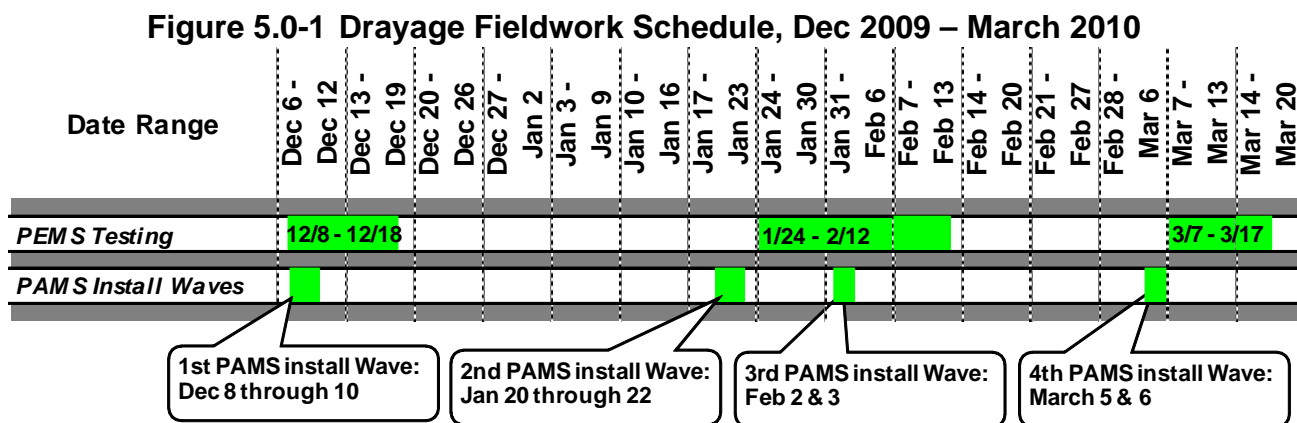
After describing the technical and logistic aspects of the study and answering any questions the contact had, ERG personnel attempted to survey as many of the eligible trucks (from the pool of 1877 trucks which had been RSD screened) as possible. This typically required personnel to wait onsite until the trucks arrived to pick up or drop off a load or until they arrived to stop for the night. Since many of the trucks were operated by independent

owners / operators (IOOs), ERG personnel would typically attempt to recruit these drivers at this time. The onsite contact typically assisted with this recruiting to assure the driver that the study (and incentives) was legitimate. ERG found that although some drivers were reluctant at first, ultimately no drivers refused the study, once their questions were answered and their concerns were addressed.

As many eligible trucks were surveyed as possible during this time. The primary goal of this survey was to assess each truck for testability. Some issues evaluated were the condition of the truck, the number and location of the exhaust stacks on the truck, whether the truck had visible exhaust leaks, how much room was available for equipment outside and inside the cab, availability of access points for routing sample and gas hoses and electrical lines into the cab, ECU connector type, etc. A copy of the complete evaluation form is provided in Appendix G, and PDF copies of all completed forms are provided in Appendix Y. Multiple photographs were also taken of each truck to help PEMS and PAMS installation team members prepare equipment for each individual installation.

5.0 PEMS and PAMS Testing

PEMS and PAMS installations were performed at trucking companies operating at the Port of Houston. These companies were located in the cities of Houston, Texas and La Porte, Texas. The fieldwork for this study was conducted in three phases, over the period of December 8, 2009 through March 17, 2010. Four waves of PAMS installations, monitoring, and removals were performed over this time, concurrent with three waves of PEMS testing. The overall fieldwork schedule is shown in Figure 5.0-1.



The work assignment for this study specified PEMS testing be conducted over a six-week period, and PAMS testing over a four-week period. Approximately two to five PEMS tests per week were anticipated, for approximately 32 total PEMS tests over the six-week period. Approximately 6 PAMS installations were also anticipated per week over the four week period, based on an estimate of approximately 2 PAMS installs per day, installations being performed over the weekend as much as possible. This would yield roughly 24 week-long PAMS installations.

As described in Section 5.1, the PEMS test team performed both PM and gaseous tests as well as gaseous-only tests. A total of 46 tests were conducted, 22 of these were full PM and gaseous tests, and 24 were gaseous-only tests. A total of 23 week-long activity measurements were also collected, as summarized in Section 5.3.

5.1 PEMS Testing

5.1.1 Process Overview

As described in Section 4.4, ERG staff performed preliminary site visits to all companies prior to the arrival of the field testing team. Tentative plans were developed for PEMS and

PAMS testing at each company, and candidate trucks were evaluated for testability. ERG personnel then coordinated onsite testing once the field team was ready to deploy at each company's site.

PEMS installation teams consisted of an ERG PEMS/PAMS field manager, two EPA technologists from EPA's Laboratory Operations Division (LOD), two (or more) EPA staff members from EPA's Assessment and Standards Division (ASD) and one technician from Sensors, Inc. Additional staff, such as ERG PAMS installation team members or additional ASD staff members, also periodically assisted with PEMS support operations, as needed.

The ERG field manager served as a liaison between the participating establishment and the installation team (as well as the PAMS installation team), performed scheduling and coordination of deployment, provided assistance with PEMS installations, setup and testing, assisted with collection of truck and instrumentation data on instrumentation data collection forms, assisted with PAMS installations and removals and reviewed and posted PEMS data onto the project-secure FTP site. The field manager also tracked incoming and outgoing PM filters and coordinated PM filter shipments between the field and the EPA laboratory. The EPA LOD technologists and ASD staff members performed PEMS installation and operation duties, including equipment installation, setup and gaseous and PM testing. Sensors technicians assisted with PEMS installation, setup and operation, assisted with resolving in-use testing issues, performed in-field review of the PEMS data and performed service and maintenance of the PEMS gaseous and PM sampling equipment, along with EPA ASD personnel. EPA ASD personnel also performed on-going testing support, in which one person would "ride-along" with each truck during testing.

As described in Section 3.2.2, trucks were selected for PEMS testing from the pool of 1877 trucks which had previously received one or more successful RSD measurements, and truck selection was stratified using truck model year and RSD NO_x emission categories. Table 3.2-4 lists the distribution of the target sample of trucks within the 25 sample strata. Following this weighting scheme, prioritized lists of trucks to be sampled were created for each trucking company in an effort to fill all 23 strata (two bins had zero recruitment goals). In order to maximize testing across as many bins as possible, priority was given to "uncommon" bins (bins with few trucks) with consideration of eligible trucks at companies where testing was scheduled but had not yet taken place. Also, as described in Section 3.2.2.4, vehicle selection within each strata was based on the probability that the vehicle's true NO_x emissions were within the NO_x emissions strata and also the number of times RSD readings were successfully captured on each

truck. The “probability within a bin” and “RSD count” criteria were used to create the prioritized stratum rankings shown in Appendix B.

Prioritized lists of desired trucks were provided to each company contact, and information was collected regarding availability of each truck. Trucks could be excluded from testing for several reasons, as listed below:

- The truck’s usage shift did not allow the team adequate time to install and prepare the PEMS equipment (i.e., the truck would leave too early in the morning for the team to complete the installation, warm-up and calibration of the equipment)
- The truck was not scheduled to operate within a port
- The truck was not testable (dual exhaust, side stacks or insufficient available space behind or in the cab prevented PEMS equipment installation from being possible)
- The truck was out of service or no longer worked at the company
- The truck was domiciled elsewhere and could not be left at the installation site overnight

It should be noted that no drivers refused to participate in the program, suggesting the PEMS incentive was sufficient, and in fact a smaller incentive could suffice in future studies with a similar participation commitment.

After equipment selection for PEMS testing, the ERG onsite installation manager scheduled instrumentations with the appropriate establishment contact(s), sought permission to instrument the specific pieces of equipment, and asked the driver about each truck’s expected operation during the measurement period (likelihood of port operations, local driving, over the road, etc.). If the driver or dispatch contact indicated the truck was not to be used for port operations or would not be available for testing during the anticipated measurement period, an alternate truck was selected for instrumentation from the list of candidate trucks. Dispatch personnel were generally accommodating and willing to schedule drivers for port work during days when PEMS testing was to occur.

PEMS installations began with thorough collection of truck-specific data, which was hand written onto “Instrumentation Data Collection Forms” as shown in Appendix H. Digital photographs were taken of plates, VINS, and equipment serial numbers and specification tags whenever possible, to help clarify or correct any ambiguous or inaccurate information which may have been recorded during data collection. Photographs were also taken of engine tags, when possible, in order to help confirm power and torque ratings, engine family and serial numbers and other identifying information. Vehicle odometer readings were also recorded, though neither odometer or engine family data was used as a part of any analysis discussed in this report. A compilation of all information collected for all PEMS and PAMS instrumentations

throughout the study is provided in Appendix I, with PDFs of the original hardcopy forms provided in Appendix X. Emissions and instrumentation data is also being provided as part of the MSOD data submission for this project. In Appendix I (and elsewhere), the primary key field for each test is the test ID, which provides a unique identifier for each PEMS or PAMS test conducted. The naming convention is as follows: PEMS; plate_date_E , PAMS; plate_A. For example, “ERG983_20100202_E” would represent a PEMS test performed on February 2, 2010 on a truck with license plate “ERG983”. “ERG983_A” would represent a PAMS installation on a truck with license plate “ERG983”. No dates were assigned for PAMS instrumentations since PAMS testing spanned multiple days and only one PAMS file (containing all test data) is provided for each instrumentation.

Drayage trucks tested during the study are expected to have been operated on Texas Low Emission Diesel (TxLED), in accordance with the Texas Commission on Environmental Quality’s TxLED program⁽³⁾. Diesel fuel samples were collected for each PEMS-tested truck. An electric automotive fuel pump along with a small rechargeable 12V battery was used to collect fuel samples, which were labeled with sample ID tags and stored in fuel sample jars provided by the EPA. All fuel samples were collected and handled according to guidelines listed in Appendix N, Drayage Fuel Sampling SOPs, and stored and transported to the EPA laboratory in Ann Arbor in the EPA PEMS trailer. After fieldwork was complete, fuel analysis was performed by both the EPA in-house laboratory and by Paragon Laboratories. Results from all fuel sample analysis are presented in Appendix O. Specific gravity and molar ratio (hydrogen to carbon ratio) obtained from this sample analysis was used as input values when processing the PEMS data. However, analysis was only performed on a subset of the samples collected, and some samples were damaged (the sample containers were broken) during transport, so complete sample analysis results were not available for all samples. Average values were used when sample analysis results were not available for specific tests. For IOO trucks with unknown refueling sources, these averages were based on the overall averages calculated over the entire study. For fleet trucks refueled from an establishment’s common fuel source, averages were based on the fleet average for that establishment.

PEMS installation, operation and maintenance was scheduled and performed in such a way as to minimize interruption of operations. PEMS instrumentation teams generally performed installations during each site’s non-working hours (after the trucks were no longer needed for that working day). Hence, PEMS installations usually took place the evening prior to the day of testing, and the instrumentation team would then arrive the next morning at least two hours prior to the truck’s scheduled departure time to warm-up, calibrate and verify the functionality of the PEMS equipment prior to emissions testing. Generally, two trucks were

instrumented each night (installations were generally performed Sundays through Thursdays), one for gaseous only and one for gaseous and PM. Although equipment was available to perform two concurrent PM tests, approximately six hours of cleaning and calibration of an MPS system was required after each use, so performing two concurrent PM tests would prevent the team from being able to perform PM testing the following day. Therefore, the optimum test schedule incorporated one PM test each day.

5.1.2 PEMS Equipment Installation

After team members evaluated each truck for testability and test equipment layout, various support activities associated with each installation were initiated. The primary equipment installation tasks are described in the following subsections.

5.1.2.1 Determine Layout of Major Equipment Components

Prior to each installation, PEMS installation team members evaluated the truck to be tested to identify the best configuration for the test system and to resolve any potential installation or operation issues. Assessments were made of the space available behind the cab for mounting the generator, MPS box, nitrogen and FID fuel gas bottles and other equipment, and the exhaust system was evaluated to determine how to mount the exhaust flowmeter and how to route the heated sample lines into the cab. As discussed in Section 4.1.1, gaseous-only installations were somewhat less complex than full PM and gaseous installations since an MPS chamber wasn't required and therefore the exhaust flowmeter could be mounted directly on the muffler (after removal of the truck's exhaust stack). In addition, no gravimetric sampling chamber, PM sampling line or nitrogen cylinder were needed for gaseous-only testing. Figure 4.1-2 shows the equipment used for full PM and gaseous installations (on a bus), and figure 4.1.3 shows a gaseous-only instrumentation on a truck the team tested during this study. As shown in Figure 5.1-1, a gaseous-only installation could be performed on trucks with bulkheads, but full PM installations were not possible without removal of the bulkhead, as insufficient room was available between the bulkhead and the fifth wheel to mount the additional equipment.

Figure 5.1-1 Gaseous-only Installation on Truck with Bulkhead



5.1.2.2 Install Deck Plates and Exterior Test Components

Many trucks were already equipped with deck plates, which were grated aluminum plates clamped to the truck's frame rails directly behind the cab. If not already equipped, these were installed on the trucks to be tested and served as platforms on which to mount equipment. Deck plates were purchased at local truck supply outlets located near our various testing sites. After the deck plates were installed, the exterior test system components were placed in their respective locations. Figure 5.1-2 shows the placement of a MPS/flowmeter assembly on a deck plate with generators mounted on a rack over the cab of a 1980 Kenworth cabover truck. In this figure, the sample lines are routed along different paths into the sleeper cab through the passenger's window. Figure 5.1-3 shows a full PM/gaseous system on a 2004 Kenworth sleeper cab. Note that in Figure 5.1-3, due to space constraints, the nitrogen cylinder used for gravimetric solenoid activation is mounted on the frame steps near the deck plate. Figure 5.1-4 shows installation of both the MPS chamber and the gravimetric sampler outside the cab of a 1993 Freightliner sleeper cab. Although the gravimetric sampler was usually located inside the cab, insufficient room was available in this particular cab for the sampler, so this was mounted on the deck plate adjacent to the MPS. The gravimetric sampler was positioned with the access door facing outward to allow gravimetric filter changes when the truck was stopped. Figure 5.1-5 shows installation of a MPS and gravimetric sampler outside a day cab on a 2003 Freightliner, again, due to insufficient room inside the cab.

When installing equipment on the deck plate behind the cab, it was critical to ensure adequate distance was available between the tractor's fifth wheel coupling device and the sampling / measurement equipment. Even though adequate distance may be available when the truck is pulling a trailer in a straight path, once a turn is made, the corner of the trailer (or cargo container) arcs toward the cab and significantly reduces the available distance from the rear of the cab as it travels through the arc path. During installation, care was taken to ensure adequate clearance was maintained in order to prevent trailer or cargo container interference, and in "tight" installations (where limited room was available), before starting the workday (but after a trailer was installed) the driver of the truck was asked to slowly make a sharp turn as installation personnel watched the arc of the trailer corner to ensure sufficient clearance was available. Adjustments were made to mounting configurations and locations as needed.

Figure 5.1-2 PM/Gaseous Test Components with Generators on Roof



Figure 5.1-3 PM/Gaseous System on 2004 Kenworth



Figure 5.1-4 Grav and MPS Box Outside of a 1993 Freightliner



Figure 5.1-5 Grav and MPS Box Outside 1993 Freightliner Day Cab



5.1.2.3 Install Exhaust Flowmeter

As previously described, procedures for installing the exhaust flowmeter varied depending on whether the test was a gaseous-only test or a PM/gaseous test. For PM/gaseous testing, LOD personnel removed the truck's existing exhaust stack and fabricated (using welding and band clamps) a new exhaust system to route the exhaust through the exhaust flowmeter mounted on the MPS, as shown in Figures 5.1-3 through 5.1-5. For gaseous-only testing, the exhaust flowmeter was mounted directly on the truck's muffler (after removal of the stack), as shown in Figures 5.1-6 and 5.1-7. In Figures 5.1-6 and 5.1-7, it can be seen that no MPS was required, so only the generator and the FID fuel cylinder were needed, and were secured to the deck plates which had been installed by LOD team members.

Figure 5.1-6 Gaseous-only Installation on 2003 Freightliner Fleet Truck



Figure 5.1-7 Gaseous-only Installation on 1998 International Sleeper Cab



5.1.2.4 Install In-cab Test Equipment and Route Heated Sample Lines

Concurrent with installation of the deck plate, external test systems and exhaust flowmeter equipment, the interior of the truck was prepared for installation of the test equipment.

For sleeper cabs, generally objects on the bed were cleared, the mattress was removed and mounting platforms were installed to secure the test equipment. Some installations were hampered due to the excessive distance from the MPS (outside) to the gravimetric sampling chamber (inside). This was limited by the length of the system's heated PM sampling lines, so it was critical that the proper location and orientation of all equipment be determined before installations began, in order to avoid having to remove and reinstall equipment in new locations. Figures 5.1-8 through 5.1-10 show various sleeper cabs with PEMS and gravimetric sampling equipment installed. Figure 5.1-8 shows a sleeper cab in which the PEMS and gravimetric sampling unit were mounted on the lower sleeper platform. Sample lines were routed into the cab through a sleeper window. Routing lines through the sleeper window generally provided the most flexibility in equipment locations due to the relatively short distance required for routing the sample lines. On the other hand, the sleeper cab shown in Figure 5.1-9 had no convenient access ports through which the sample lines could be routed, so these lines were routed into the cab through the passenger window (this is the 1980 Kenworth cabover shown in Figure 5.1-2). In Figure 5.1-10, the mattress of this sleeper cab was removed and the rear side window was removed in order to mount the equipment and route the sample lines into the cab. Figure 5.1-11 shows the outside of this same cab with the rear side window removed. Cardboard was placed over the window opening in order to protect the cab from rain while the equipment was installed.

Figure 5.1-8 PEMS and Gravimetric Sampler in Large Sleeper Cab



Figure 5.1-9 PEMS and Gravimetric Sampler in 1980 Kenworth Cabover



Figure 5.1-10 PEMS and Gravimetric Sampler in Cab with Window Removed



Figure 5.1-11 Sleeper Cab with full PM System and Window Removed



For sleeper cabs with dual over/under bunks, frequently the best location for mounting the PEMS was on the top bunk, as shown in Figure 5.1-12. Mounting the PEMS on the top bunk minimized the distance the gaseous sample line had to travel from the exhaust flowmeter, and it also made more room available on the floor of the cab for the gravimetric box and other equipment. Figure 5.1-13 shows equipment in a sleeper cab where placement on a top bunk was not possible and the sample line was not long enough to reach the PEMS. For this installation, the team members installed the PEMS on a shipping crate in order to position the PEMS close enough to the exhaust flow meter to allow the sample line to reach the PEMS. Figure 5.1-13 also shows the blue PM sample line attached to the gravimetric filter box, shown in the lower portion of the picture.

Figure 5.1-12 PEMS installed on Top Bunk of Sleeper Cab



Figure 5.1-13 PEMS On Crate in Sleeper Cab



Generally, team members attempted to route the sample lines into the sleeper cab through a vent or window, as shown in Figures 5.1-7, 5.1-11, 5.1-14 and 5.1-15. Another option was to route the sample lines through an access port within the cab's external tool box, as shown in Figure 5.1-16. Team members also attempted to route sample lines through the deck's work light located on the back of the cab, but this was not generally possible due to the small size of the hole and obstructions such as interior panels. Often, it was necessary to route the lines through the passenger front window, as shown in Figure 5.1-17 (this can also be seen in Figures 5.1-1, 5.1-2 and 5.1-5). Due to the weight of the heated sample lines, perches were sought on which to support the lines. In the absence of these, duct tape was used to secure the lines to the side of the cab, as shown in Figure 5.1-17. No residue remained as the tape was removed the next day. Duct tape was also used to seal passenger window openings through which heated sample lines were routed.

Other installation parameters of concern included access to the front of the PEMS unit to monitor controls, reset the unit if necessary and change system filters, access to the gravimetric sampling access door (to allow the operator to change gravimetric filters throughout the day), access to the generator to allow refueling and routing of the PEMS exhaust and FID drain tubes from the PEMS to outside the cab. Figure 5.1-9 shows an installation with easy access to both the gravimetric sampling unit access door and the PEMS control panel. The red cooler between the PEMS and the gravimetric unit contains the gravimetric filters to be used during the day's testing, and the small white box on top of the PEMS unit contains extra PEMS system filters. Figure 5.1-12 shows the clear PEMS FID and exhaust drain tubes routed outside the cab.

Figure 5.1-14 Sample Lines Routed through Sleeper Cab Window



Figure 5.1-15 Sample Lines Routed through Sleeper Cab Vent



Figure 5.1-16 Sample Lines Routed through Toolbox



Figure 5.1-17 Sample Lines Routed through Passenger Window



Installation in day cabs was more challenging, due to space constraints, as shown in Figures 5.1-18 and 5.1-19. As shown in these images, the PEMS unit was installed between the driver's and passenger's seats. Figure 5.1-5 shows the associated PM sampling equipment located outside of the cab for the in-cab PEMS shown in Figure 5.1-18. Figure 5.1-19 shows a platform that was constructed to support the PEMS rack, which minimized seat interference with the PEMS' sample line, control lines, and heated filter.

Limited by the length of the heated sample lines, it was imperative that careful planning occur prior to installing sampling equipment, especially for PM tests (primarily the SEMTECH-DS, MPS chamber and gravimetric sampler). Even small changes such as switching locations between the SEMTECH-DS and gravimetric sampler within the cab could be a significant undertaking because of the cab's space constraints and the size and weight of the sampling equipment, so minimizing changes after equipment installed was critical. This was especially true when testing vehicles for which the sampling lines could not be routed into the cab except through the passenger side window (as shown in Figure 5.1-17).

Figure 5.1-18 PEMS Between Seats in Day Cab



Figure 5.1-19 PEMS Mounting Platform in Day Cab



5.1.2.5 Install Test System Accessories

Other test system components that were installed included the weather station, GPS antenna and VI connector (or optical sensor for RPM measurements if no VI connector was available). Weather stations can be seen mounted to the cab hand rails in Figures 5.1-14 through 5.1-16, and on the rear view mirror in Figure 5.1-17. Figures 5.1-20 and 5.1-21 show two common locations for VI connectors. Another common location was at the outside (door-facing side) base of the driver's seat. Figure 5.1-22 shows a mounted optical sensor. The cardboard strip at the base of the sensor was used to reduce the strength of the high-powered magnet while positioning the optical sensor, and this cardboard was removed once the optical sensor was aligned. GPS antennas were frequently located on the dash below the windshield, although occasionally they were routed outside the cab and mounted on cab exterior platforms.

Due to the heat of the generator exhaust, the generator had to be mounted in such a way as to direct the exhaust away from the pneumatic hoses attaching the cab to the trailer (glad hands). In addition, cable tie-wraps were used to tether the pneumatic hoses away from the generator exhaust or other hot or pinch points on the sampling equipment.

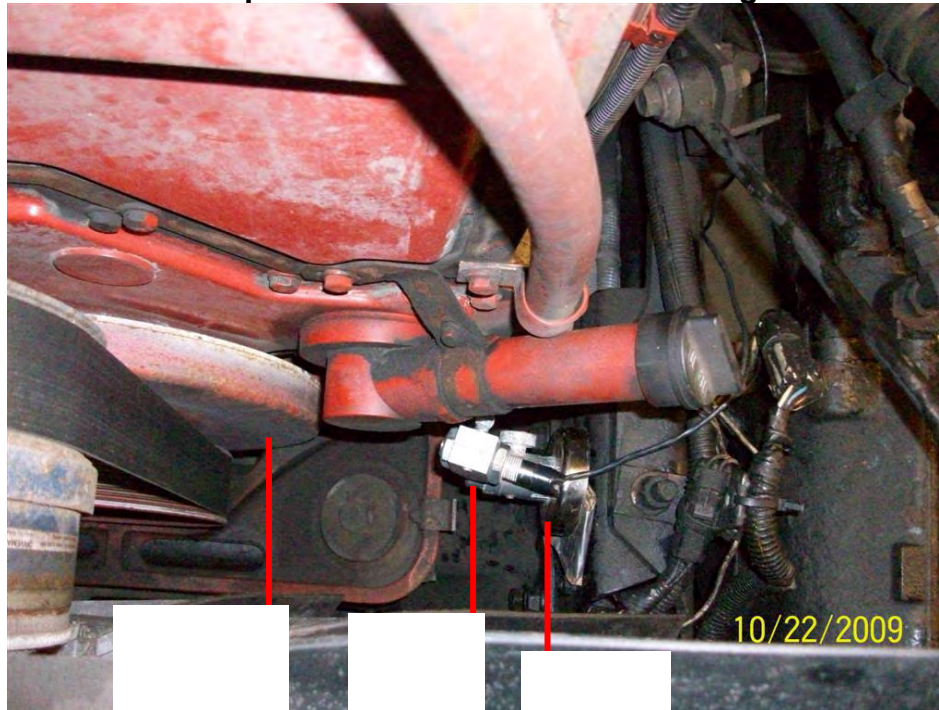
5.1-20 Typical Under-Dash VI Connector Location



Figure 5.1-21 Typical Dash Front VI Connector Location



Figure 5.1-22 Optical Sensor with Cardboard Alignment Tool



5.1.3 Prepare Equipment for Testing

5.1.3.1 Preparations the Night of Installation

Once all equipment was installed and connected, the system was turned on, warmed up, calibrated and prepared for the following days' testing. System checks were performed which included verification of the proper exhaust flow meter and input settings, review of measured exhaust flow rates, verification of dilution ratios, verification of MPS block pressures and verification of MPS proportionality. The SEMTECH heated filters were replaced, and a system leak check was performed. Gas audits and calibrations were then performed, as necessary, and all system settings were established and verified. Acquisition of external data, including weather station data, GPS data and engine computer datastream data or external RPM data was also verified at this time. If any systems were found to be malfunctioning or operating out of range, in-vehicle repairs were made or the system was replaced with a backup unit. An overview checklist of the tasks associated with preparing the system for testing is provided in Appendix P, "Drayage PEMS Checklist_20100129".

After all systems were prepared for the following day's testing, the vehicle was secured for overnight storage. Generally, the team attempted to leave all systems "hot", operating on shore power, eliminating the need for lengthy warm-ups the following morning. If rain was

forecast, the system was covered with a large tarp to prevent water incursion, as shown in Figure 5.1-14.

5.1.3.2 Test Day Preparations

The next morning, on the day of testing, field crew members would arrive approximately two hours before the truck's scheduled departure time to prepare the truck for testing. If shore power had not been available to keep the system "hot" overnight, some field crew members would arrive approximately additional hour earlier (before the calibration/setup crew) in order to start the generators and equipment to allow the pre-test warm-up using generator power.

The functionality of all systems would again be verified, including acquisition of external parameters. Gravimetric filters were inventoried and recorded on gravimetric filter data collection sheets, which were provided to the person scheduled to do the ride-along (along with tools necessary to switch gravimetric filters). The ride-along also carried spare SEMTECH heated filters, in case they were needed during the day.

All systems were verified and recalibrated as needed and described in Appendix P. This would include performing a zero on the MPS transducers, checking for proportionality and appropriate exhaust flow rate ranges, and performing zeros and calibrations on the PEMS gaseous measurement systems.

Immediately before testing was to commence, the ride-along would install the gravimetric filters in their holders, recording all necessary information on gravimetric filter data collection forms as shown in Appendix Q. Gravimetric filters were handled according to the "Gravimetric Filter Handling SOPs" provided in Appendix R. A PEMS test session and a PEMS test were initiated immediately before the truck was placed into service.

5.1.4 PEMS Testing

When the truck driver arrived, typically the truck was started and allowed to warm up for 10-15 minutes (or more) while the driver received the day's orders from dispatch. During this time, any last minute system checks or calibrations were performed, along with collection of an "idle" gravimetric filter (if sufficient time was available after the truck had been warmed up but prior to departure). Immediately before departure, the generator fuel was topped off, spare gasoline containers (for generator refills) were secured on the truck behind the cab, all tie-down cables were tightened, and hoses and lines were routed away from the generator exhaust or interference points.

PEMS measurements were gathered over a complete working day, usually between six and ten hours. No specific drive cycles were used during testing, and all PEMS testing was based on actual in-use loads and speeds. Using a laptop computer, the ride-along monitored all system parameters and also refilled the generator and collected and recorded data on gravimetric filters. If questionable readings or problems were encountered during the day, the ride-along would contact ASD or Sensors personnel back at the on-site support trailer. Remote diagnostic support was provided, as needed, and if necessary the team would meet the truck during the day (usually on a return visit to the installation facility) in an effort to diagnose or correct any problems that could not be remotely corrected.

Gravimetric filters were collected and switched throughout the day, as listed in Appendix T, the Drayage Filter Log. As shown in this appendix, certain filters were dedicated to “in port” activities. The in-port (vs. non-port) emissions are segregated in Section 7, Study Results. Appendix U identifies “port” activity for all testing (including gaseous-only testing), as identified through review of ride-along activity logs presented in Appendix V. PDF scans of all hardcopy filter data collection forms are provided in Appendix W.

Throughout the day, the ride-along would reload gravimetric filters, following guidelines in Appendix R, the Gravimetric Filter Handling SOPS, and Appendix Z, the Filter System User Manual. Figure 5.1-23 shows the gravimetric filter access door open, allowing access to the URG gravimetric filter holders within.

Figure 5.1-23 Access to Filters within the Gravimetric Sampler Assembly



When not in use, gravimetric filters were transported and handled in plastic holders sealed in Ziploc plastic bags and carried/stored in small coolers. However, since these filters were loaded in the field, they were briefly exposed to ambient contamination as they were removed from their bags and holders and placed in the sampling equipment. Filter loading was performed inside the cab of the truck to minimize exposure to ambient contamination. Dynamic and field gravimetric filter blanks were collected during the study in order to identify and quantify the extent of ambient PM contamination on PM data resulting from gravimetric filter transport and handling activities. Field blanks were treated as actual samples, including all shipping, handling and transport to the field during testing, although they were not placed in the gravimetric sample system holder. Dynamic blanks were also treated as actual samples but in addition to field handling they were placed in the gravimetric sample system holder rack during emissions testing. However, no exhaust sample (or air) was routed through the dynamic blanks (the flow-control solenoid on the gravimetric sampler which held the dynamic blank remained closed during testing). Comparison of the measurement results for dynamic blanks and field blanks can help provide information regarding potential system contamination resulting from either the filter holder or leaks in the flow-control solenoids used to isolate that specific filter holder in which the dynamic blank was placed. Dynamic and field blank results are presented in

Table 7.1-1. Appendix T (Drayage Filter Log) lists results for each sampled filter and also lists sample type such as port or idle operation. Appendix M (Drayage Emissions Measurement Results) lists by-filter emissions for all sampled filters.

Other ride-along support activities included refueling the generator during breaks in activity, monitoring data and system parameters and ensuring all systems remained safely secured. Upon return to the facility at the end of the day's activities, the PEMS test would be ended, and a post-test calibration and zero would be performed to quantify the measurement instrument's drift throughout the day. After the post-test calibrations, the PEMS data file session was ended, and the data was processed, plotted and reviewed to identify any problems. All gravimetric filters were retrieved and transferred to the onsite manager for logging and recording. A complete list of ride-along responsibilities are provided in Appendix S, the Drayage Ridealong Checklist.

5.1.5 Post-Test Activities

As mentioned in the preceding section, immediately after retrieval from the PEMS, all data was processed using the SEMTECH-DS post-processor for an in-field data review. System settings, flow rates, proportionality and pollutant concentrations were evaluated to assess test validity. If any suspicious parameters or suspect data was encountered, an equipment evaluation was performed and onsite managers would discuss whether an additional day of testing would be performed on that truck.

PEMS data (along with all other relevant project data and information) was archived in multiple locations for later transfer to the project-specific secure FTP site.

Every day after testing, the MPS was removed from service for a complete disassembly, cleaning and recalibration to be performed the following day (while the next day's test was underway). In this manner, two MPS units were alternated for use/service every other day, allowing daily PM testing (as weather permitted). Service on the MPS was performed according to guidelines presented in Appendix AA, the MPS User Manual (rev 1.01, revision still underway).

5.2 PAMS Installations

This task involved the instrumentation of selected drayage trucks with Isaac PAMS for acquiring activity data, including date/time, engine speed (via ECU data when possible) and position (GPS). As described later in Section 5.3, fourteen of the twenty-three trucks which were used in the PAMS study also received a PEMS test. The remainder of trucks generally were also

trucks which had received an RSD test, but a few of the trucks were not part of the 1877-truck RSD-tested fleet. During the course of the study, a mutual decision was made between onsite ERG and EPA personnel that trucks not included in the fleet of 1877 RSD-sampled trucks could receive PAMS instrumentations, as long as the trucks would be doing port work and fell within the model year profile of the 1877 truck fleet which had received RSD tests. For those trucks which received both a PEMS test and a PAMS test, the PAMS unit was disconnected from the truck during the day of the PEMS test (to allow the ECU datastream or optical RPM signal to be used for the PEMS test). For these trucks, the activity data from the PEMS test was later merged into the PAMS data for a complete activity datafile (in essence adding an extra day of activity data).

Prior to each PAMS instrumentation, vehicle information was written onto data collection forms (the same form as used for PEMS testing) shown in Appendix H. All information collected on these forms is included with the PEMS instrumentation data provided in Appendix I. As with PEMS instrumentation, all PAMS data collection was enhanced with digital photographs.

As shown in Figure 5.0-1, PAMS installations occurred in four waves coinciding with the PEMS fieldwork activities. PAMS data was collected for approximately one week for each installation. This relatively short activity collection cycle was believed to be appropriate for several reasons:

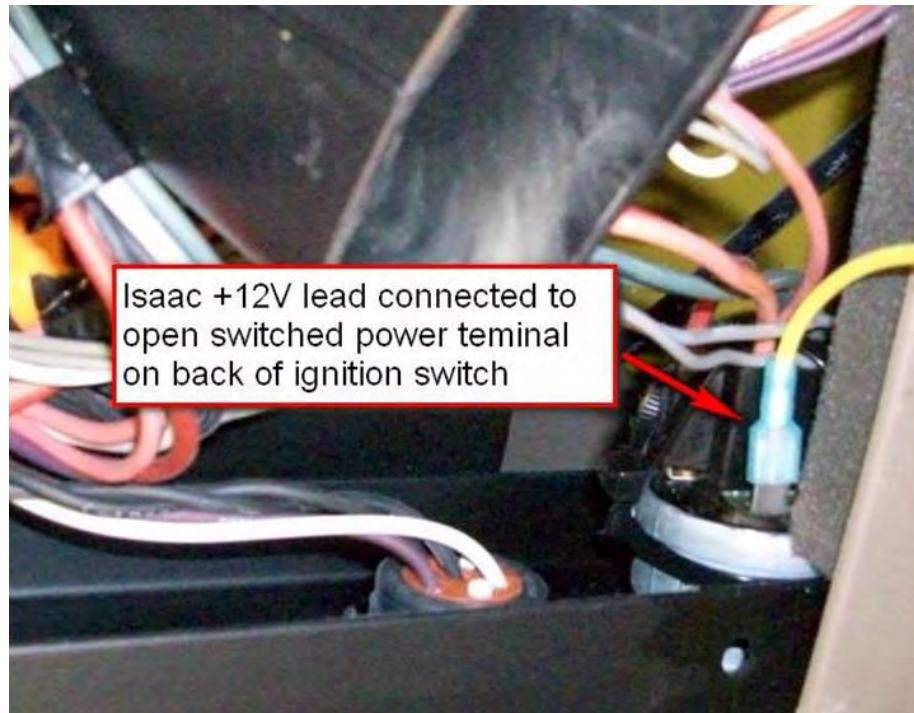
- Because drayage drive-cycle variability was expected to be lower than that for many other source categories, a one-week data collection duration would allow collection of adequate activity information for most vehicles
- One-week data collection periods reduced the need for staff to revisit instrumented vehicles in order to download data, verify functionality and correct problems
- Because of a lower chance of instrumented vehicle reassignment, shorter data collection duration was felt to reduce the risk of loss of equipment, and
- Short data collection duration allowed a greater number of vehicles to be tested over a given timeframe

Six PAMS units were used throughout the study, as shown in Figure 5.0-1. PAMS installations generally began near the start (or prior to) each PEMS testing phase, and continued until all six dataloggers were installed, calibrated and functioning properly. Two to three ERG personnel performed PAMS installations, and each phase of six truck installations was completed in two to three days. The ERG PEMS/PAMS field manager served as a liaison between the participating establishment and the installation team (as well as the PEMS

installation team) to ensure PAMS instrumentations did not disrupt drayage activities or impede PEMS testing.

Two general types of PAMS instrumentations were performed during this study. For vehicles which were not computer controlled (or ECU data was not available for any reason), RPM was captured using an optical RPM sensor (with reflective tape affixed to a rotating object, such as the engine's harmonic balancer), and DC power for the datalogger was taken from the truck's switched power source (generally the ignition switch), as shown in Figure 5.2-1. For computer-controlled vehicles with an available ECU port, power was taken from the ECU port (either a 6-pin or 9-pin Deutsch connector). ECU-port installations collected RPM (along with a number of other engine parameters) broadcast in the ECU datastream.

Figure 5.2-1 Switched Power Terminal used for Non-ECU PAMS Installations



Once the type of installation was determined, a suitable location was identified for the PAMS box and an appropriate harness was selected. As the Isaac units are equipped with 3-D accelerometers, an attempt was made to mount each PAMS vertically, so its “z” axis (as indicated on the top of the unit) pointed along the length of the truck, and the “y” axis pointed directly upwards. However, this was not always possible, depending on the type of truck and available mounting options. Datalogger orientations were noted on the instrumentation forms (and static values of the 3-accelerometers while the truck is at rest can also be used to determine datalogger orientations). Figure 5.2-2 shows a PAMS installed against a seat base. For this

particular installation, the “z” axis is properly aligned, but the “x” and “y” axes are not in their ideal orientations (although this can be corrected during data analysis, as needed).

Figure 5.2-2 PAMS Installed on a Seat Base



Once a suitable mounting location for the PAMS unit was identified, the appropriate wiring harness was routed from the optical sensor or the 6-pin or 9-pin connector (whichever method was used). The installation type (optical, 6-pin or 9-pin) determined the type of harness to use. The GPS antenna was also connected to the Isaac harness and mounted somewhere on the dash, as shown in Figure 5.2-3. Wires were routed from the GPS antenna and the power switch (or Deutsch connector) carefully to be hidden from the truck driver and occupants (as much as possible). Figure 5.2-4 shows wires leading from a Deutsch connector to the Isaac datalogger prior to them being covered by the truck’s sill plate (which had been removed for the installation).

Figure 5.2-3 Typical PAMS GPS Mounting Location



Figure 5.2-4 PAMS wiring from a Deutsch Connector



Once the hardware was installed and the wiring was connected, a laptop was connected to the PAMS and configured using an appropriate configuration file developed during the mockups

described in Section 4.2. One of three configuration files was used for each installation, either external RPM/GPS (for trucks with an optical RPM sensor), SAE J1708 data (for trucks with 6-pin Deutsch connectors), and either the SAE J1708 configuration file or the SAE J1939 configuration file (depending on model year, for trucks with 9-pin Deutsch connectors). After download of the configuration file, the truck was started, successful data acquisition of all parameters was verified, and the protocol was changed as necessary. All parameters were reviewed, and a final check was performed of the datalogger and harness/accessory installations. At this time, the truck was ready for release. Detailed installation guidelines are provided in Appendix F, Drayage PAMS SOPS.

After installation was complete, a tentative appointment for removal of the unit was made with each truck driver and the truck was released. After the week of instrumentation had passed, ERG contacted each driver and confirmed the removal appointment. During removal, data from each PAMS unit was downloaded onto a laptop, processed and evaluated (while the PAMS was still installed on the truck). The PAMS and accessories were then removed, and the truck was restored to its original condition.

5.3 PEMS and PAMS Testing Summary

PEMS and PAMS testing totals are shown in Tables 5.3-1 through 5.3-3. Table 5.3-1 summarizes PEMS testing, by NO_x bin and model year group, as described in Section 3.2.2. In Table 5.3-1, bins which were completed (i.e., the target number of trucks received full gaseous/PM tests) are shaded gray. Green numbers (shown italicized in the top of each cell) in Table 5.3-1 represent bin targets, and red numbers (bottom of each cell) represent the total number of trucks which received gaseous/PM tests. Black numbers (which are shown in parenthesis) represent trucks which received gaseous only (oversample) tests. Some trucks received multiple PEMS tests, as shown in Table 5.3-2. In total, 37 trucks received PEMS tests, and 9 of these 37 trucks were tested twice (resulting in 46 PEMS tests performed throughout the study). Overall, 22 gaseous/PM tests were conducted, and 24 gaseous only tests were conducted. In Table 5.3-1, only one test is shown for trucks which received more than one test, i.e., a PM test represents either two gaseous/PM tests or a gaseous and a PM test for trucks 2JC711, 1190901-A, 0182003-A and 0182022-A. Consequently, the totals obtained by summing the cells in Table 5.3-1 will not yield 37 (trucks) or 46 (PEMS tests) shown in Table 5.3-2.

Table 5.3-1 PEMS Testing by NOx Bin and Model Year Group

| | | NOX Emission BINS | | | | | No RSD |
|-------------------|-------------|-------------------|------------|------------|--------|--------|--------|
| | | -2 | -1 | 0 | 1 | 2 | |
| Model Year Groups | 2007 - 2010 | 1 0 | 1 0 | 1 0 | 1 0 | 0 0 | |
| | 2004 - 2006 | 1 0 | 2 2 | 1 1 | 1 0 | 1 1 | (2) |
| | 1998 - 2003 | 1 0 | 2 2 (2) | 3 2 (8) | 2 2 | 2 0 | (4) |
| | 1994 - 1997 | 0 0 | 1 0 (1) | 2 1 (1) | 2 3 | 2 0 | (2) |
| | 1978 - 1993 | 1 0 | 1 1 | 1 1 | 1 1 | 1 0 | |

Table 5.3-2 PEMS and PAMS Test Counts, By Truck

| Recruiting Bin Info | | Truck Information | | | | PEMS Test Types | | PAMS |
|---------------------|---------|-------------------|-----------|----------|---------------|-----------------|--------------|------|
| MY Group | NOx Bin | Model Yr | Plate | Truck ID | Make | Gaseous Only | Gaseous & PM | |
| 04-06 | 2d | 2004 | 1191083-A | 3300 | Kenworth | | 2 | 1 |
| 04-06 | -1d | 2004 | 0185067-A | 787 | Kenworth | | 1 | 1 |
| 04-06 | -1d | 2004 | 1191018-A | 647 | Freightliner | | 1 | |
| 98-03 | -1c | 2003 | 0190306-B | 321 | Volvo | | 1 | |
| 98-03 | -1c | 2000 | 0218126-A | 232 | Freightliner | | 2 | |
| 98-03 | -1c | 1999 | 0180990-A | 829 | Freightliner | 1 | | |
| 98-03 | -1c | 2000 | 0186029-A | 455 | Freightliner | 1 | | |
| 94-97 | -1b | 1997 | 0160699-A | 559 | Freightliner | 1 | | |
| 78-93 | -1a | 1980 | 0181276-B | 668 | Kenworth | | 2 | 1 |
| 04-06 | 0d | 2004 | 1191084-A | 3400 | Kenworth | | 1 | |
| 98-03 | 0c | 2003 | 0183710-A | C105 | Freightliner | | 1 | 1 |
| 98-03 | 0c | 2000 | 0185774-B | 260 | Kenworth | | 1 | |
| 98-03 | 0c | 2003 | 0183713-A | C108 | Freightliner | 1 | | 1 |
| 98-03 | 0c | 2003 | 0183716-A | c111 | Freightliner | 1 | | 1 |
| 98-03 | 0c | 2001 | 1095729-B | 1800 | Freightliner | 1 | | 1 |
| 98-03 | 0c | 1998 | 0185576-A | 778 | International | 1 | | 1 |
| 98-03 | 0c | 1999 | 1144157-A | None | International | 1 | | |
| 98-03 | 0c | 1999 | 0183558-A | 356 | International | 1 | | |

| Recruiting Bin Info | | Truck Information | | | | PEMS Test Types | | PAMS |
|---------------------|---------|-------------------|-----------|----------|---------------|-----------------|--------------|------|
| MY Group | NOx Bin | Model Yr | Plate | Truck ID | Make | Gaseous Only | Gaseous & PM | |
| 98-03 | 0c | 2001 | 0185728-A | 812 | Freightliner | 1 | | |
| 98-03 | 0c | 2001 | 1095730-A | 2000 | Freightliner | 2 | | 1 |
| 94-97 | 0b | 1994 | 0178515-B | 414 | Freightliner | | 2 | 1 |
| 94-97 | 0b | 1997 | 0190992-A | 834 | Freightliner | 1 | | |
| 78-93 | 0a | 1993 | 0181096-A | 435 | Freightliner | 1 | 1 | |
| | | | | | | | | |
| 98-03 | 1c | 2003 | 1190901-A | 771 | International | 1 | 1 | 1 |
| 98-03 | 1c | 2003 | 0183718-A | C113 | Freightliner | | 1 | 1 |
| 94-97 | 1b | 1996 | 0182003-A | 9210 | Volvo | 1 | 1 | 1 |
| 94-97 | 1b | 1996 | 0181157-A | 398 | Kenworth | | 1 | |
| 94-97 | 1b | 1997 | 0184781-A | 776 | Freightliner | | 2 | |
| 78-93 | 1a | 1993 | 0181021-A | None | International | | 1 | |
| | | | | | | | | |
| 04-06 | NONE | 2004 | 0160910-A | T796 | Freightliner | 1 | | |
| 04-06 | NONE | 2006 | 1157629-A | 851 | Freightliner | 1 | | |
| 94-97 | NONE | 1997 | 0190786-A | T639 | Freightliner | 1 | | |
| 94-97 | NONE | 1997 | 0267938-A | 20 | Freightliner | 1 | | |
| 98-03 | NONE | 1999 | 0188529-B | 830 | International | 1 | | |
| 98-03 | NONE | 1998 | 0189106-A | T657 | Freightliner | 1 | | |
| 98-03 | NONE | 2000 | 0182291-A | 794 | Kenworth | 1 | | |
| 98-03 | NONE | 1998 | 0182022-A | 1161 | International | 1 | | 1 |
| 98-03 | N/A | 2002 | 0183438-A | L-0247 | International | | | 1 |
| 98-03 | N/A | 2003 | 0183439-A | L-0306 | Freightliner | | | 1 |
| 98-03 | N/A | 1999 | 0186809-A | 459 | Freightliner | | | 1 |
| 98-03 | N/A | 2001 | 0186844-A | 785 | Freightliner | | | 1 |
| 94-97 | N/A | 1997 | 0190758-A | L-9754 | Freightliner | | | 1 |
| 98-03 | N/A | 2000 | 1075087-A | 001 | Peterbilt | | | 1 |
| 98-03 | N/A | 2000 | 1190370-A | 3000 | International | | | 1 |
| 98-03 | N/A | 2003 | 1191097-A | C121 | Freightliner | | | 1 |
| 98-03 | N/A | 2000 | Temp | 821 | Freightliner | | | 1 |

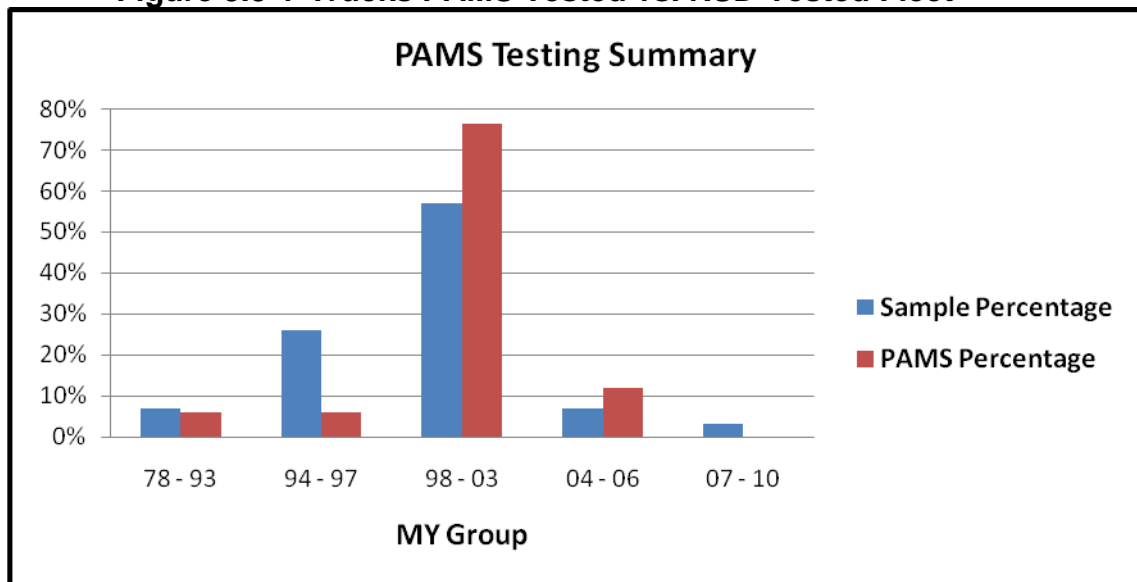
Occasionally some of the gaseous-only oversampled trucks were not part of the 1877 RSD-tested fleet (some gaseous-only trucks did not received a pre-study RSD test). The decision to test non-RSD sampled trucks was made between ERG and EPA onsite staff in order to maximize the number of trucks tested, since an adequate number of RSD-sampled trucks was insufficient to meet gaseous/PM and gaseous-only sampling needs at some facilities. All trucks which received gaseous/PM tests were within the fleet of 1877 RSD-tested trucks.

Table 5.3-2 also lists the 23 PAMS instrumentations which were performed during the study. Of the 23 PAMS instrumentations, 14 of those were on trucks which also received PEMS testing. As previously described, during the course of the study, a mutual decision was made between ERG and EPA that trucks not included in the fleet of 1877 RSD-sampled trucks could receive PAMS instrumentations, as long as the trucks would be doing port work and fell within the model year profile of the 1877 truck fleet which had received RSD tests. Table 5.3-3 lists general statistics regarding the number of PAMS-instrumented trucks within each model year group. This is shown graphically in Figure 5.3-1. Due to truck availability and fieldwork logistics, the 1998-2003 model year group was oversampled, while the 1994-1997 group was undersampled. However, this is not expected to influence the nature of activity data collected during this study.

Table 5.3-3 PAMS Tests by Model Year Group

| MY Group | 78 - 93 | 94 - 97 | 98 - 03 | 04 - 06 | 07 - 10 |
|-------------|---------|---------|---------|---------|---------|
| # in Sample | 122 | 494 | 1065 | 131 | 65 |
| Sample % | 7% | 26% | 57% | 7% | 3% |
| PAMS Count | 1 | 3 | 17 | 2 | 0 |
| PAMS % | 6% | 6% | 76% | 12% | 0% |

Figure 5.3-1 Trucks PAMS Tested vs. RSD-Tested Fleet



Additional information pertaining to each PEMS or PAMS test, including details instrumented trucks PEMS/PAMS operating and setup parameters for each test is provided in

Appendix I. A log summarizing all tests performed throughout the study and participation incentive payments issued for each test is provided in Appendix L.

6.0 Data Analysis and QC

As much as possible, all PEMS and PAMS systems (and datastreams) were monitored during collection followed by extensive QC and processing performed after data collection was completed. Data processing, QC and analysis steps are described for PEMS and PAMS data in the following sections.

6.1 PEMS Data Processing and QC

As mentioned in Section 5, the operation of PEMS test equipment was continuously monitored by personnel throughout each test. Real-time monitoring of test parameters was performed by the ride-along team member via a laptop communicating with the PEMS (and MPS) in order to identify and correct any data or equipment issues. In addition, test files were extracted during and immediately after each test, processed and reviewed for data quality issues or problems. This real-time “in-field” QC was performed in order to identify issues with exhaust and MPS flows and gravimetric filter system flowrates, system temperatures and pressures, pollutant concentrations and other measured and recorded parameters.

After fieldwork was complete, all PEMS data underwent processing to create time-aligned, comma-delimited data files incorporating test-specific input settings for each test. Initial data review and QC was also performed at this time. This initial data processing and QC was performed by Sensors, Inc. using their SEMTECH post-processing software, Excel-based plotting macros, and also through manual review of data files. Once Sensors processed, QC'd and corrected all PEMS files, they transferred these files along with all notes pertaining to data review and corrections to ERG. All data correction and review notes provided by Sensors can be found in Appendices J and K. Appendix J contains general PEMS data QC guidelines used during data review (App J-1), notes compiled by Sensors during data processing and corrections (App J-2), and information pertaining to data issues, processing and corrections which were made to the PEMS data during Sensors' processing and QC (App J-3). Appendix K contains a by-test/by filter review of all PEMS second-by-second data performed by Sensors. This appendix contains details of the QC described in Appendix J.

Upon receipt of the processed PEMS data and notes from Sensors, ERG performed additional data analysis and validation in order to resolve all outstanding data issues. Results of this second data review are provided in Appendix J-4. Once the second review was complete, ERG imported the data into Statistical Analysis Software (SAS) and processed results for analysis, reporting and data delivery. In addition to applying data analysis filters within SAS, all

previously identified issues were flagged or corrected, as appropriate. A complete list of filters, corrections and flags applied in SAS is provided in Appendix J-5.

The following sections describe the specific areas of focus during processing and analysis of the drayage PEMS data. Test-specific details of analysis can be found in Appendices J and K.

6.1.1 Initial Drayage Processing and QC

The primary areas of focus during Sensors' data processing and QC included the following:

Exhaust transport delays: Sensors time-aligned all data, accounting for exhaust transport and gas bench measurement delays, ECU data acquisition delays and GPS signal acquisition delays. Alignments were performed using known system rates and were confirmed visually by comparing relevant time-series plots (i.e., CO₂ concentration vs. exhaust mass flow rate, CO₂ concentrations vs. ECU derived torque, exhaust mass flow rate vs. ECU RPM, and GPS speed vs. ECU speed and PEMS fuel rate vs. ECU fuel rate). Data was generally aligned within one second during Sensors' post-processing.

Mass emission calculations: Mass emission calculations were based on measured carbon concentrations and exhaust flowrates, excluding tests in which the flowmeter data was invalid or missing. In those cases, mass emission calculations were based on the ECU fuel rate. Mass-based emissions from the following tests were based on ECU fuel rate: 0182003-A_20100309_E, 0183710-A_20091215_E (only part of this test) and 1190901-A_20100208_E.

Vehicle speed: Vehicle speed was primarily based on GPS data. If GPS-based speed was found to be invalid, vehicle speed from the ECU datastream was used for that particular test.

Engine speed: Engine speed (RPM) was primarily taken from the ECU datastream, if an ECU datastream was available. For a few tests, the truck was either mechanically controlled (hence no ECU data) or the ECU port was inaccessible, i.e., the available diagnostic link connector (DLC) had been removed. In these instances, an optical RPM probe was used and calibrated with either a handheld optical tachometer or the truck's onboard tachometer. The following tests were performed using an optical sensor: 0181021-A_20091215_E, 0181276-B_20091208_E and 1191084-A_20080127_E. For these tests, Sensors verified the PEMS software's RPM multiplier was correct during post-processing.

Kh Calc method: 40 CFR 1065.670 methodology was used for the NO_x humidity correction factor.

Weather data: Sensors post-processed PEMS results using data from the weather probe.

Fuel settings: #2 diesel, specific gravity and hydrogen to carbon molar ratios used during post processing were based on fuel testing results EPA performed on samples collected during the study. Specific values based on fuel testing results are provided in Appendix AC, Drayage Processing Parameters. When data was not available for an individual truck, averages were used

from that establishment (when fleet vehicles were refueled from a common source), or overall study averages, as appropriate.

Detection Limits: All zero (default value) detection limits were applied

Calculation limits: Default values (1000 rpm/s, 21 mph/s, 0.05 gal/s, 0.5 % C for fuel specific dropout, 0.005 bhp-hr for brake specific dropout, 4 samples for THC FID auto range) were applied.

Drift corrections: For tests in which valid pre and post-zeros and spans had been collected, drift corrections were applied during data processing. Frequently, this required Sensors merge separate XML files containing the various pre and post-test calibrations. Once these were merged into the test data file, the SEMTECH post-processor applied drift corrections (on a percentage basis) based on zeros and spans (linear interpolation correction of drift throughout the test). The post-processor also applied corrections based on any autozeros which had been performed during testing. The test files ERG received from Sensors had drift corrections applied (on a percentage basis) whenever possible. Details of which files were drift corrected are provided in Appendices J-4 and K.

O₂ sensor corrections / adjustments: O₂ ranges were evaluated, but O₂ sensor corrections were not applied. Exhaust is assumed to have no dilution.

Autozeros: Sensors output the sample path field to identify when autozeros were performed during sampling (an “ambient” sample stream suggests an autozero is being performed). In SAS, ERG has flagged and excluded autozeros. Field guidelines specified autozeros only be performed during times when the truck was not in active use, so autozeros generally did not affect active data collection.

Other data review & corrections: Through review of time-series plots of all primary measured and system parameters, Sensors identified and flagged improper temps, flows, dilution, pollutant concentration, proportionality, etc., as listed in Appendices J and K. In addition, any data corrections which were applied during post-processing are described in these appendices.

Correct certain test files collected when flowmeter 33341 was plumbed incorrectly: At some point during the study (prior to February 9th, 2010), the tubing on flowmeter 33341 was switched (labeled wrong and tubing consequently plumbed incorrectly). This was identified (and corrected) by a Sensors technician during a field installation on March 14, 2010. Four tests were performed with this “misplumbed” flowmeter. This resulted in an associated bias in the exhaust mass flow rate (measured flowrate was approximately 40% underreported). To correct this, Sensors performed a lab correlation comparing measurements from the flowmeter in the misplumbed configuration with results from their laminar flow element across varying flow ranges. This comparison was used to develop a correction factor (of 1.62) to be applied to the exhaust flow data during post-processing, as described in Appendix J-3. This correction should be applied if the PEMS data is reprocessed in the future. This affects the following four tests: 0160910-A_20100211_E, 1144157-A_20100308_E, 0267938-A_20100310_E, and 0185728-A_20100312_E.

6.1.2 Subsequent Drayage QC, Analysis and Reporting Summaries

Building on the work already performed by Sensors, ERG continued analysis and QC of the processed PEMS data using Sensors' data review notes. The following steps were performed.

Perform final data QC and validation: As described in Section 6.1, ERG performed additional data engineering review and analysis on the drayage PEMS data in order to identify and resolve all outstanding data issues. Second-by-second review involved evaluation of all gaseous pollutants, review of sampling system pressures such as the MPS inlet pressure and SEMTECH pressures, evaluation of all system flows including the exhaust mass flow rates, calculation of fuel flow rate, all MPS sampling flowrates and gravimetric filter flowrates, and evaluation of all system and sampling temperatures such as exhaust temperatures, external heated line, chiller, cyclone, manifold and gravimetric filter temperatures, and ambient and internal PEMS temperatures. Results of this secondary data review are provided in Appendix J-4. This review was primarily performed by analyzing the time-series plots of all measured pollutants and system parameters that had been created by Sensors during the initial data processing process.

Perform date and time assignments and corrections – All dates and times were reviewed and corrected, as necessary. This primarily corrected all timestamps to be consistent with the central time zone (either Central Standard Time or Central Daylight Savings Time). Adjustments were made based on GPS times recorded in the datafile, which represent Greenwich Mean Time.

Perform gravimetric filter reconciliation: As previously described, information pertaining to gravimetric filters collected during a test was recorded by ride-along personnel on filter data collection forms. Information collected in order to identify the filter during data processing included filter ID (unique laboratory serial number for each filter) along with holder location (sample holder 1, 2 or 3). In this way, the overall sequence of holder IDs activated could be used to identify each gravimetric filter. However, for several reasons, including multiple sampling of filters (with bypass in-between) and switching back and forth between filters multiple times, some discrepancies were identified between the gravimetric filter sequence recorded in filter data collection forms and the gravimetric sampling sequence recorded in the data file for each test. Using information contained in the ride-along notes collected during sampling and filter pressure differential data recorded in the data file, ERG reconciled information in the filter log to information recorded in each data file. The final sampling sequence is shown in Appendix T, Drayage Filter Log.

SAS readin and QC: All data provided by Sensors was read into SAS. Test files were compiled into a single file for each day of testing. In SAS, ERG flagged data collected during autozeros, data in which one or more pollutant or RPM values are missing and data identified during ERG's or Sensors' second-by-second engineering review as suspect or invalid. In general, suspect data is excluded from emission summaries included in this report, and is also identified in the final emissions database provided for this project. The filter ID sampling sequence previously determined was assigned in SAS, and filters affected by excluded data are identified in emission summaries included in this report and in the filter log in Appendix T. GPS speed ("iGPS_Ground_Speed, mph") was used as the primary vehicle speed. Vehicle speed from the

ECU “iVEH_SPEED, mph” was used if the GPS speed was invalid, missing, or suspect. When GPS speed was used, this variable was advanced by 2 seconds (2 seconds earlier relative to the rest of the data file) in order to refine the GPS alignment to other system parameters. All corrections/adjustments made to variables are listed in Appendix J-5.

MPS proportionality to flow review: In SAS, ERG plotted the MPS average sample flow rate (iMPS_Average_Q, SCCM) against the exhaust mass flow rate (icMASS_FLOW, kg/hr) and calculated the best fit line slope, intercept, coefficient of determination (r^2) and root mean square error (RMSE) in order to assess the quality of proportionality. Results are provided in Appendix AF, MPS to Exhaust Flow Proportionality Plots. Proportionality plots are provided both for the overall test and also for only the time periods when filter sampling was being performed. Filter proportionality is also used in assessing gravimetric filter result validity listed in Appendix T (Drayage Filter Log).

Calculate brake-specific power for each observation: In SAS, ERG calculated brake-specific emissions using several different methods. Most vehicles were electronically controlled and some indication of load was available via the ECU datastream. For these vehicles the ECU load was used, but needed to be manipulated in order to calculate the net ‘brake’ torque at the flywheel for VSP bin assignments.

For this discussion of the calculations that were performed in order to calculate brake torque, the following definitions apply (much of this information is listed in Section 12.6.2 of the Oct 2008 SEMTECH-DS User Manual):

Brake torque – Engine torque value (N-m or ft-lb), which is the total torque (cylinder torque) minus the engine’s frictional torque loss. Brake torque is zero when engine is running with no accessory or powertrain loads. The brake torque value is used for VSP calculations.

Frictional torque – Frictional torque, representing the frictional losses within the engine, is calculated by multiplying the two J1939 ECU datastream parameters “percent friction torque” and “reference engine torque”. Frictional torque may then be subtracted from the calculated cylinder torque to calculate brake-torque (i.e., net torque). For trucks using the J1708 protocol, the frictional torque is accounted for by using the recorded cylinder torque values at idle as described below.

Cylinder torque – Total engine torque value (N-m or ft-lb) before frictional torque is deducted. Cylinder torque is non-zero during unloaded engine operation.

Derived torque – ECU datastream torque value (N-m or ft-lb) representing the engine’s torque output at any point in time – ECU derived torque may be brake or cylinder torque, depending on the engine’s operating load at that point in time and the way in which the different engine manufacturers program ECUs.

Lug curve – Total maximum brake torque value achievable for any specific RPM, as defined by the engine manufacturer. Lug curves are included in J1939 datastream as

“reference engine torque” but needed to be obtained from engine manufacturers for many of the J1708 tests. Most of the lug curves used for these calculations were taken from advertising brochures printed by the engine manufacturers.

Percent load – ECU datastream value (%) which is the derived torque divided by the lug curve torque at the current RPM (ie for a given RPM, it is the current torque output divided by the maximum torque output). Note that percent load may be brake or cylinder. Ideally, the “unloaded” percent load would be determined by operating the engine at various speeds with no load (no accessories, a/c, power take off, or vehicle motion). However, the status of air conditioner or other accessories was not known for this study’s tests. Therefore, for this analysis, we assume that the “unloaded” percent load is just the average of the values seen with the vehicle at idle with no motion.

Idle Offset - As defined by ERG, this is the value of either ECU torque or percent load that is read from the ECU while the engine is at idle with zero net torque output. ERG calculated this value based on the average torque or percent load during the first extended idle recorded for each truck in which the engine was warmed up to or near its typical coolant temperature. It can also be thought of as the friction torque at idle.

For the data from each truck, one of the following three methods was used for correcting the ECU derived torque to brake torque:

Method 2 (J1708) – This is Method 2 listed in Section 12.6.2.2 of the Oct 2008 SEMTECH-DS User Manual (Method 1, the 30 second window, is not applicable for this study). Method 2 uses a manufacturer-provided lug curve to convert percent load to derived torque. Specifically:

$$\text{Derived torque}_{\text{brake}} = \text{percent load}_{\text{brake}} \times \text{lug curve}$$

In Method 2, if percent load is given as cylinder load, it may be converted to brake load using the following WVU equation which uses the percent load idle offset as defined above:

$$\% \text{ load}_{\text{brake}} = (\% \text{ load}_{\text{cyl}} - \% \text{ load}_{\text{cyl}} @ \text{ idle}) / (100 - \% \text{ load}_{\text{cyl}} @ \text{ idle})$$

This method was used for the trucks that used the 1708 protocol but did not output a derived torque, only a percent load.

Modified Method 2 (J1708) – This method was created by ERG to adjust derived torque values from J1708 protocol engines for frictional losses. It was used for all J1708 trucks that output an absolute value for derived torque such that an outside lug curve was not necessary. The method uses a similar correction to Method 2, in which the torque is adjusted downward at low load to account for frictional losses, but not adjusted at the maximum load. The adjustment is linear across the range of engine loads. The equation is as follows:

$$\text{Net Torque}_{\text{brake}} = (1 + \text{Torque}_{\text{idle}} / (\text{Torque}_{\text{max}} - \text{Torque}_{\text{idle}})) \times \text{Torque} - (\text{Torque}_{\text{idle}} + \text{Torque}_{\text{idle}}^2 / (\text{Torque}_{\text{max}} - \text{Torque}_{\text{idle}}))$$

Where

$\text{Torque}_{\text{idle}}$ = The average derived torque reading when the engine is idling (idle offset)

$\text{Torque}_{\text{max}}$ = The maximum recorded derived torque reading over the entire test

Torque = The derived torque reading to be corrected to net torque

Modified Method 2 was created because the maximum derived torque values observed in the ECU data were very close to the maximum torque values given in the torque curves found based on engine tag data. If $\text{Torque}_{\text{idle}}$ had been subtracted directly from the maximum torque, the resulting data would not have matched the maximum torque curve values for many of the trucks. For this reason, the equation was developed to adjust for frictional losses at idle, but not to adjust the torque at points where the torque was close to the correct net torque as given by the manufacturer.

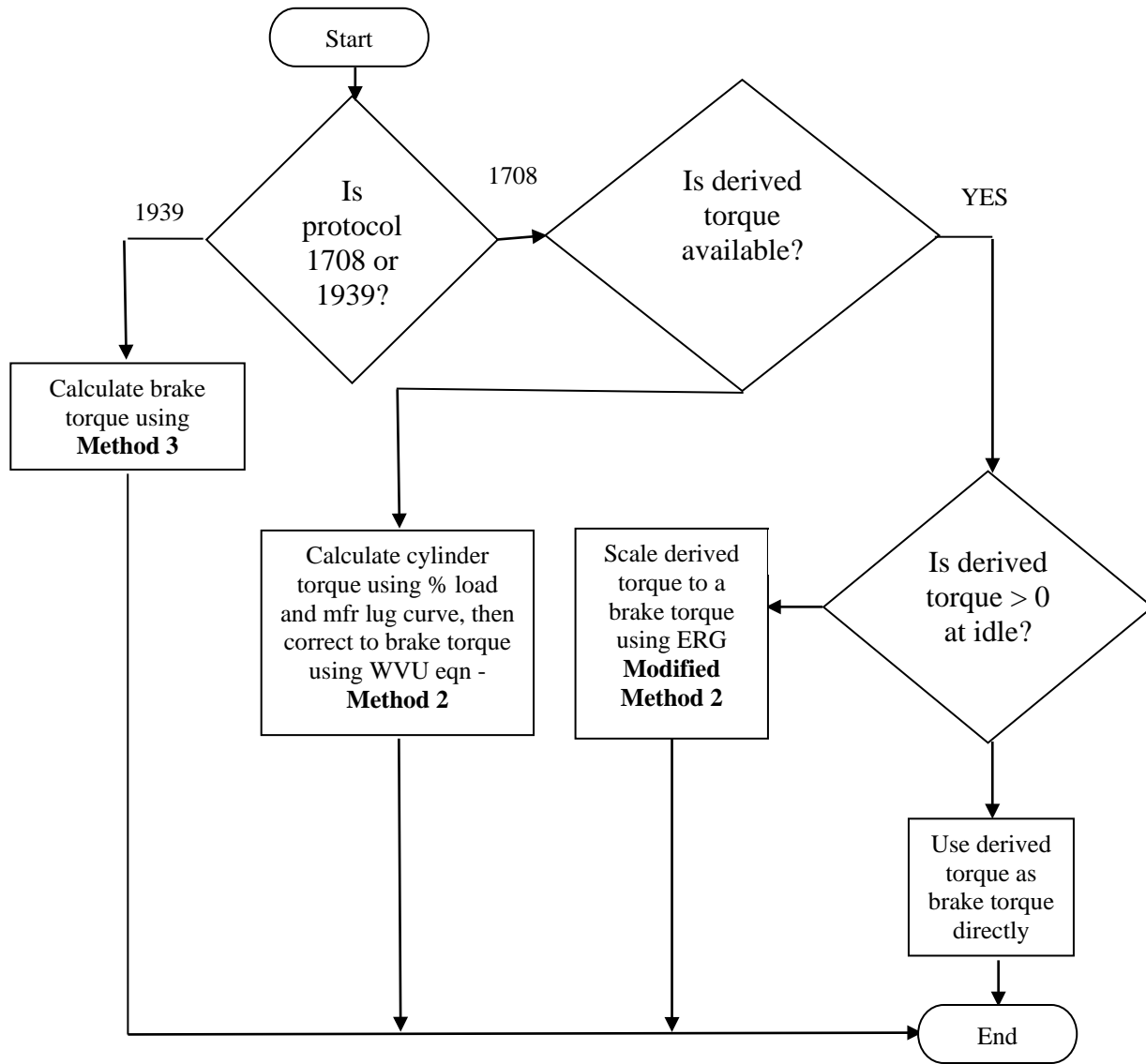
All J1708 protocol trucks had a single assigned idle offset value, but the idle torque (or load) value was not constant during operation and each truck had variability in this value. Because of this, the recorded data would still include many positive and negative values for torque at idle. Because net torque cannot be negative at idle and because negative torque does not have any significance from an emissions perspective, all negative values for torque were set to zero. In order to avoid the upward bias in the total engine work output that this would cause, all positive idle torque values were then set to zero based on other parameters. At times when the vehicle was stationary, the engine was on, and the accelerator pedal was not depressed, the net torque was set to zero.

Method 3 (J1939) – This is the method listed in Section 12.6.2.3 of the Oct 2008 SEMTECH-DS User Manual in which the derived torque is calculated as in Method 2, except the “reference engine torque” (max engine torque provided in the ECU datastream) is used instead of a lug curve. The derived torque is then converted to a brake torque by subtracting out the friction torque (also calculated from ECU parameters). This procedure was used for all J1939 protocol trucks. Specifically

$$\text{Net Torque}_{\text{brake}} = (\text{Percent Torque} - \text{Friction Percent Torque}) \times \text{Reference Torque}$$

The method used to calculate $\text{Net Torque}_{\text{brake}}$ from the ECU derived values for each truck was chosen according to the Figure 6.1-1.

Figure 6.1-1 Process for Calculating Brake Specific Power Output with ECU Data



Sourcing torque and BSFC curves: As mentioned above, engine manufacturer advertising brochures were the primary source of torque and BSFC curves. ERG conducted Internet searches to find brochures to match the different engines tested during the program. EPA assisted by providing a number of brochures and torque curves from its own internal records. Torque and BSFC curves were matched to the engines tested based on the engine tag information from each engine. It is possible that an engine could have been reprogrammed to have a different rating than it had originally, but there was no practical way to check for this so all curves were chosen based on the observed engine tags. ERG also contacted both Caterpillar and Cummins in search of lug curves that were more difficult to find, but there were three trucks for which curves could

not be found. For these trucks, ERG has supplied the logged engine and exhaust emissions data without any torque or VSP data.

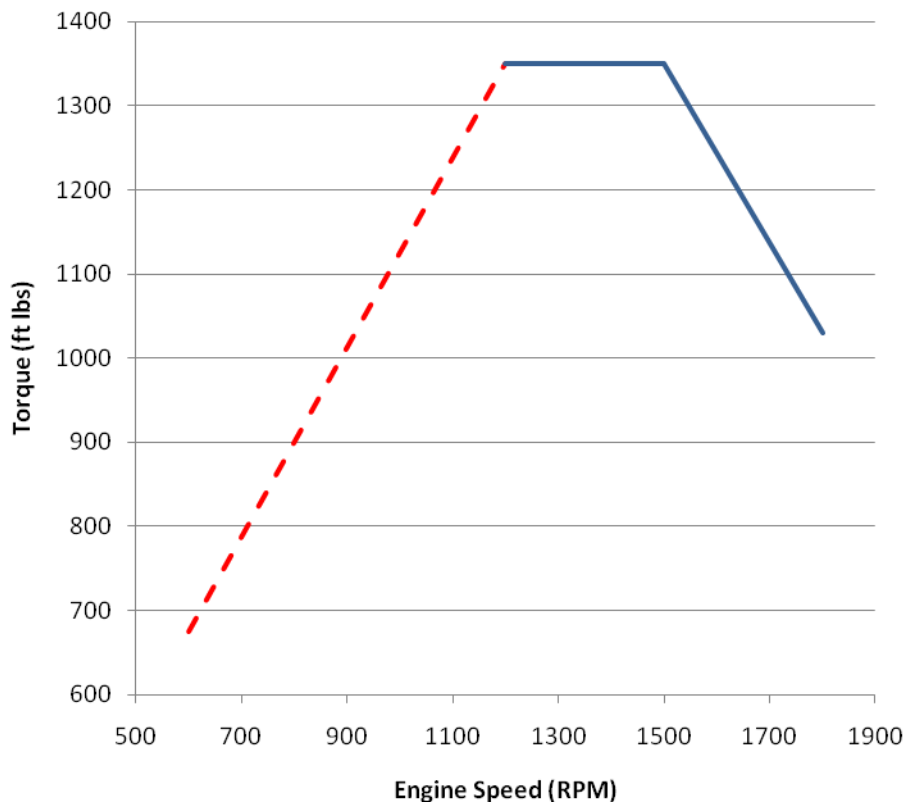
The published torque curves of most engines consist of linear segments depending on RPM. Most engines have flat, constant torque values at the middle of the RPM range, with a linear decrease in torque at higher engine speeds. For this reason, ERG used torque tables for each engine based on linear, piece-wise functions that were fit to the advertised curves.

Many of the published advertising curves do not plot the engine torque at low engine speeds. Most of the available curves begin between 1000 and 1200 RPM and extend up to maximum engine speed. Because the PEMS and PAMS data included points throughout the entire engine speed range including these lower engine speeds, ERG made an assumption for the shape of all curves at low engine speeds. Two torque curves were found in research literature that included full sweeps of maximum torque over the complete range of engine speeds^(4,5). For both of these curves, it appeared that the maximum torque at idle speed was about half of the maximum torque value for the engine, and increased continuously up to the maximum torque value. For this reason, ERG applied a similar shape to the other curves which had published curves that began at elevated engine speeds. The maximum idle-speed torque was taken to be half of the maximum engine torque, with a linear increase up to the first point on the published advertising curves. An example of this assumption, made for the Caterpillar 3406E engine rated at 355 hp, is provided in the Figure 6.1-2. The solid blue line represents the torque as given by the advertised torque curve, which does not contain information below 1200 RPM. The dashed red line includes the extrapolation down to idle speed as performed by ERG at lower engine speeds.

For the four PEMS tests conducted on vehicles with no ECU datastream (0181021-A_20091216_E, 0181276-B_20091209_E, 0181276-B_20100125_E and 1191084-A_20100128_E), BSFC emissions could be calculated by dividing the SEMTECH-DS' fuel consumption rate and optically-measured RPM by the maximum fuel consumption rate obtained from each engine's brake-specific fuel consumption (BSFC) vs. RPM curves. Multiplying this ratio of "measured" fuel consumption (via PEMS) to maximum fuel consumption (from the lug curve) by the maximum engine power output at that RPM for each observation would provide an estimate of power for each second of data, which could be summed over the test to provide overall brake-specific emission estimates. This was the methodology employed in the Nonroad work assignment under this contract⁽⁶⁾. However, no brake-specific fuel consumption vs. RPM curves were identified which corresponded to the known characteristics of engines in the above tests (these are the three trucks mentioned above for which no curves were available). Therefore, for the above four tests, emissions are provided on a fuel and mileage basis, but not on a work basis.

A list of which methodology was used for estimating BSFC emissions for each truck is provided in Appendix AC, Drayage Processing Parameters. Appendix AD provides the torque curves used in this study.

Figure 6.1-2 Extrapolated lug curve for the Cat 3406E Engine Rated at 355 HP



Calculate Emissions. Using the brake-specific power estimates previously calculated, ERG calculated mass-based brake-specific gaseous and PM emission estimates for all tests for which lug curves were available (lug curves and fuel maps were not available for several tests, so brake-specific emissions were not calculated for these tests). In addition, ERG also calculated fuel-based and mileage-based gaseous and PM emission estimates. Estimates are presented for the overall test, by filter, and also segregated by port/non-port and idle/non-idle operation, as described below.

Designate Port and Idle Operation: In SAS, gaseous and PM emission estimates are provided both within and outside of port terminals (based on GPS / ride-along notes). The terminals in this study were initially identified by review of the filter log (Appendix T) and ride-along notes (Appendix U). This review revealed four terminals in which operations were conducted. These were Barbour’s Cut Container Terminal, Bayport Container Terminal, Jacintoport General Cargo Terminal, and Greens Port Industrial Park Terminal. Boundaries for these four areas were then established as shown in Appendix AB, and all PEMS and PAMS data with GPS coordinates falling within these boundaries was identified as “port” activity. In addition to port identification, gaseous and PM emission estimates are distinguished as idle vs. non-idle operation. Idle operation was determined by evaluating vehicle speed (under 1 mph), throttle position (under 3%), and engine status (on). Filters collected during idle periods were identified using filter data collection notes (Appendix T).

Assign Emissions to MOVES Operational Bins: Using the brake-specific power estimates previously calculated, ERG categorized emissions into MOVES operational bins according to methodology provided in the Heavy-Duty MOVES Emission Rate Development Documentation⁽¹⁾.

The equation used to assign MOVES operational bins was:

$$VSP = \eta_{\text{driveline}} \times ((P_{\text{bs}}) \times 0.746 - P_{\text{loss,acc}}) / m_{\text{avg,regclass}}$$

For our analysis, the following values were used:

$\eta_{\text{driveline}}$, driveline efficiency, was estimated to be 90% for all trucks tested, based on information in the guidance document.

P_{bs} , brake specific horsepower, was calculated as described above. Note that the factor of 0.746 is used to convert HP to kW.

$P_{\text{loss,acc}}$ was set at 8 kW to account for total accessory loads, and is roughly equivalent to the low HDT value provided in Table 6 of the reference document. This value was selected based on conversations between ERG and EPA⁽²⁾

$m_{\text{avg,regclass}}$, the average running weight value, was set to 17.1 metric tons, to fall within the MHD to HHD range listed in Table 8 of the reference document. This value was selected based on conversations between ERG and EPA⁽²⁾

Once a VSP value was calculated for each second of operation, an operating mode bin was assigned according to the definitions in Table 6.1-1.

RSD vs. PEMS emissions comparison – Using results in MOVES operational mode bins, ERG compared truck emissions as measured during the July 2009 RSD study to PEMS results collected for the same trucks.

Table 6.1-1 MOVES HD Operating Mode Definitions (update)

| Operating Mode | Operating Mode Description | Vehicle-Specific Power (VSP _t) (kW/ metric tonne) | Vehicle Speed (v _t ,mi/hr) | Vehicle Acceleration (g _s , i.e., acc/gravity) |
|----------------|----------------------------|---|---------------------------------------|--|
| 1 | Idle | | $-1.0 \leq v_t < 1.0$ | |
| 11 | Coast | $VSP_t < 0$ | $1 \leq v_t < 25$ | |
| 12 | Cruise/Accel | $0 \leq VSP_t < 3$ | $1 \leq v_t < 25$ | |
| 13 | Cruise/Accel | $3 \leq VSP_t < 6$ | $1 \leq v_t < 25$ | |
| 14 | Cruise/Accel | $6 \leq VSP_t < 9$ | $1 \leq v_t < 25$ | |
| 15 | Cruise/Accel | $9 \leq VSP_t < 12$ | $1 \leq v_t < 25$ | |
| 16 | Cruise/Accel | $12 \leq VSP_t$ | $1 \leq v_t < 25$ | |
| 21 | Coast | $VSP_t < 0$ | $25 \leq v_t < 50$ | |
| 22 | Cruise/Accel | $0 \leq VSP_t < 3$ | $25 \leq v_t < 50$ | |
| 23 | Cruise/Accel | $3 \leq VSP_t < 6$ | $25 \leq v_t < 50$ | |
| 24 | Cruise/Accel | $6 \leq VSP_t < 9$ | $25 \leq v_t < 50$ | |
| 25 | Cruise/Accel | $9 \leq VSP_t < 12$ | $25 \leq v_t < 50$ | |
| 27 | Cruise/Accel | $12 \leq VSP_t < 18$ | $25 \leq v_t < 50$ | |
| 28 | Cruise/Accel | $18 \leq VSP_t < 24$ | $25 \leq v_t < 50$ | |
| 29 | Cruise/Accel | $24 \leq VSP_t < 30$ | $25 \leq v_t < 50$ | |
| 30 | Cruise/Accel | $30 \leq VSP_t$ | $25 \leq v_t < 50$ | |
| 33 | Cruise/Accel | $VSP_t < 6$ | $50 \leq v_t$ | |
| 35 | Cruise/Accel | $6 \leq VSP_t < 12$ | $50 \leq v_t$ | |
| 37 | Cruise/Accel | $12 \leq VSP_t < 18$ | $50 \leq v_t$ | |
| 38 | Cruise/Accel | $18 \leq VSP_t < 24$ | $50 \leq v_t$ | |
| 39 | Cruise/Accel | $24 \leq VSP_t < 30$ | $50 \leq v_t$ | |
| 40 | Cruise/Accel | $30 \leq VSP_t$ | $50 \leq v_t$ | |
| 0 | Deceleration / Braking | | | $a_t \leq -0.0911$ OR $(a_t < -0.0456$ AND $a_{t-1} < -0.0456$ AND $a_{t-2} < -0.0456)$ |

6.2 PAMS Data Processing and QC

A summary of the PAMS data processing and QC steps is provided below.

Process, export, consolidate, read into SAS - All PAMS datalogger files were processed and exported to comma-separated variable (CSV) files. The CSV files were read into Statistical Analysis Software (SAS) and compiled into chronological datasets for each piece of equipment (i.e., each installation).

Perform date and time assignments and corrections – All date and times were reviewed and corrected, as necessary. For example, the PAMS units would not correctly log the time at exactly midnight and therefore corrections for all midnight times were applied. There were no indications of issues related to setting the logger time during installation. There were, however, six trucks that had loggers recording during the spring shift to Daylight Saving Time. To compensate for this, ERG increased the time by one hour for all observations that were recorded after 2:00 AM on March 14, 2010. This compensation was performed for the trucks with these license plates: 0182003-A, 0182022-A, 0183438-A, 0183439-A, 0190758-A, and 1075087-A.

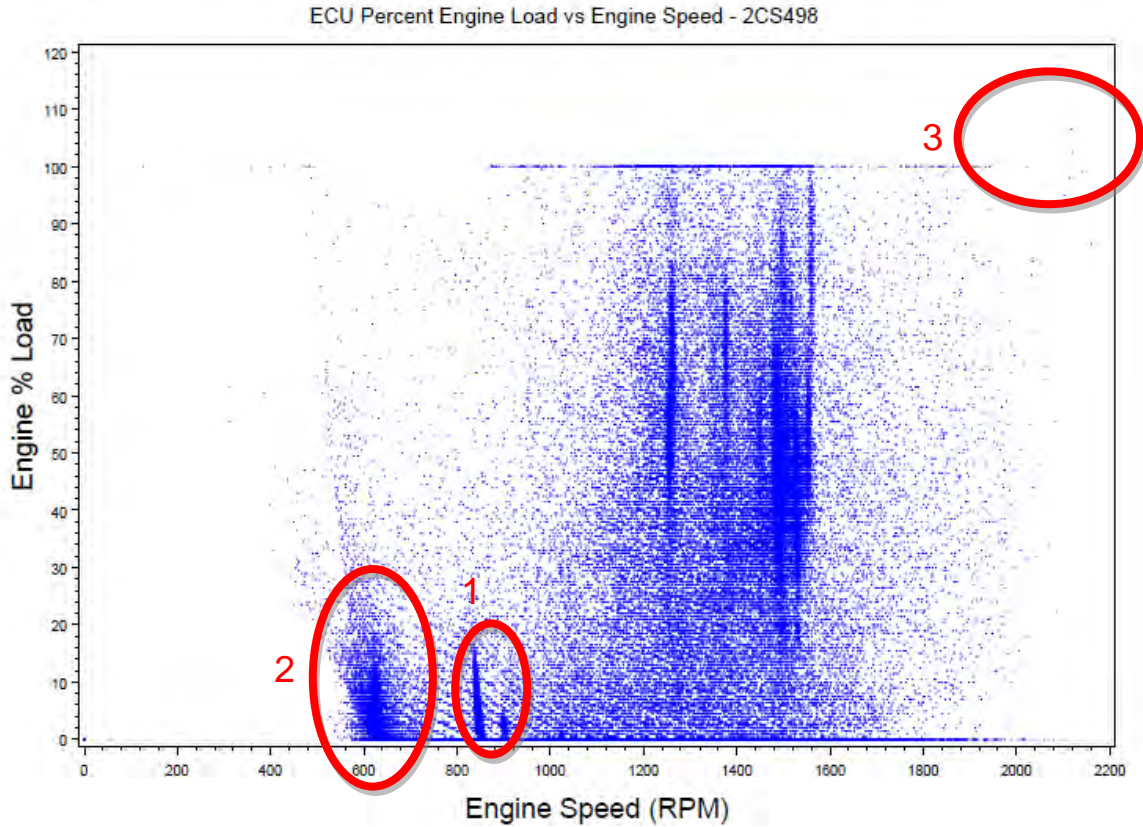
Time-align data streams: ERG performed time alignment of the data where necessary. For the PAMS units, the only signal requiring alignment was the GPS speed. The time lag was calculated by plotting the GPS speed and the ECU speed over time and finding the average lag between the maxima and minima of the two plots. This value was found to typically be two seconds, so all of the GPS speed data was aligned two seconds earlier than originally recorded.

Correct torque output spikes: ERG identified and modified all tests with ECU output torque “spikes” identified during PAMS analysis. These spikes refer to unreasonable torque values which were most often identified from the Detroit Diesel and Mercedes Benz engine datastreams while in fuel shut-off mode. These spikes appear to be associated with the way the Isaac datalogger processed the ECU datastream rather than the actual datastream from the ECU. Because these spikes occurred during fuel cutoff or at idle, the (net) output torque during these episodes was therefore set to zero in SAS. For the Mercedes-Benz trucks using the J1939 protocol, there were also spikes observed in the value for reference torque, which is the ECU value for the maximum cylinder torque of the engine. These spikes resulted in unreasonably high values for the engines’ maximum torque (approximately 65,000 newton-meters, or 48,000 ft-lbs), but would usually last only a few seconds. During these observed spikes, ERG set the reference torque to the previous reasonable value. It is likely that these observations were artifacts of the operation of the Isaac dataloggers as well.

Correct other ECU output data as required: ERG also performed all other necessary modifications of ECU torque or load values as necessary in order to calculate brake-specific power output values for MOVES classifications. Many of these corrections were necessary because of a scaling factor that is built into the PAMS units’ J1708 protocol setup. The PAMS data required a scaling factor of 50 to calculate the true torque values, and a scaling factor of 1.25 to calculate the true percent load values for all J1708 protocol trucks. ERG determined these factors by comparing the observed resolution in the data to the resolutions given in the J1708 protocol specification. Also, some trucks had brief RPM spikes that took place when the engine otherwise appeared to be off. These isolated spikes were not considered trips or engine-on time if the engine never reached its typical idle speed. Whenever a datafield was corrected, a new field was created (and the original data was retained).

An example of the percent engine load data from a J1708 protocol truck is provided below. The figure is representative of typical data recorded by the PAMS units after scaling to correct for the PAMS unit’s J1708 setup.

Figure 6.2-1 ECU Engine Percent Load vs. Speed for a J1708 protocol truck



Three areas of interest are highlighted in the above figure. The dark spikes shown in Area 1 occur during cold start idle operations. When the engine is first started, the ECU holds an elevated RPM so that the engine can run smoothly. The engine percent load as given by the ECU is initially at an elevated value as well, and it decreases as the engine warms up. This is because the friction torque of the engine is higher when cold. Area 2 is the region representing typical idle and near-idle operation. As with Area 1, the engine experiences higher percent load values during cold operation, even at idle. This results in overestimation of engine torque when the engine is cold, because the ECU percent load is elevated even though the net output torque is zero at idle. Area 3 indicates percent load values that exceed 100% at high engine speeds. This was observed for a number of the trucks. Typically, only a very few values at high RPM exceeded 100% load such as in the figure, though for one truck a large number of values exceeded 100%. The method of accounting for that vehicle’s engine load is described in Appendix AE. For all other trucks, no correction was applied and there were a few points that exceeded the maximum torque as given by the lug curves. It is not known why many of the ECUs represented load in this way.

Merge relevant PEMS Data: For trucks on which the PAMS was disconnected to perform PEMS testing, ERG merged the PEMS “activity” data into the PAMS data file during the PEMS test day when the PAMS was disconnected. The following table presents the trucks for which PEMS data was merged, along with the corresponding dates that the PEMS test took place.

| Truck | Date(s) |
|-----------|--------------------|
| 0178515-B | 12/10/09, 12/11/09 |
| 0183710-A | 12/15/09 |
| 0185067-A | 2/5/10 |
| 0185576-A | 2/4/10 |
| 1095729-B | 1/28/10 |
| 1095730-A | 2/1/10, 2/2/10 |
| 1190901-A | 2/8/10, 2/9/10 |
| 1191083-A | 2/1/10, 2/2/10 |
| 0182003-A | 3/9/10, 3/10/10 |
| 0182022-A | 3/8/10 |
| 0183716-A | 1/25/10 |
| 0183718-A | 12/14/09 |

Removal of engine-off data: The PAMS units were set to record all data continuously, irrespective of whether the engine was on or off. During analysis, only observations that occurred when the key was in the ‘on’ position were kept for analysis. Depending on the protocol, certain ECU values were used to indicate key on/off, and engine RPM was used to flag whether the engine was on or off. As a QC check, if GPS data indicated that a truck was moving even though the ECU or engine appeared to be off, this data was kept and flagged as having lost ECU data.

Assign Activity to MOVES Operational Bins: ERG categorized each second of operation into MOVES operational bins, using ECU data for power determination (and external lug curves when needed), according to the methodology described in Section 6.1.2. When ECU data was not available, no surrogates to power were available, so MOVES classifications were not performed.

Optical RPM Only one of the 23 trucks which received a PAMS instrumentation collected engine RPM optically (this was truck 0181276-B, a 1980 Kenworth). For this truck, activity data is not presented on a VSP basis, as no indicator of load was available.

Designate Port and Idle Operation: As with the PEMS data analysis described in Section 6.1.2, ERG distinguished activity both within and outside of the four primary port terminals in the study (Barbour’s Cut Container Terminal, Bayport Container Terminal, Jacintoport General Cargo Terminal and Greens Port Industrial Park Terminal). In addition, idle activity is distinguished from non-idle activity in the PAMS data, with summaries provided in this report. An engine was flagged to be at idle when the GPS speed was zero, the pedal position was at its unpressed base value, and the engine was on. Net torque values were set to zero if the idle flag was set regardless of whether they were logged as positive or negative values. This was performed to reduce the bias in total work output that would be caused by only setting negative torque values to zero at idle.

Assignment of trips and trip counts: In SAS, counts of trips (and number of observations for each trip) were assigned for each test file. Trips were defined as episodes of engine operation.

Trip counts were the total number of “trips”, separated by engine off periods. In some cases, mostly during very long trips, the PAMS unit would not record at the intended one hertz frequency and some data appeared missing. If there was no log of engine off time, the trip count was not increased even if there was a large amount of missing data. The first observation after a period of missing data (longer than 5 seconds) was flagged to indicate data was lost. Most engine start events upset the voltage to the PAMS loggers such that recording was briefly interrupted. These interruptions that occurred for all trucks for a few seconds at engine start were not flagged as missing data. Trip assignments are included in the data submission which will accompany this report.

Other QC Checks: After all of the above corrections were applied to the data, checks were performed to ensure the final data was reasonable. ERG compared the maximum torque and horsepower values from the data to those given on the engine tags where available. Also, ranges of values for each recorded variable were applied, and SAS was used to flag any data that fell outside these ranges. Based on observations in the final QC checks, ERG applied further corrections to the data recorded for a small number of the trucks. These truck-specific corrections are described in Appendix AE.

7.0 Study Results and Conclusions

7.1 Emissions results

The following subsections provide results from PEMS particulate matter and gaseous emissions measurements collected throughout the study. Emission results are provided in units of emissions per work performed and emissions per mile traveled. Idle emission rates are presented on a time basis (grams/second). Results of gravimetric measurements of dynamic and field blanks collected during the field study are also presented. A more thorough compilation of emission results is provided in Appendix M, Drayage Emissions Measurement Results.

7.1.1 PM Filter Weights

EPA supplied pre-weighed 47 mm Teflon filters in pre-loaded URG-2000-30FL filter cassettes. After PM collection, filter samples were transported to the EPA laboratory in the URG filter cassettes for post-test gravimetric measurements. Resultant data was provided to ERG on a total mass per filter basis (i.e., mg/filter).

Gravimetric sample particulate measurements were collected in accordance with guidelines provided various field SOPs described in Section 5.1. Weights of all gravimetric filters collected throughout the study are provided in Appendix T, the Drayage Filter Log.

7.1.1.1 Dynamic and Field Blanks

As described in Section 5.1, dynamic and field blanks were collected throughout the study to quantify the effect of handling and system contamination on the gravimetric filters collected during the study. Table 7.1-1 provides the laboratory measurement results from dynamic and field blanks collected during the study. These results (and additional information pertaining to collected filters) are also included in the Drayage Filter Log, Appendix T.

Table 7.1-1 Dynamic and Field Blank Measurement Results

| Date used | Filter ID | Test ID | Sample Type | Net Wt (mg) |
|------------------|------------------|-------------------|--------------------|--------------------|
| 12/9/09 | Q-8 | 0181276- B_E_1 | Dyn Blnk | 0.0422 |
| 12/15/09 | 9047499 | N/A | field blank | -0.154 |
| 1/28/10 | 9051848 | N/A | field blank | 0.0131 |
| 1/28/10 | 9051849 | N/A | field blank | 0.0133 |
| 1/28/10 | 9051850 | N/A | field blank | 0.0061 |
| 2/3/10 | 9051921 | 0184781- A_E_1 | Dyn Blnk | 0.0199 |
| 2/4/10 | 9048079 | 0184781- A_E_2 | Dyn Blnk | 0.0427 |
| 2/9/10 | 9051880 | 1190901-A-E-2 | Dyn Blnk | 0.0023 |
| 3/12/10 | 9055038 | 0190306- B_E_1 | Dyn Blnk | 0.0207 |
| 3/17/10 | 9054999 | 0181157- A_E_1 | Dyn Blnk | 0.0251 |
| 3/17/10 | 9052421 | N/A | field blank | 0.0174 |

7.1.2 Summary of Gaseous and PM Emission Results

Figures 7.1-1 through 7.1-32 present PEMS emissions (on a time-basis) within MOVES operating mode bins (aka VSP bins). Emissions are presented by the model-year bins that were used for sample stratification. Emissions are further segregated as port and non-port. As explained in Section 6.1.2, work-based emissions were not calculated for those trucks for which lug curves were not available. These results are not presented in Figures 7.1-1 through 7.1-31. “Suspect” data has been excluded from the values shown in Figures 7.1-1 through 7.1-31.

Figure 7.1-1 HC Emissions for 1978-1993 Trucks by VSP BIN, Port

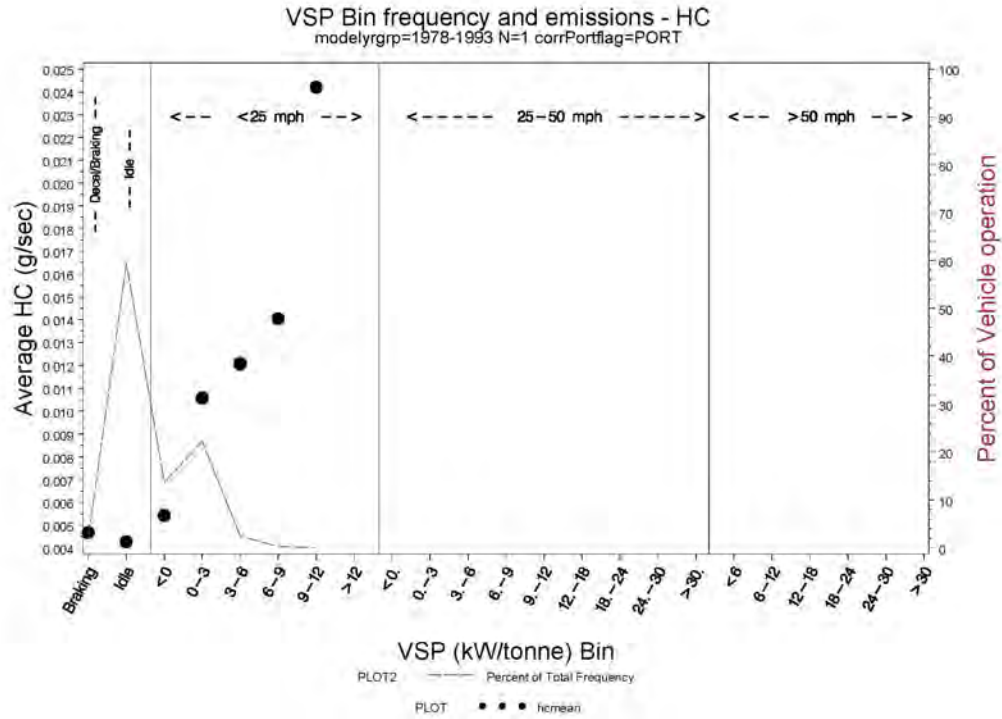


Figure 7.1-2 HC Emissions for 1978-1993 Trucks by VSP BIN, Non-port

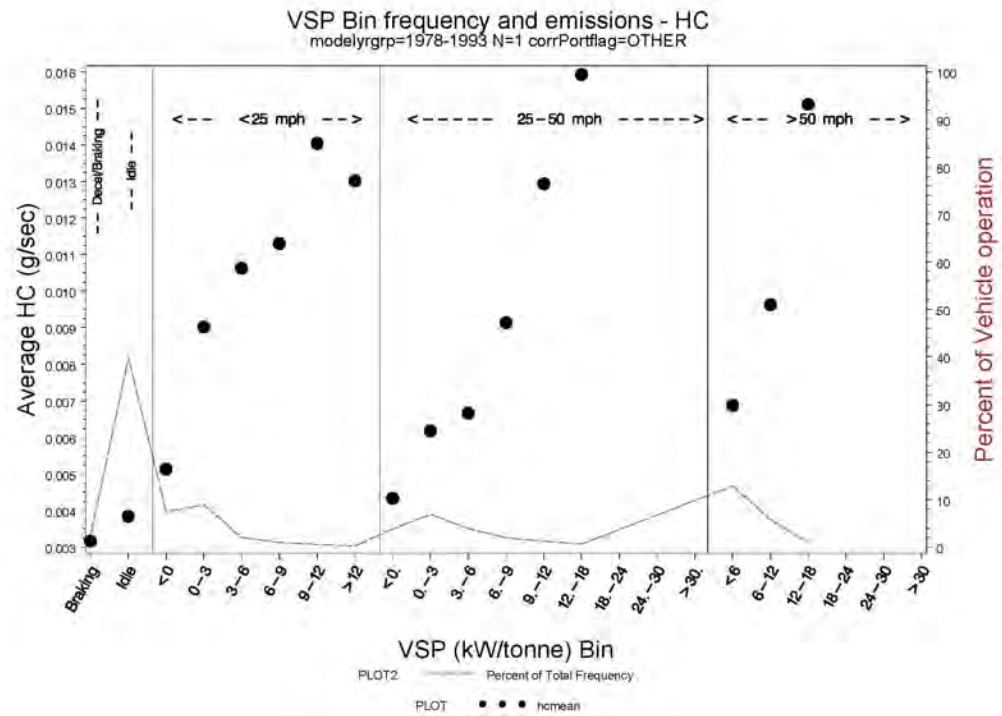


Figure 7.1-3 HC Emissions for 1994-1997 Trucks by VSP BIN, Port

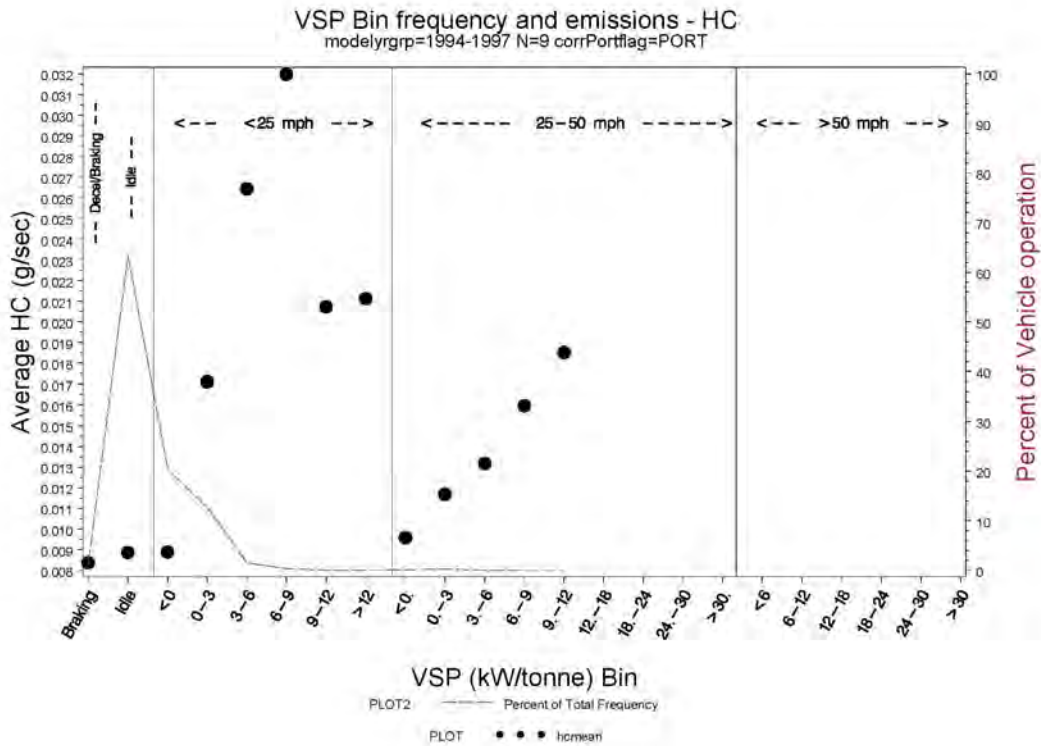


Figure 7.1-4 HC Emissions for 1994-1997 Trucks by VSP BIN, Non-port

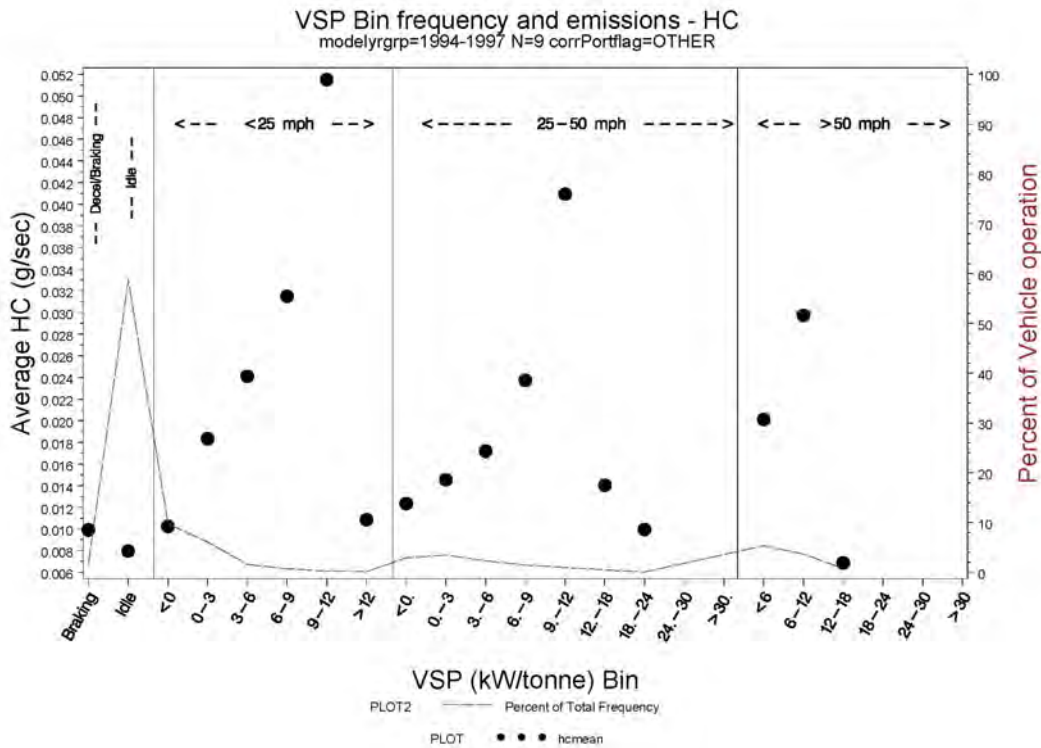


Figure 7.1-5 HC Emissions for 1998-2003 Trucks by VSP BIN, Port

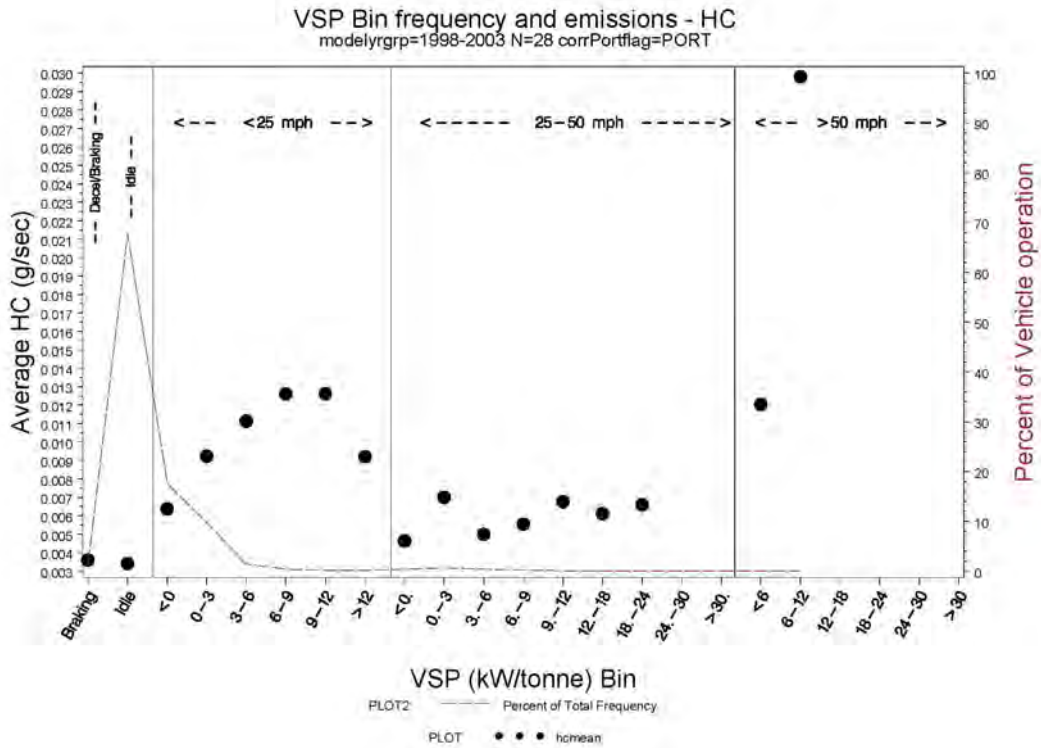


Figure 7.1-6 HC Emissions for 1998-2003 Trucks by VSP BIN, Non-port

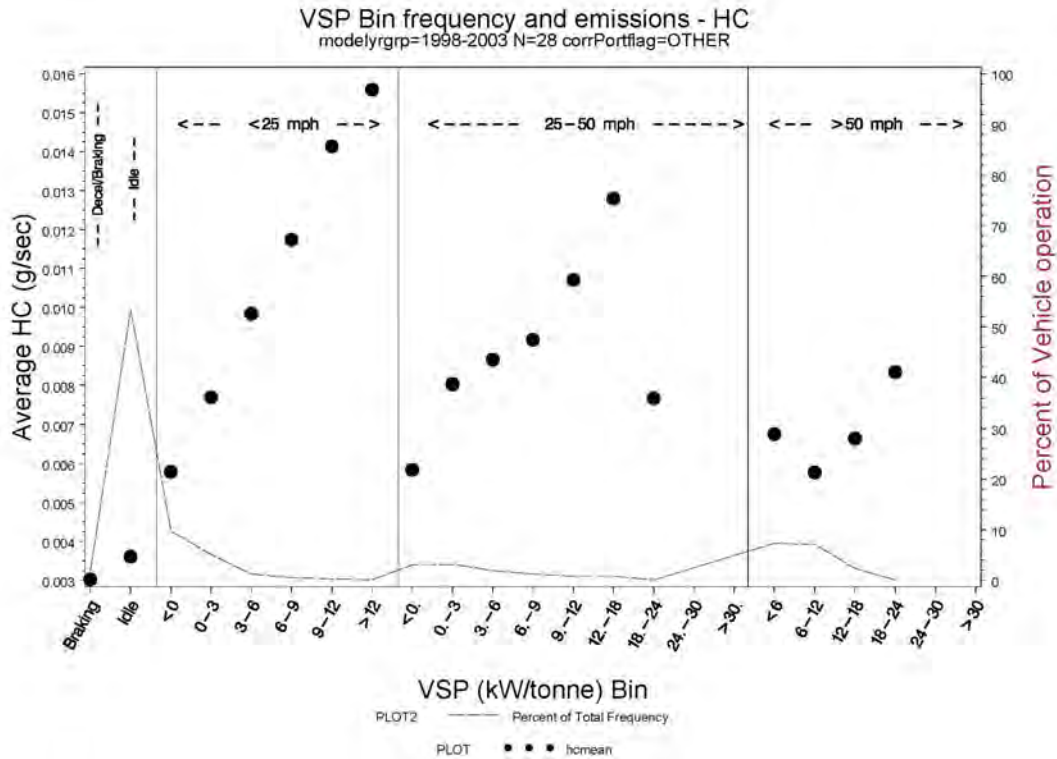


Figure 7.1-7 HC Emissions for 2004-2006 Trucks by VSP BIN, Port

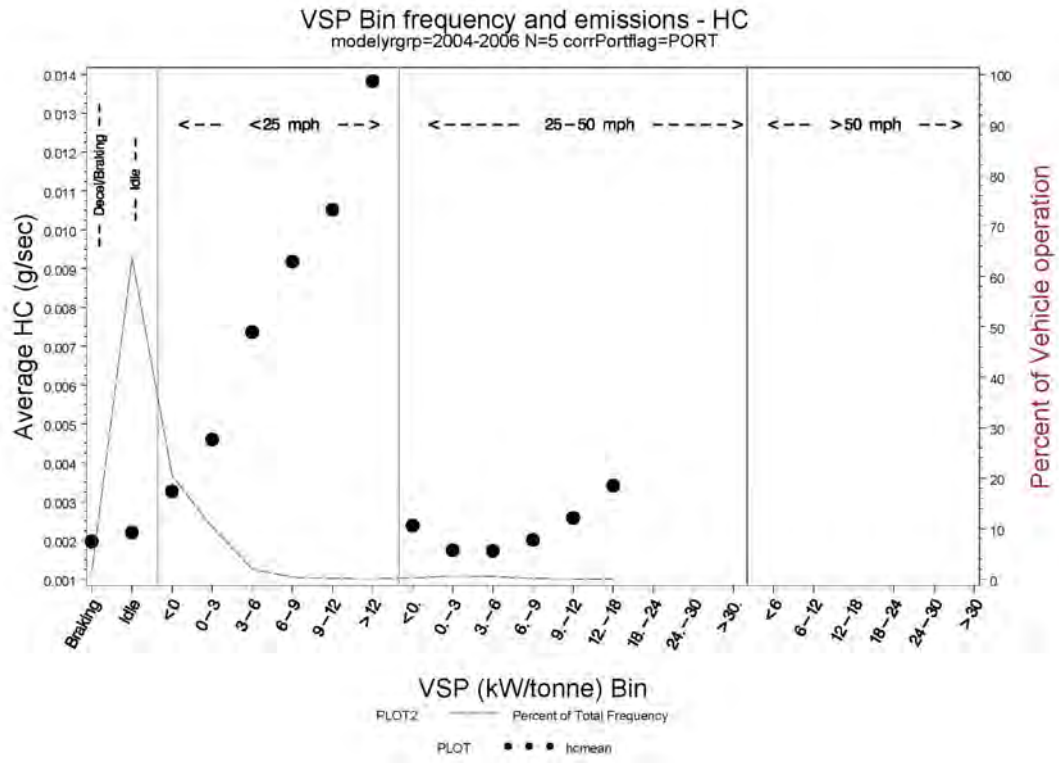


Figure 7.1-8 HC Emissions for 2004-2006 Trucks by VSP BIN, Non-port

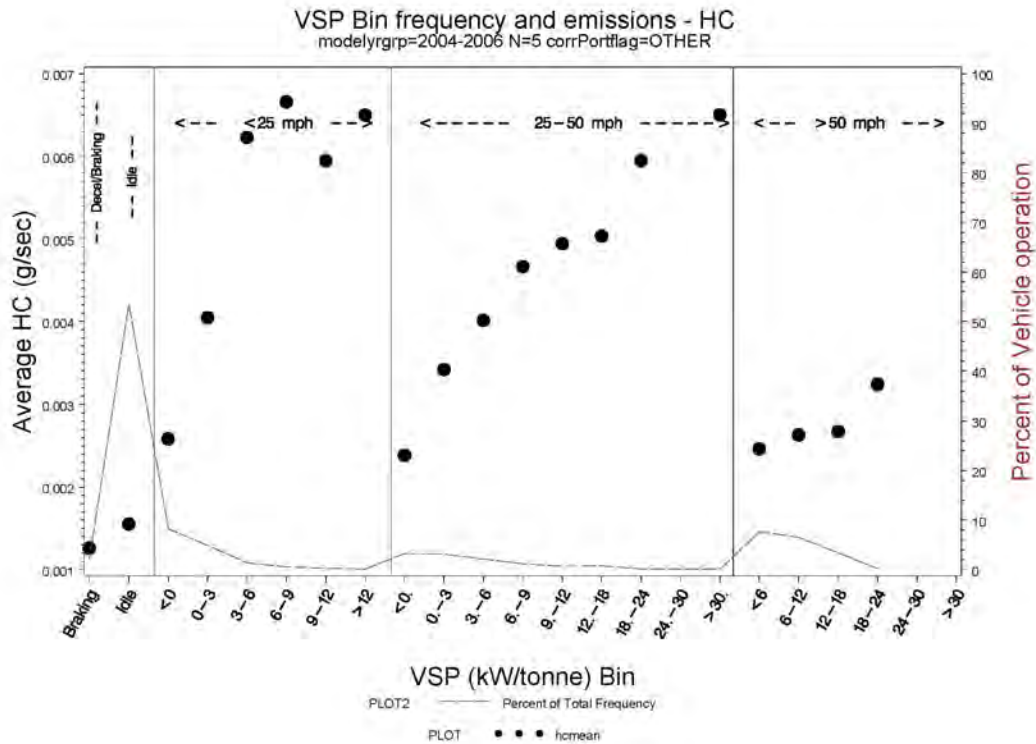


Figure 7.1-9 CO Emissions for 1978-1993 Trucks by VSP BIN, Port

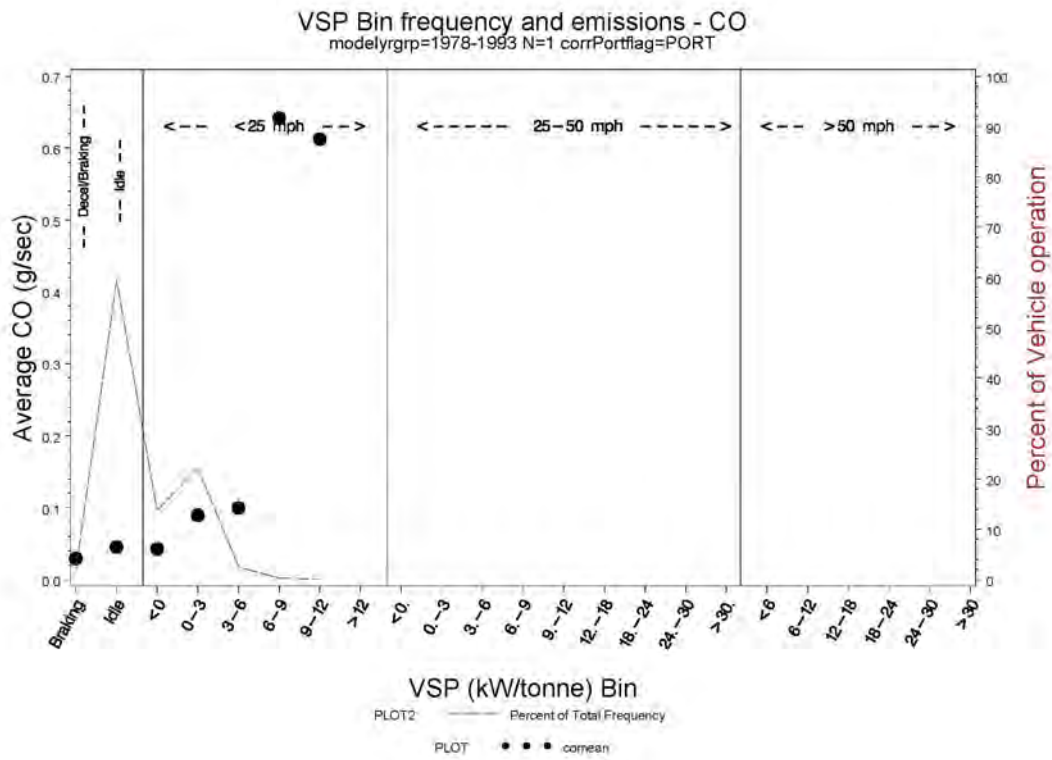


Figure 7.1-10 CO Emissions for 1978-1993 Trucks by VSP BIN, Non-port

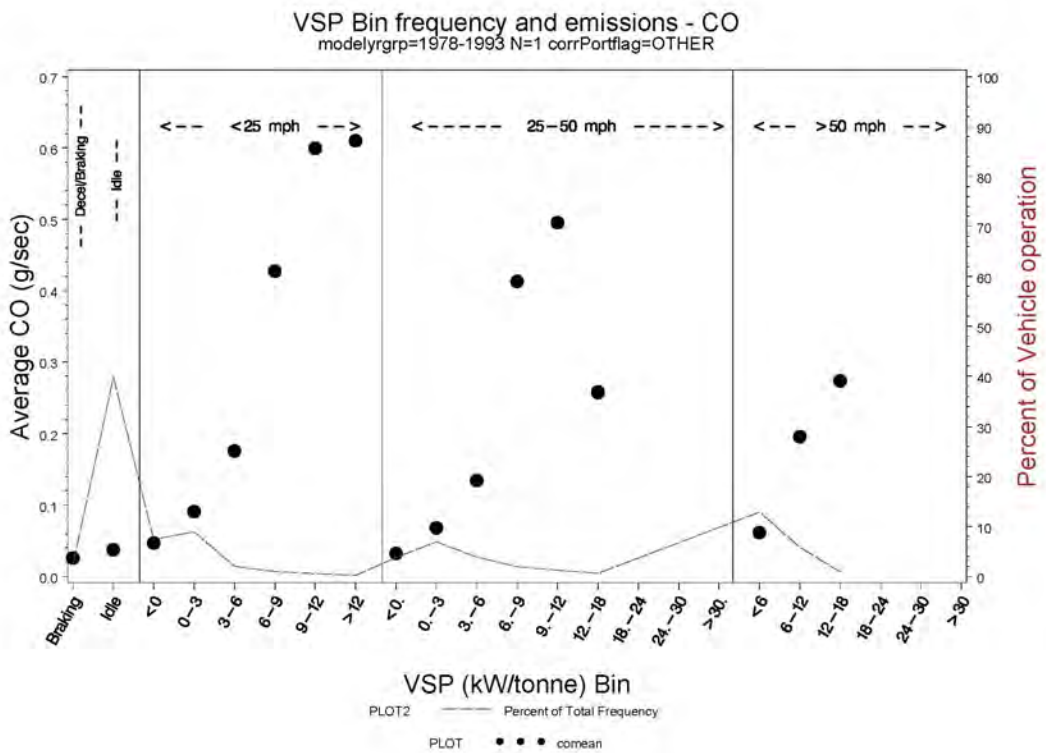


Figure 7.1-11 CO Emissions for 1994-1997 Trucks by VSP BIN, Port

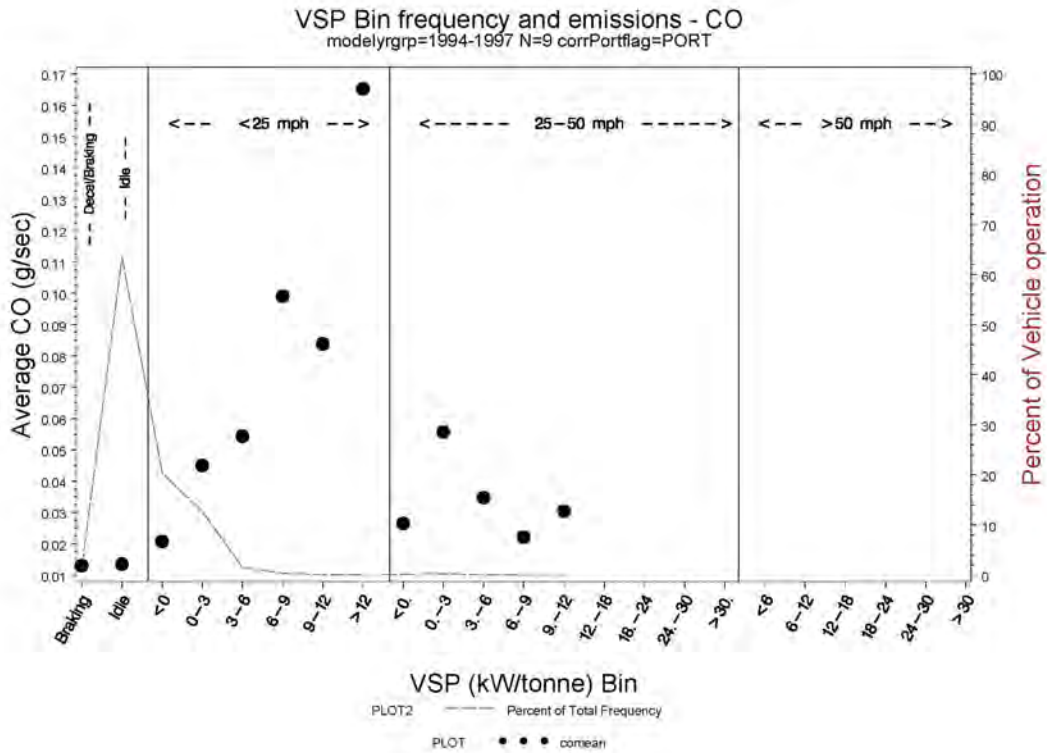


Figure 7.1-12 CO Emissions for 1994-1997 Trucks by VSP BIN, Non-port

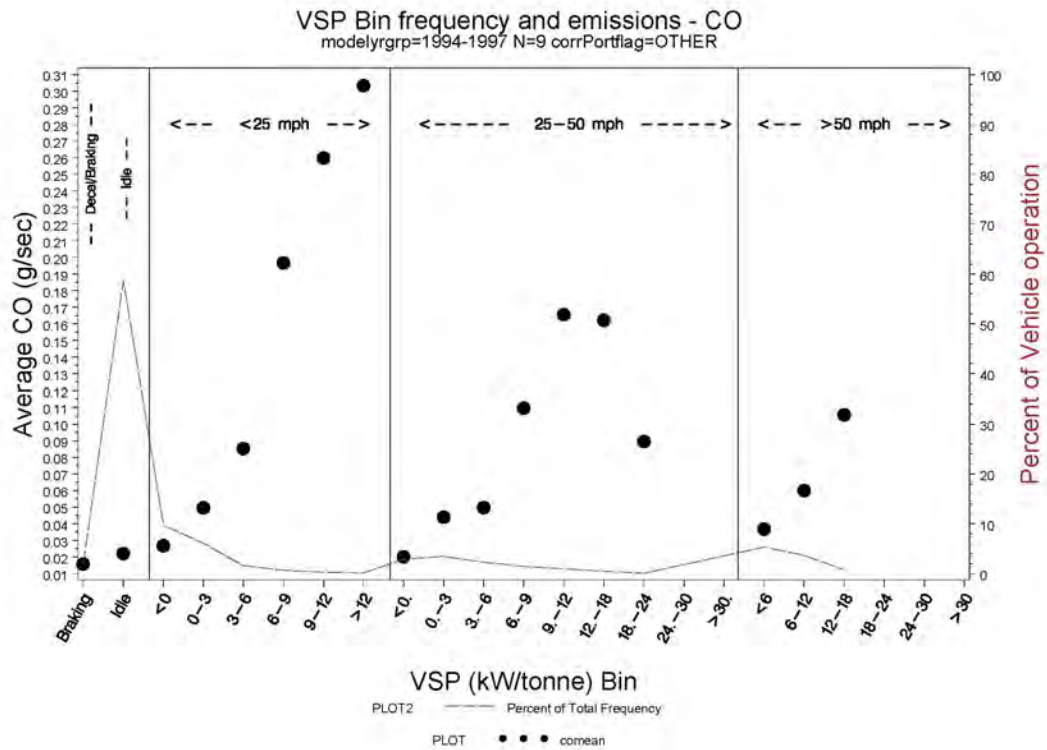


Figure 7.1-13 CO Emissions for 1998-2003 Trucks by VSP BIN, Port

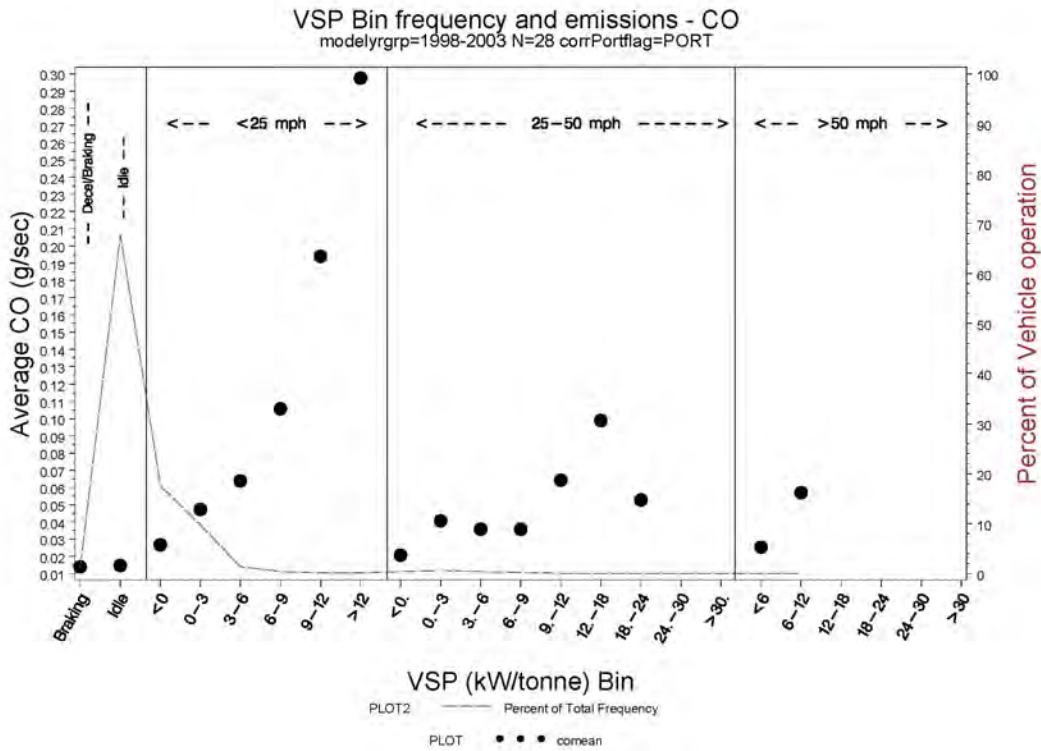


Figure 7.1-14 CO Emissions for 1998-2003 Trucks by VSP BIN, Non-port

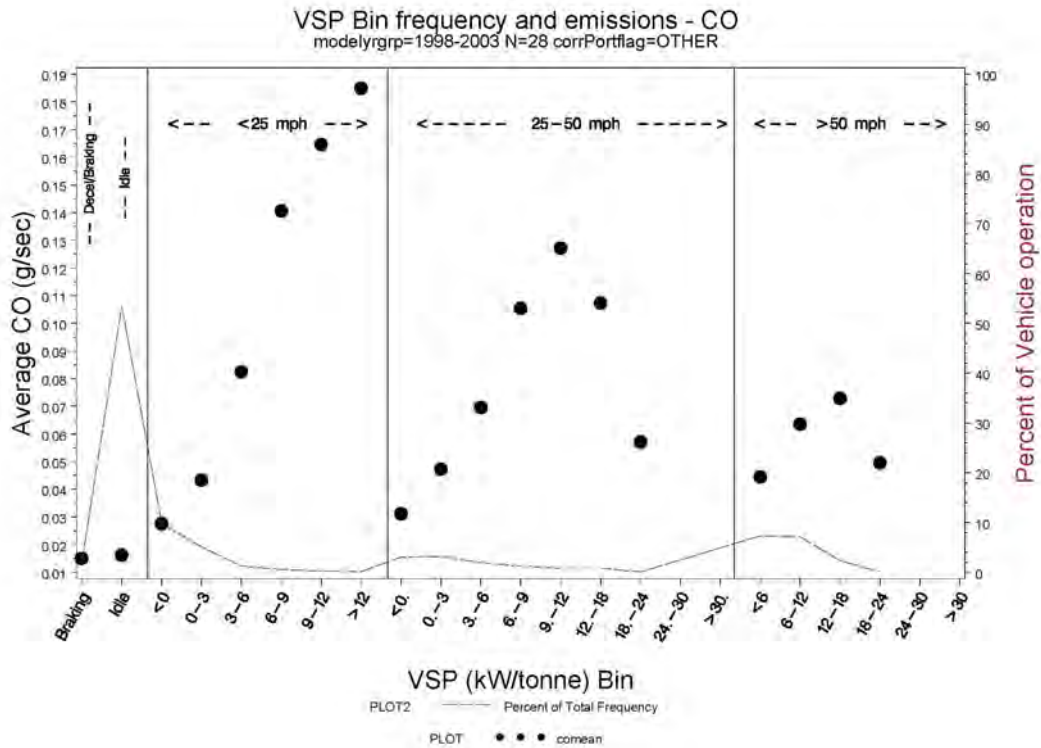


Figure 7.1-15 CO Emissions for 2004-2006 Trucks by VSP BIN, Port

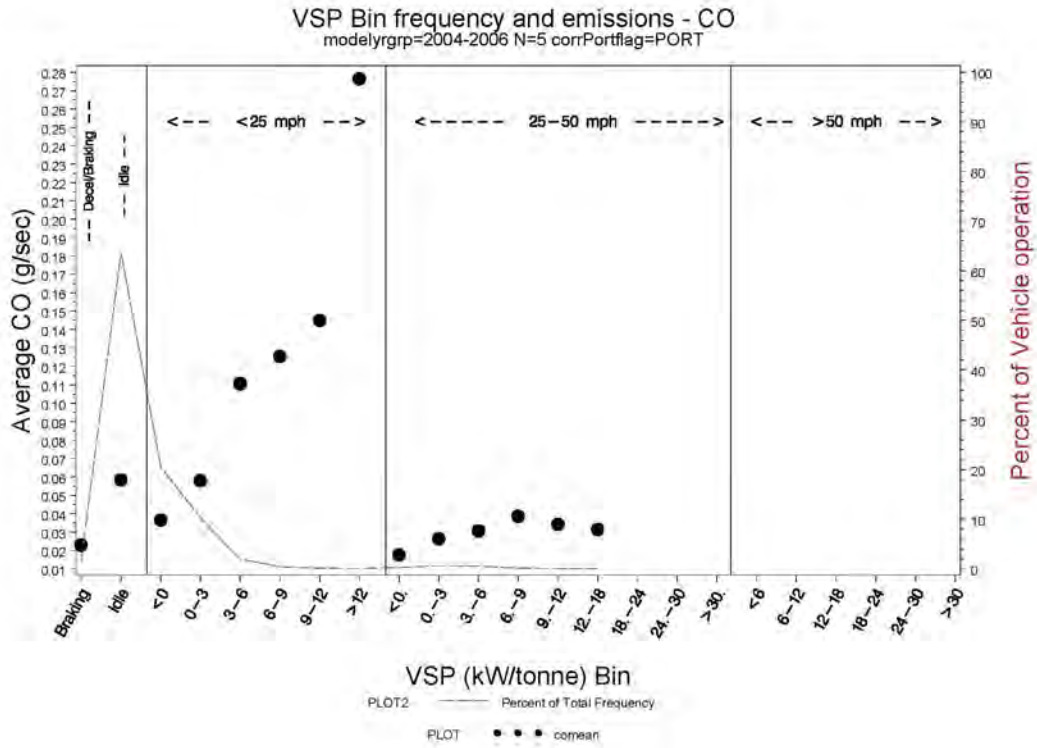


Figure 7.1-16 CO Emissions for 2004-2006 Trucks by VSP BIN, Non-port

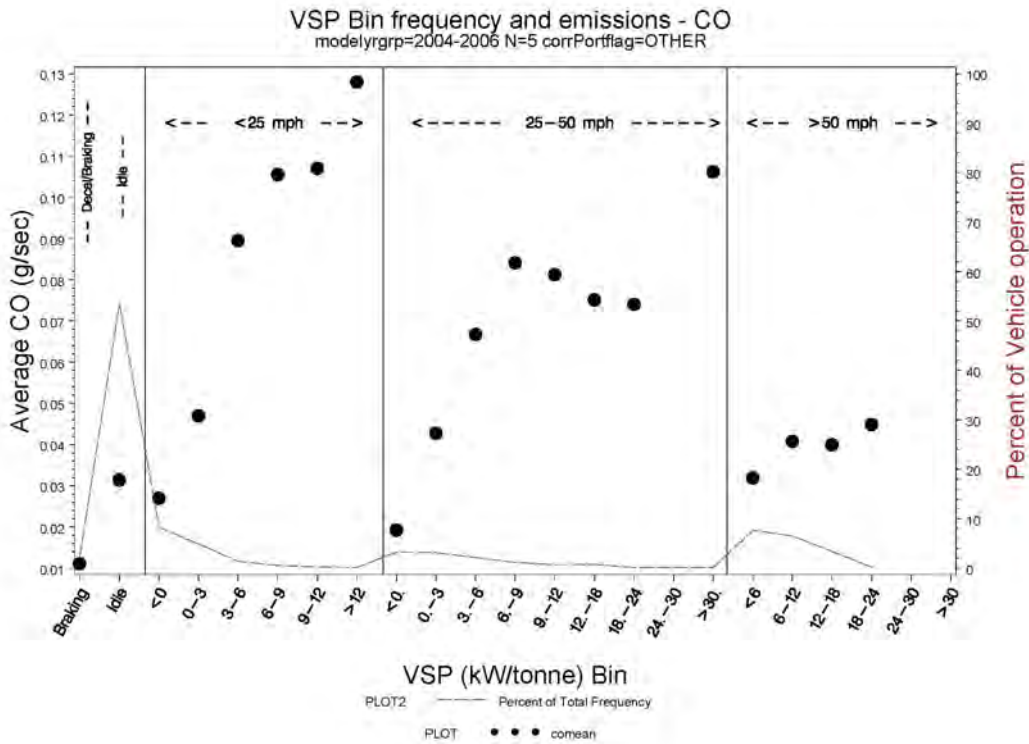


Figure 7.1-17 CO₂ Emissions for 1978-1993 Trucks by VSP BIN, Port

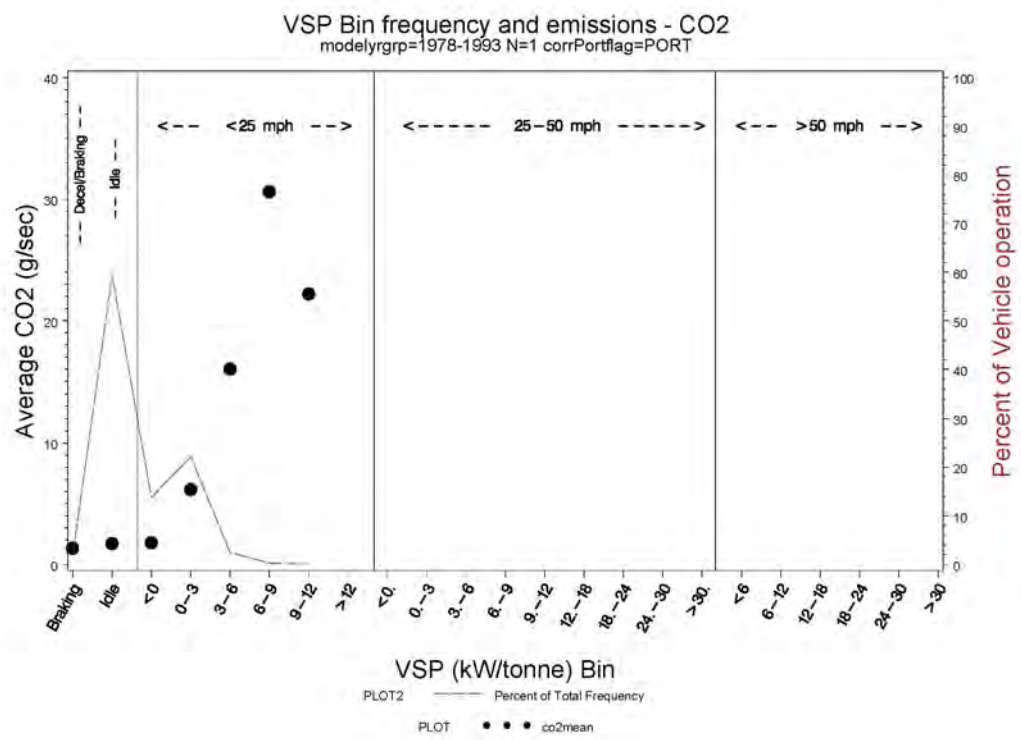


Figure 7.1-18 CO₂ Emissions for 1978-1993 Trucks by VSP BIN, Non-port

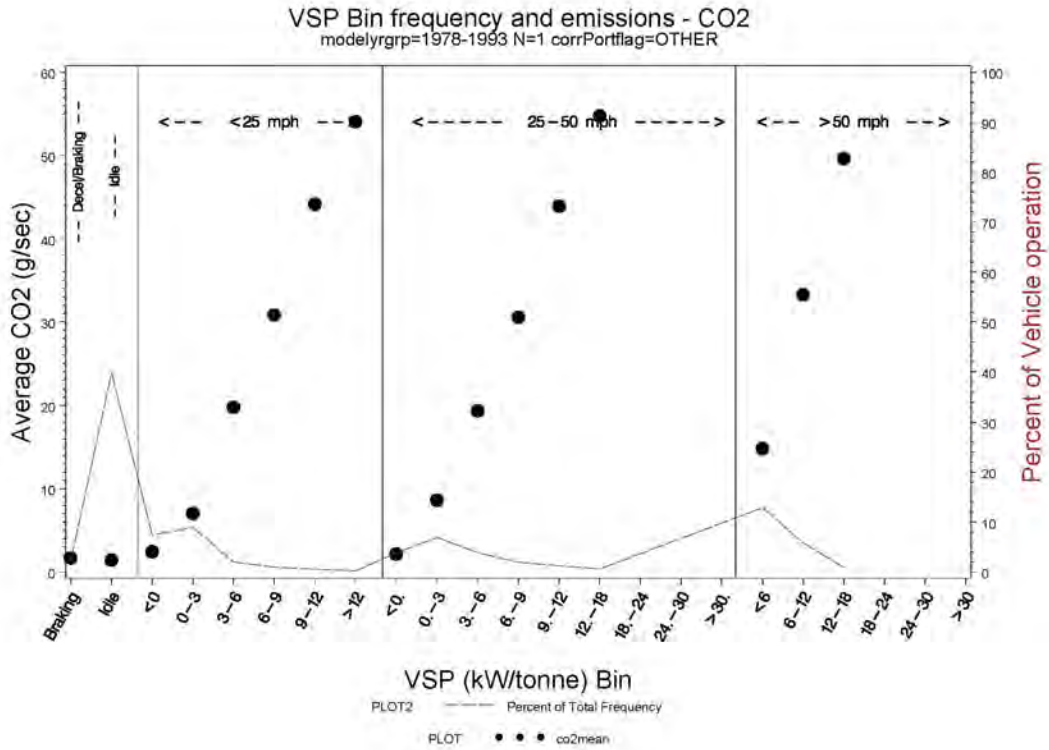


Figure 7.1-19 CO₂ Emissions for 1994-1997 Trucks by VSP BIN, Port

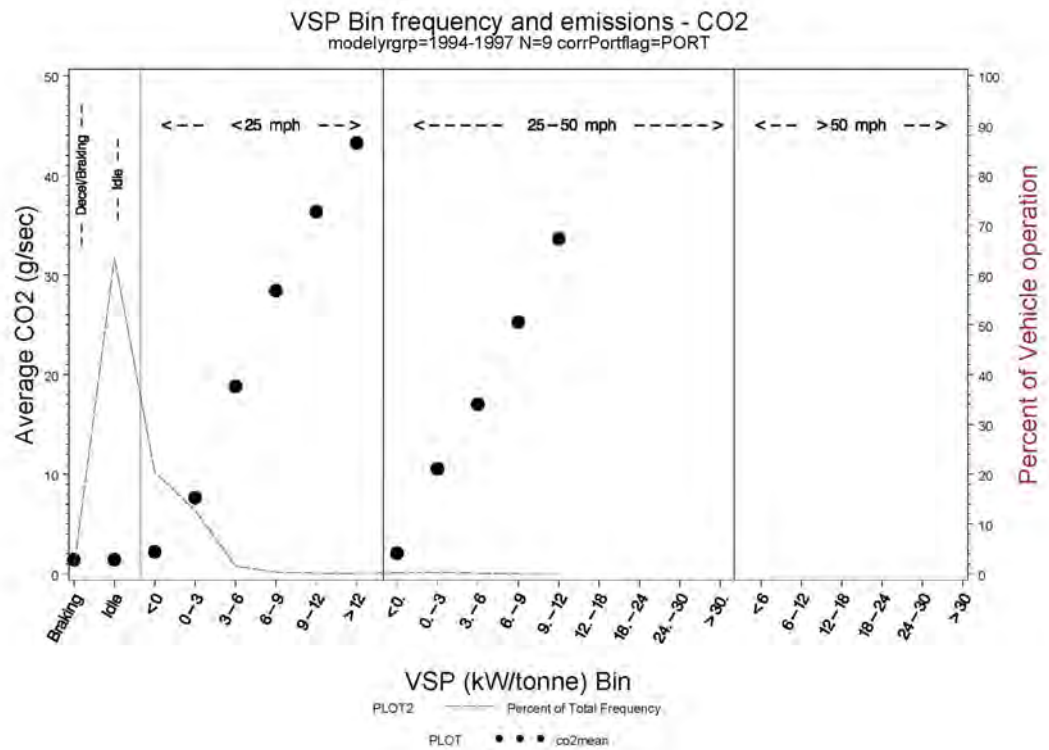


Figure 7.1-20 CO₂ Emissions for 1994-1997 Trucks by VSP BIN, Non-port

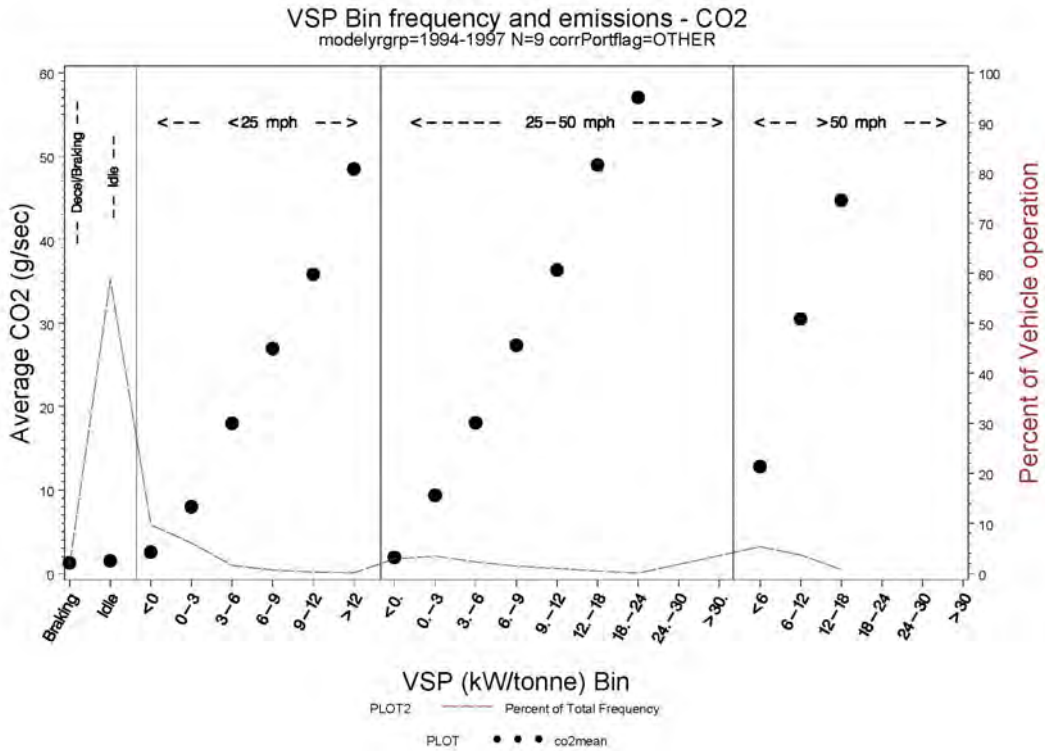


Figure 7.1-21 CO₂ Emissions for 1998-2003 Trucks by VSP BIN, Port

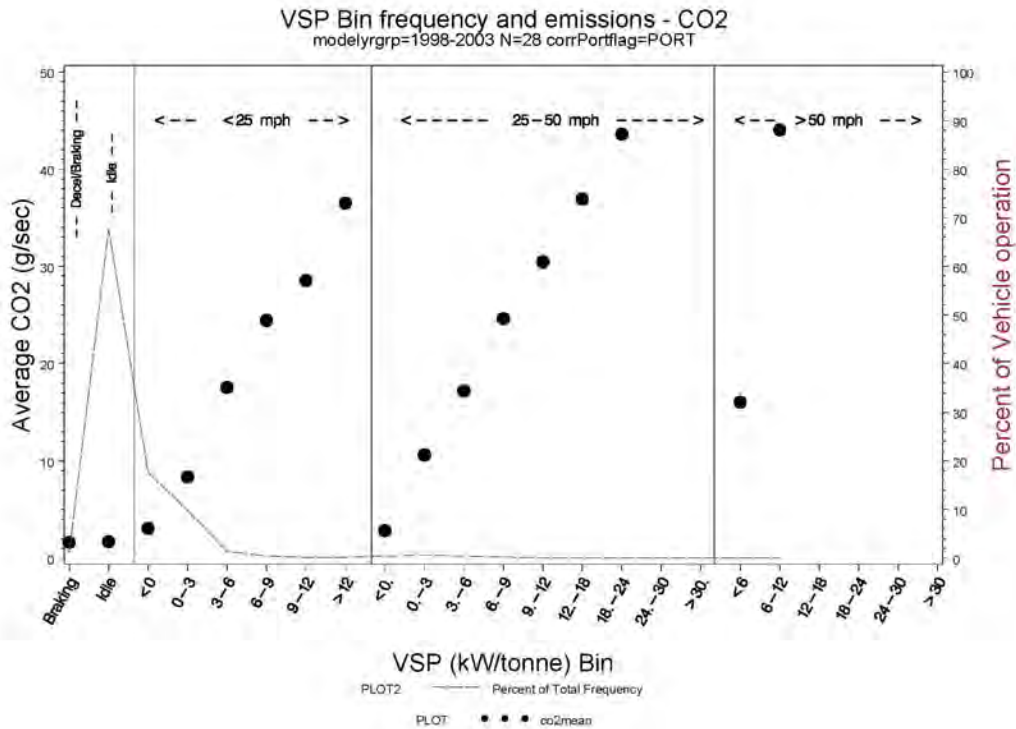


Figure 7.1-22 CO₂ Emissions for 1998-2003 Trucks by VSP BIN, Non-port

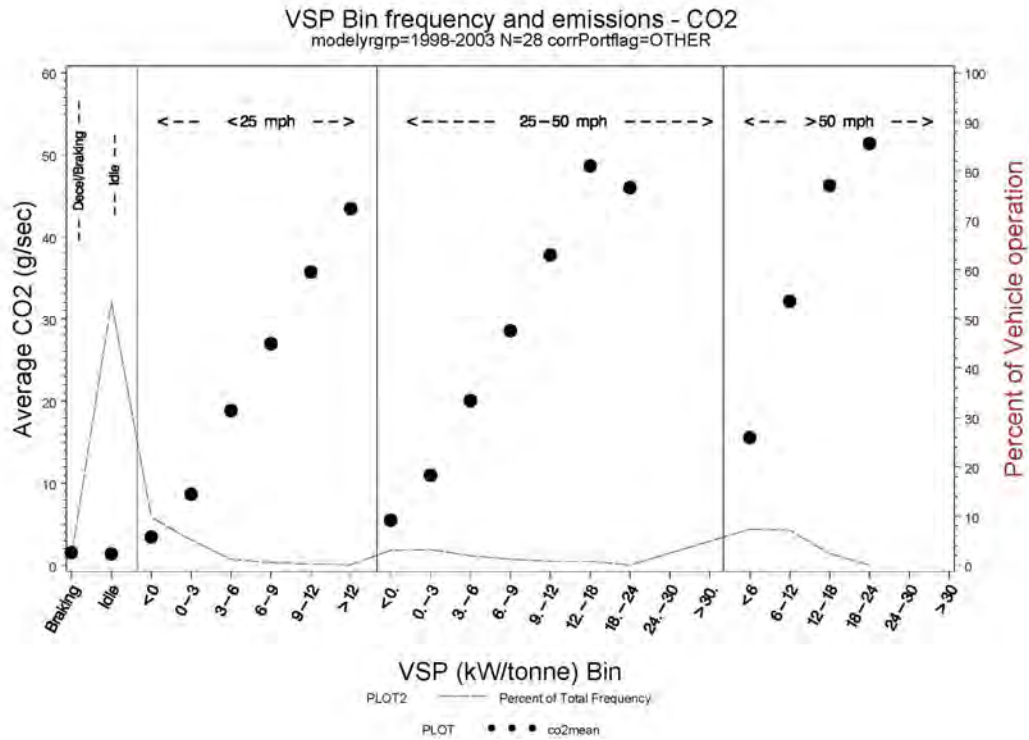


Figure 7.1-23 CO₂ Emissions for 2004-2006 Trucks by VSP BIN, Port

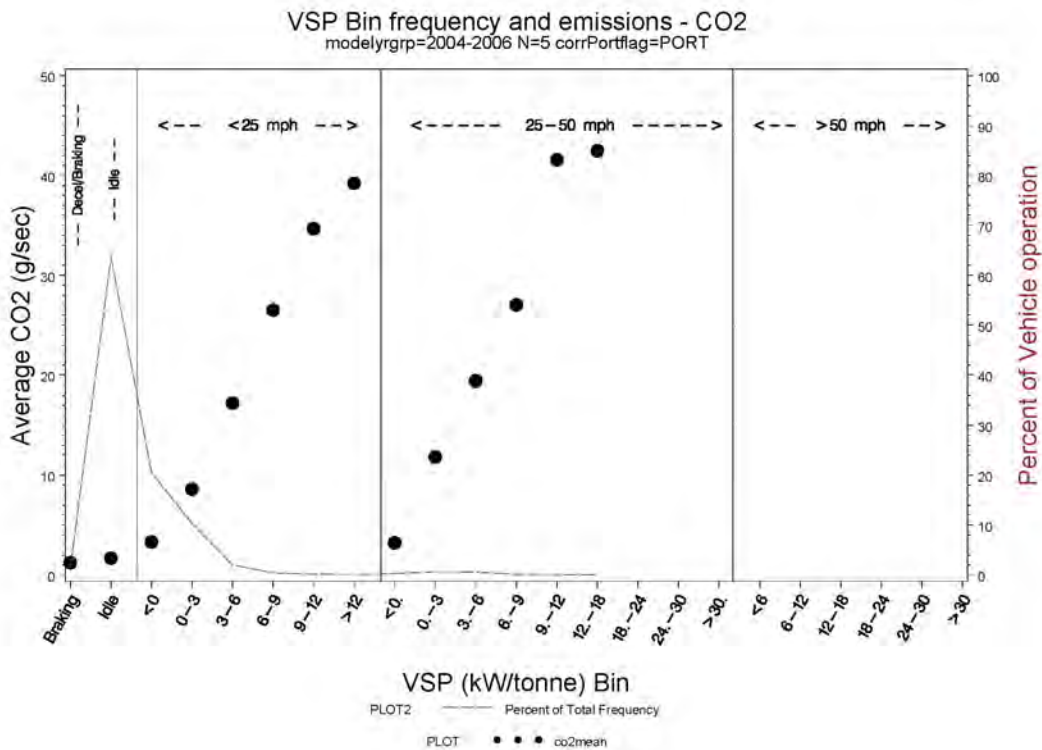


Figure 7.1-24 CO₂ Emissions for 2004-2006 Trucks by VSP BIN, Non-port

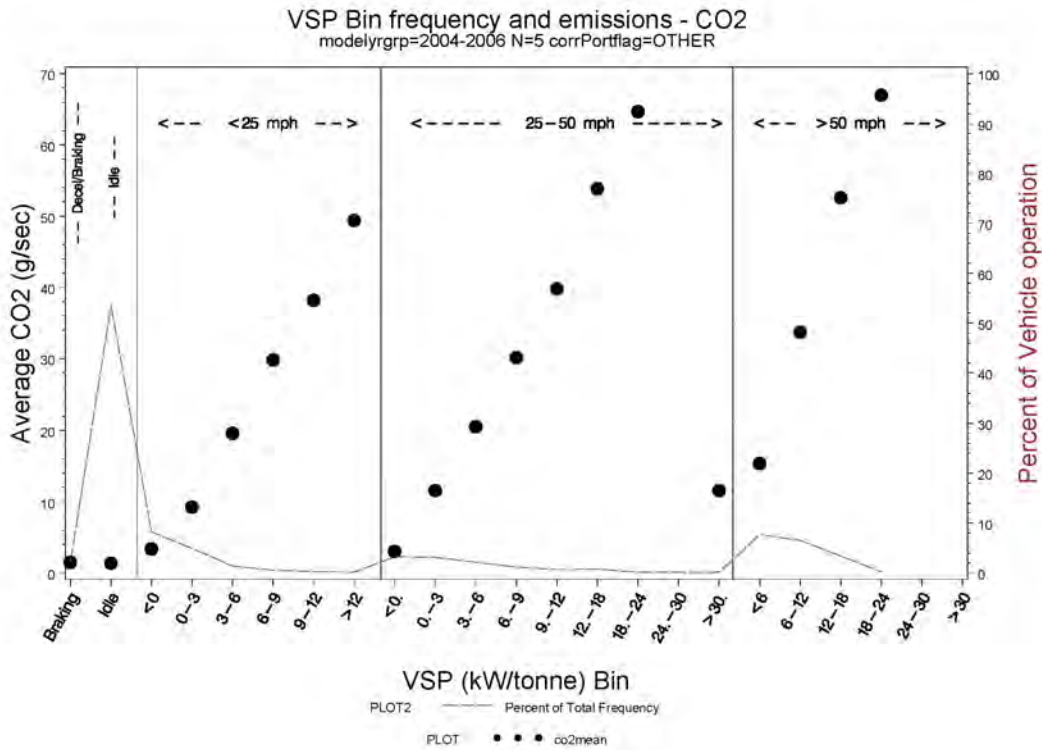


Figure 7.1-25 NO_x Emissions for 1978-1993 Trucks by VSP BIN, Port

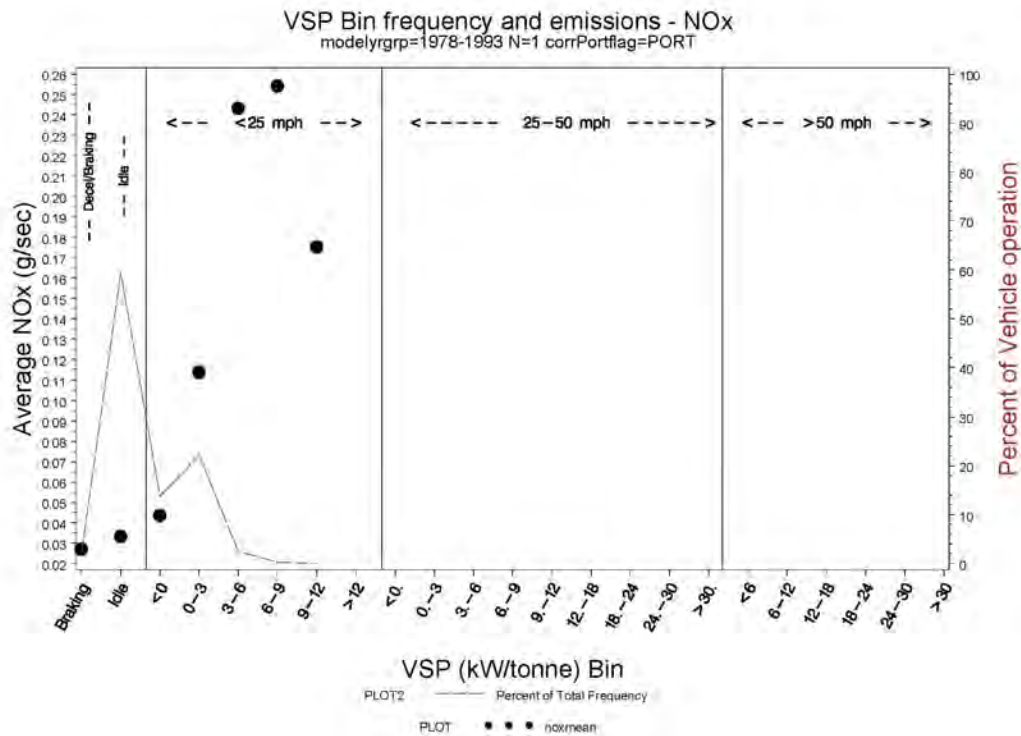


Figure 7.1-26 NO_x Emissions for 1978-1993 Trucks by VSP BIN, Non-port

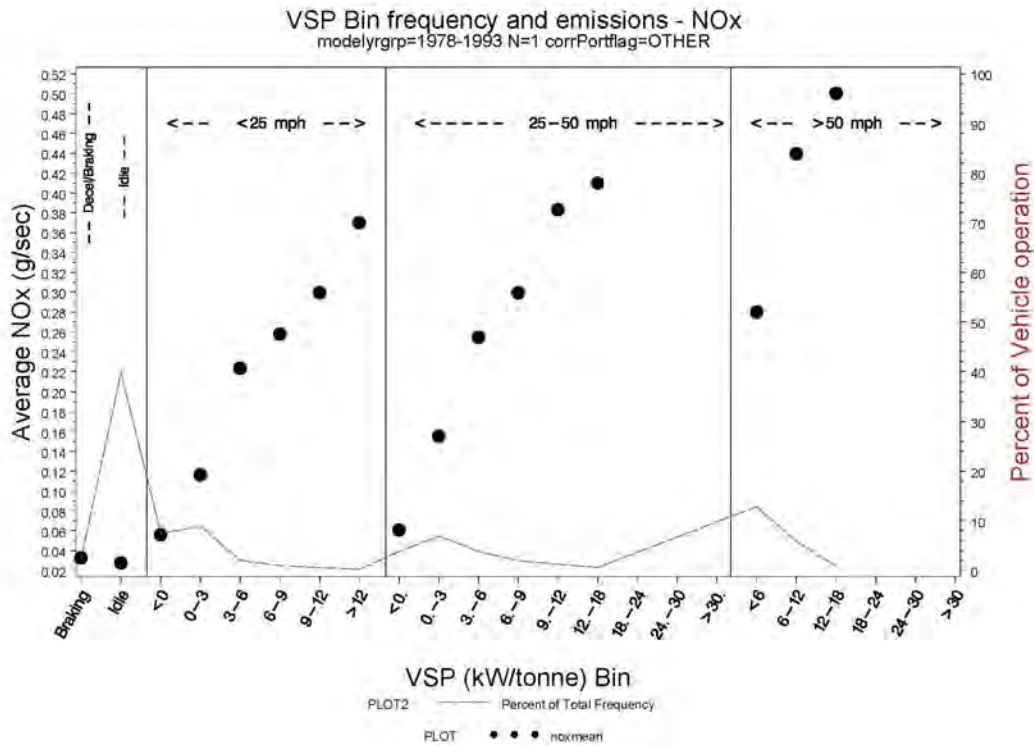


Figure 7.1-27 NO_x Emissions for 1994-1997 Trucks by VSP BIN, Port

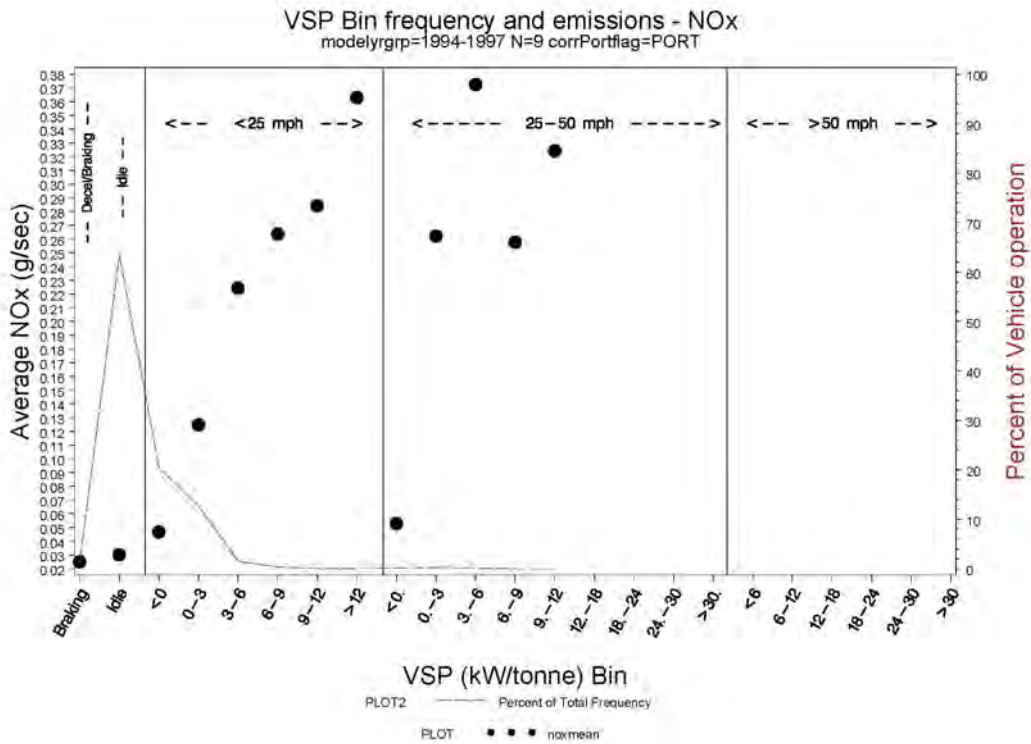


Figure 7.1-28 NO_x Emissions for 1994-1997 Trucks by VSP BIN, Non-port

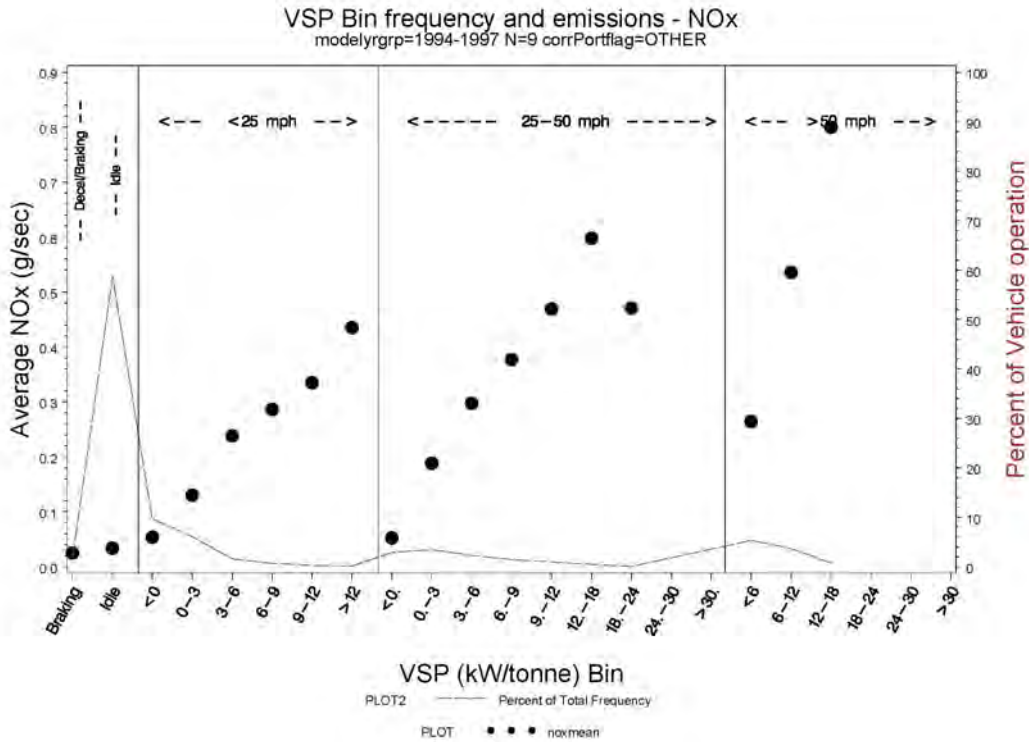


Figure 7.1-29 NO_x Emissions for 1998-2003 Trucks by VSP BIN, Port

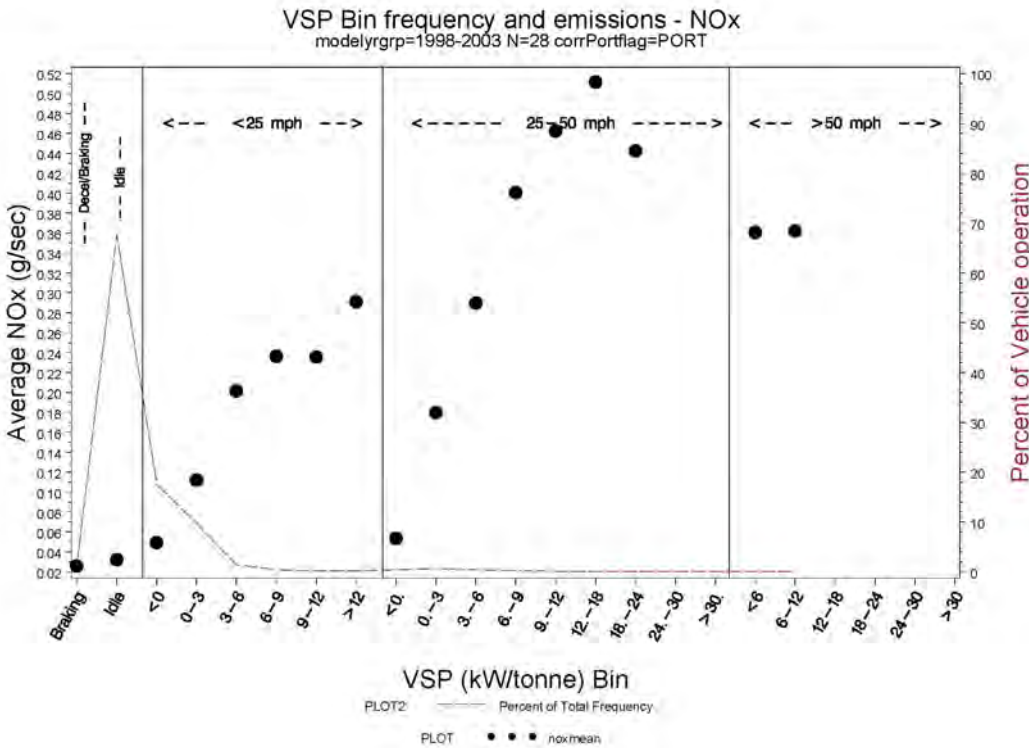


Figure 7.1-30 NO_x Emissions for 1998-2003 Trucks by VSP BIN, Non-port

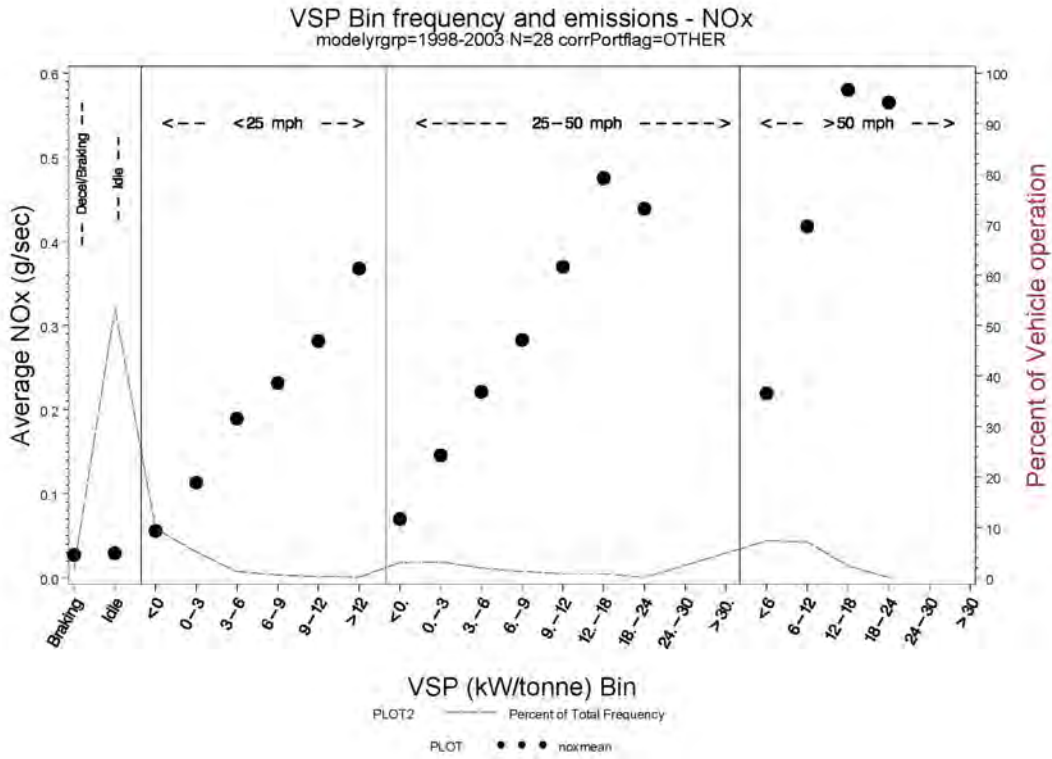


Figure 7.1-31 NO_x Emissions for 2004-2006 Trucks by VSP BIN, Port

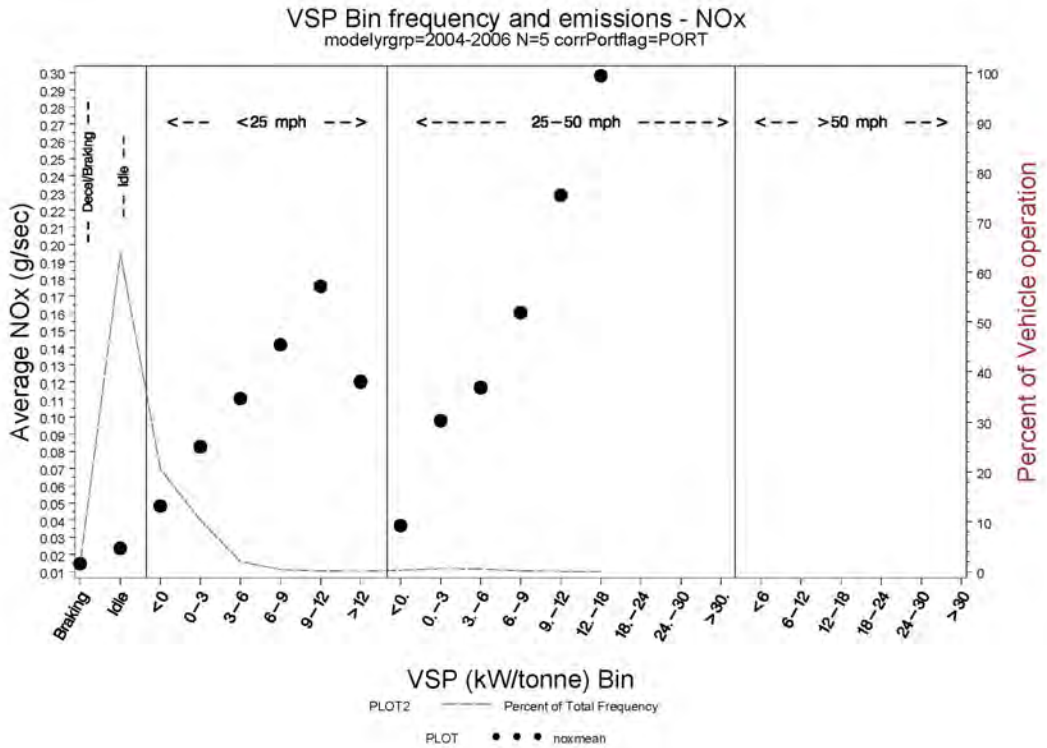
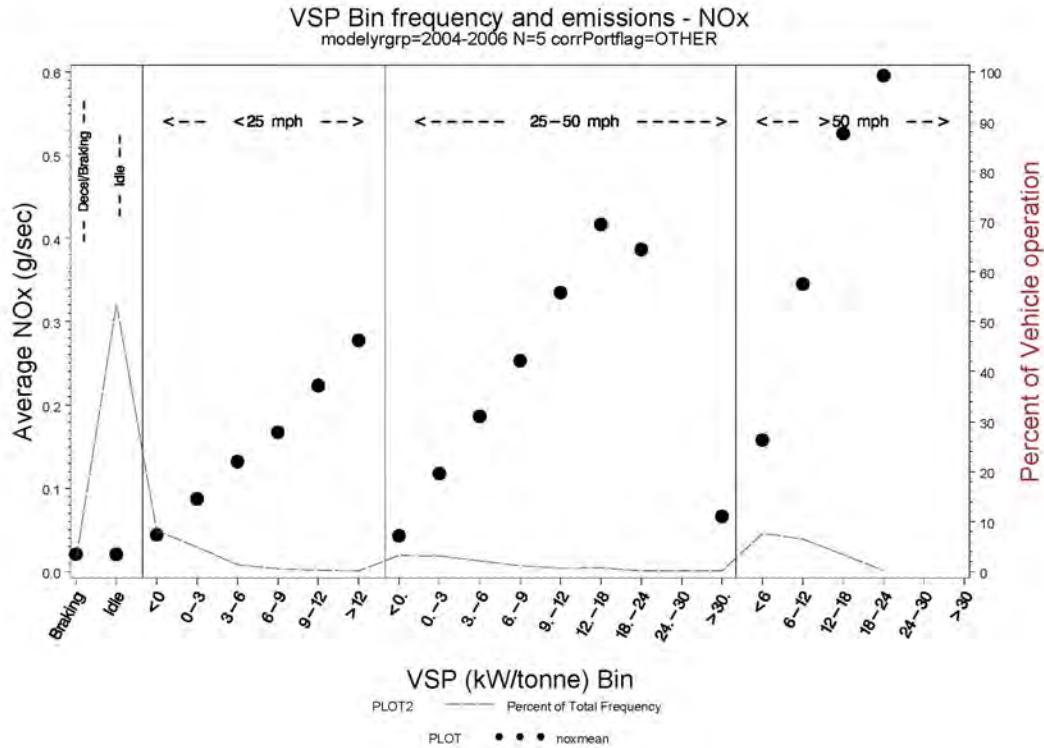


Figure 7.1-32 NO_x Emissions for 2004-2006 Trucks by VSP BIN, Non-port



Figs 7.1-1 through 7.1-32 generally show a higher percentage of operation in the lower MOVES operating mode bins (braking, idle, and under 25 mph bins 0-12) for port operations when compared to non-port operations. As would be expected, “bumps” in vehicle operation are generally seen for operation in the 25-50 mph bins and the > 50 mph bins for non-port activity (representing truck activity on surface streets and interstates). No discernible trend was seen for maximum HC or CO emission rates (g/s) between port and non-port activity in the <25 mph speed range, while < 25 mph maximum CO₂ and NO_x g/s emission rates were higher for non-port operation than they were for port operation.

Figures 7.1-33 through 7.1-66 present PEMS emissions (in grams of pollutant per kg of fuel) within MOVES operating mode bins (aka VSP bins). Emissions are presented by truck. For trucks which received RSD measurements, the associated RSD measurement for that truck is also shown on the plot (within its appropriate VSP bin). Several of the trucks tested in the study did not receive RSD measurements. As explained in Section 5.3, these were gaseous-only oversample trucks not included in the sample of 1877-RSD tested trucks. Again, results for trucks for which no lug curves were available are not presented in Figures 7.1-33 through 7.1-66.

Figure 7.1-33 VSP-Based Activity And NO_x Emissions for 0160699-A

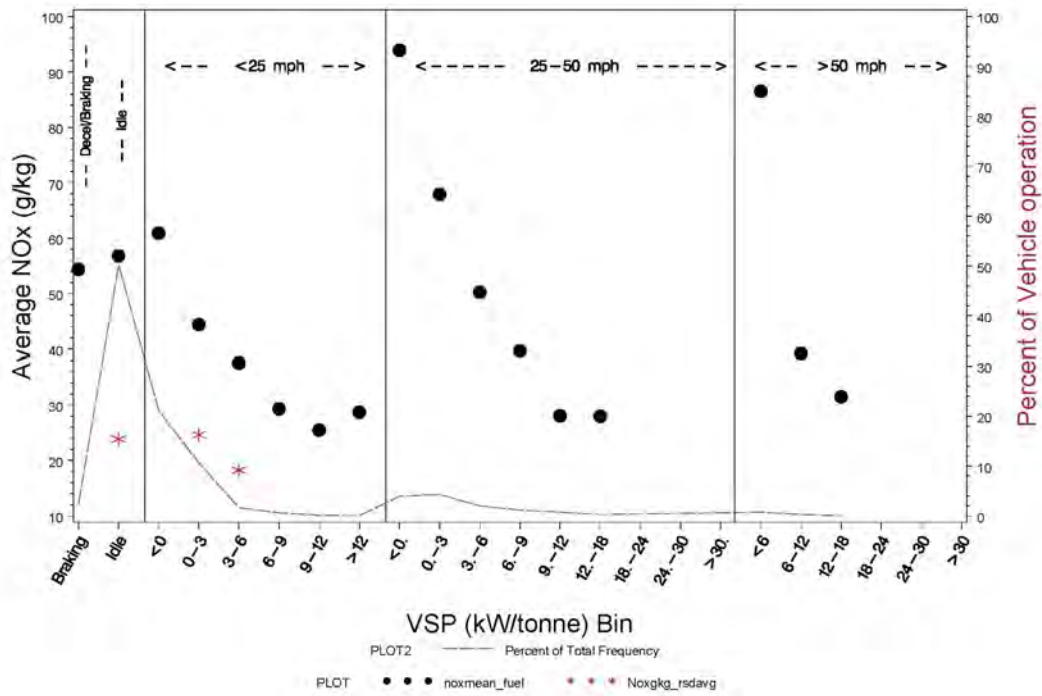


Figure 7.1-34 VSP-Based Activity And NO_x Emissions for 0160910-A

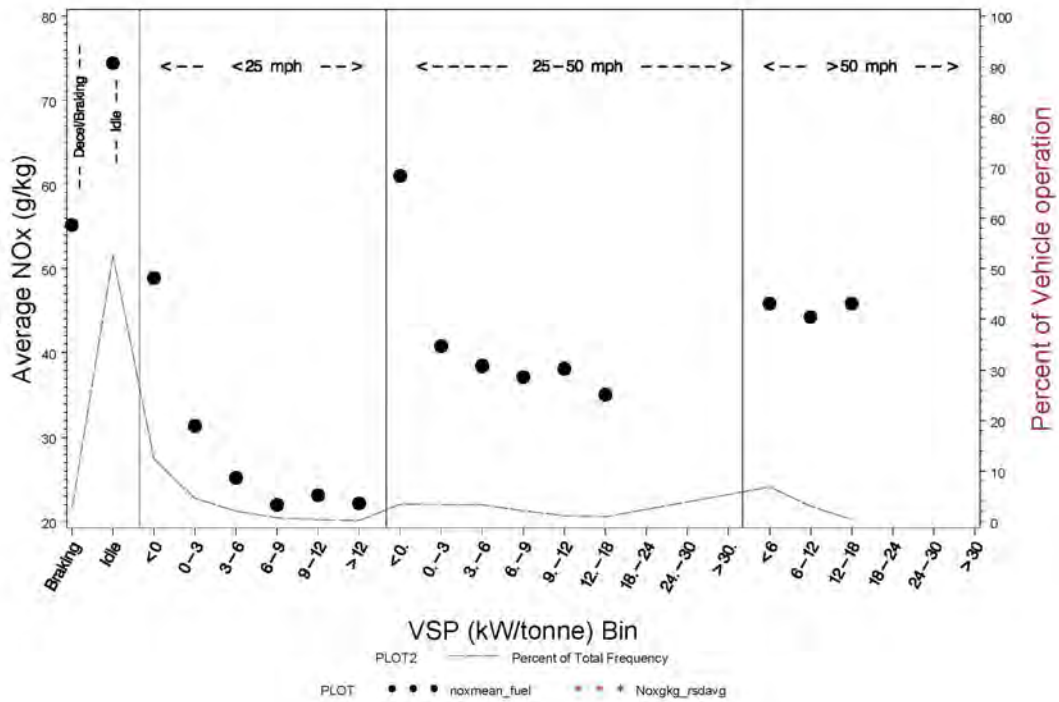


Figure 7.1-35 VSP-Based Activity And NO_x Emissions for 0178515-B

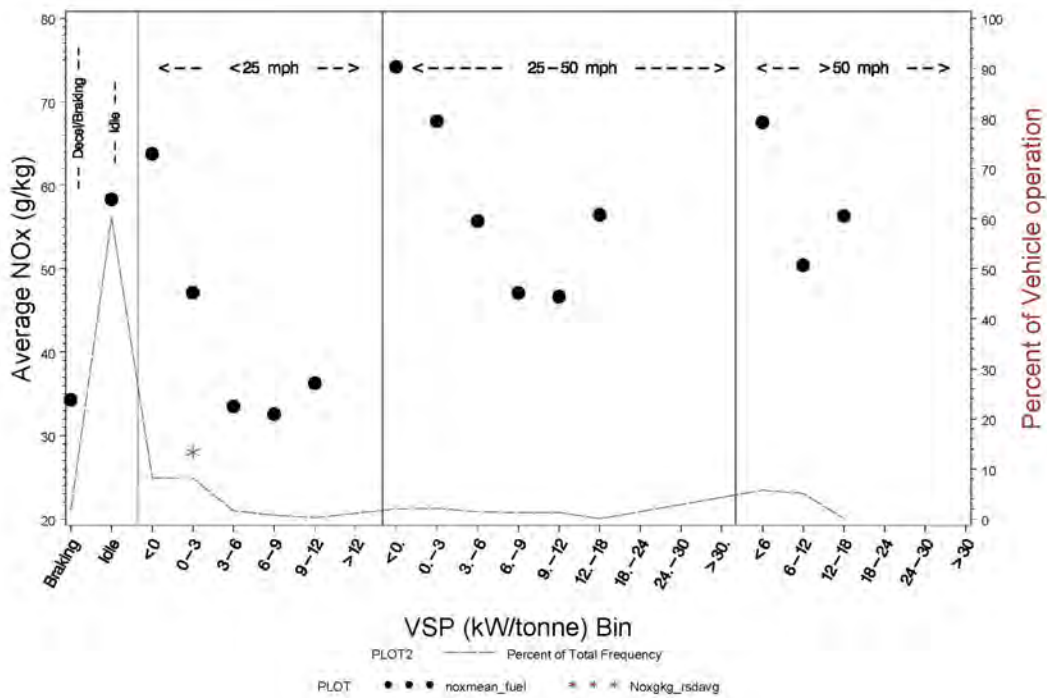


Figure 7.1-36 VSP-Based Activity And NO_x Emissions for 0180990-A

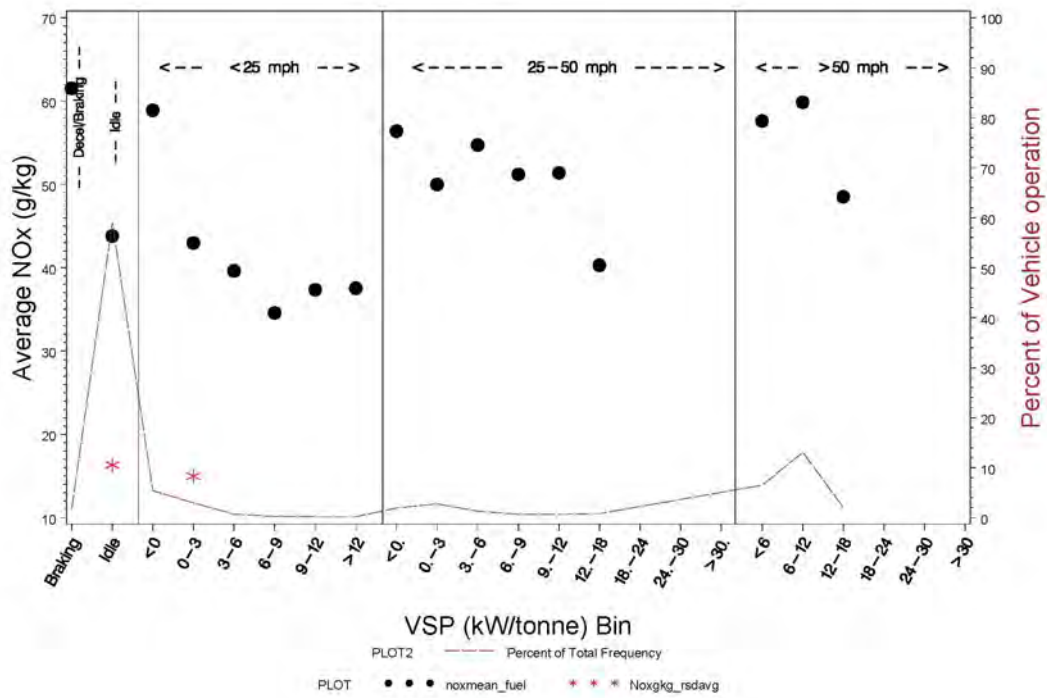


Figure 7.1-37 VSP-Based Activity And NO_x Emissions for 0181096-A

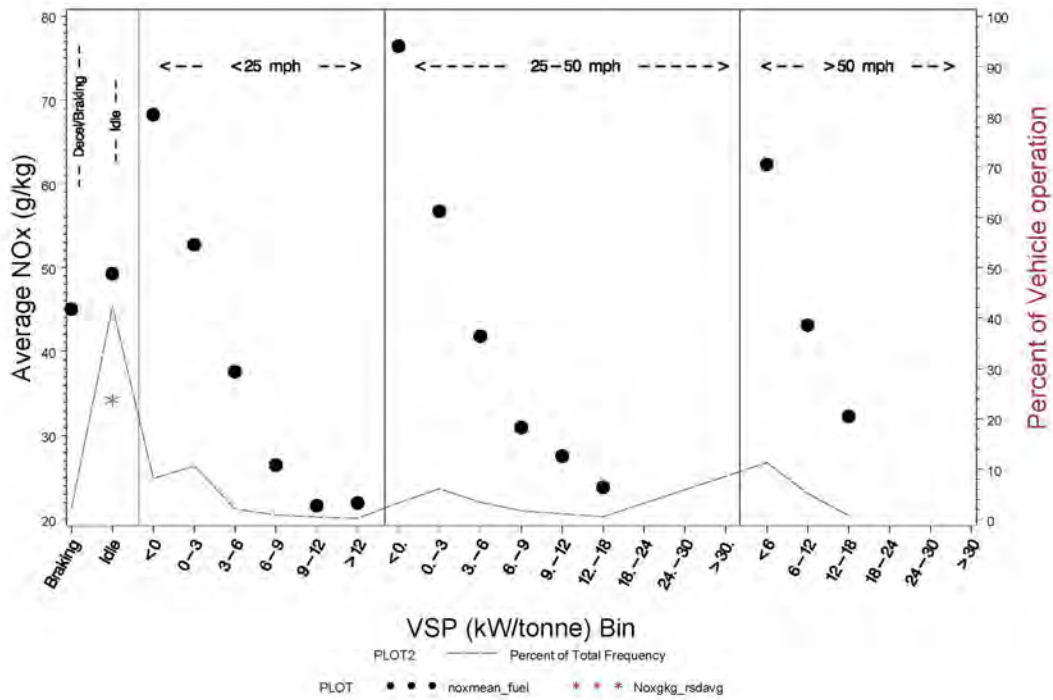


Figure 7.1-38 VSP-Based Activity And NO_x Emissions for 0181157-A

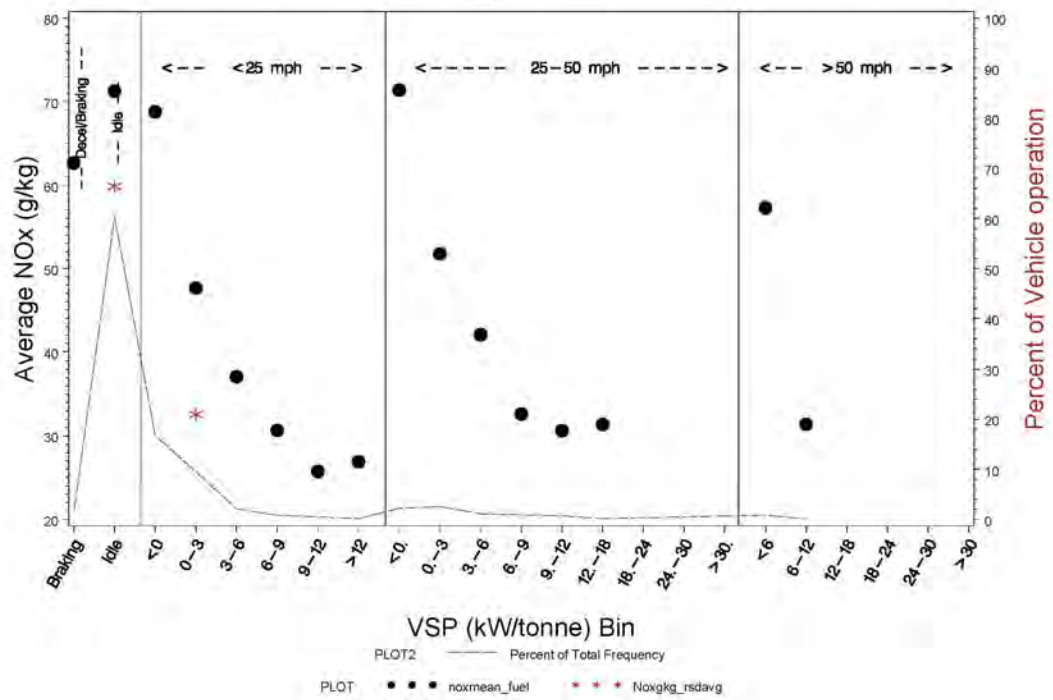


Figure 7.1-39 VSP-Based Activity And NO_x Emissions for 0182003-A

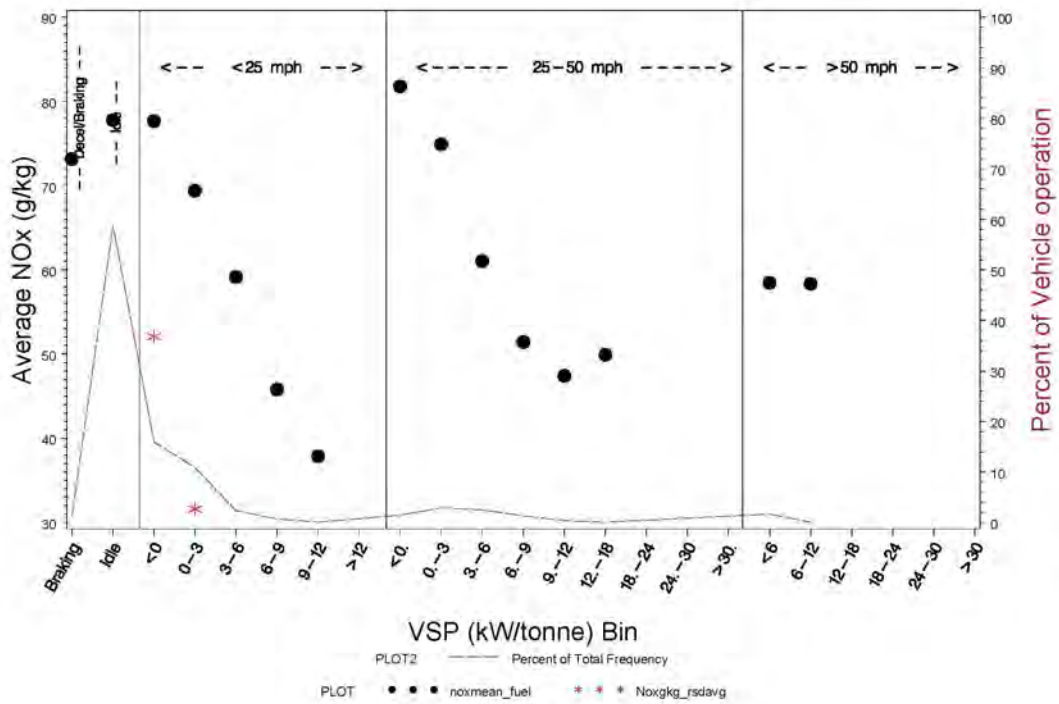


Figure 7.1-40 VSP-Based Activity And NO_x Emissions for 0182022-A

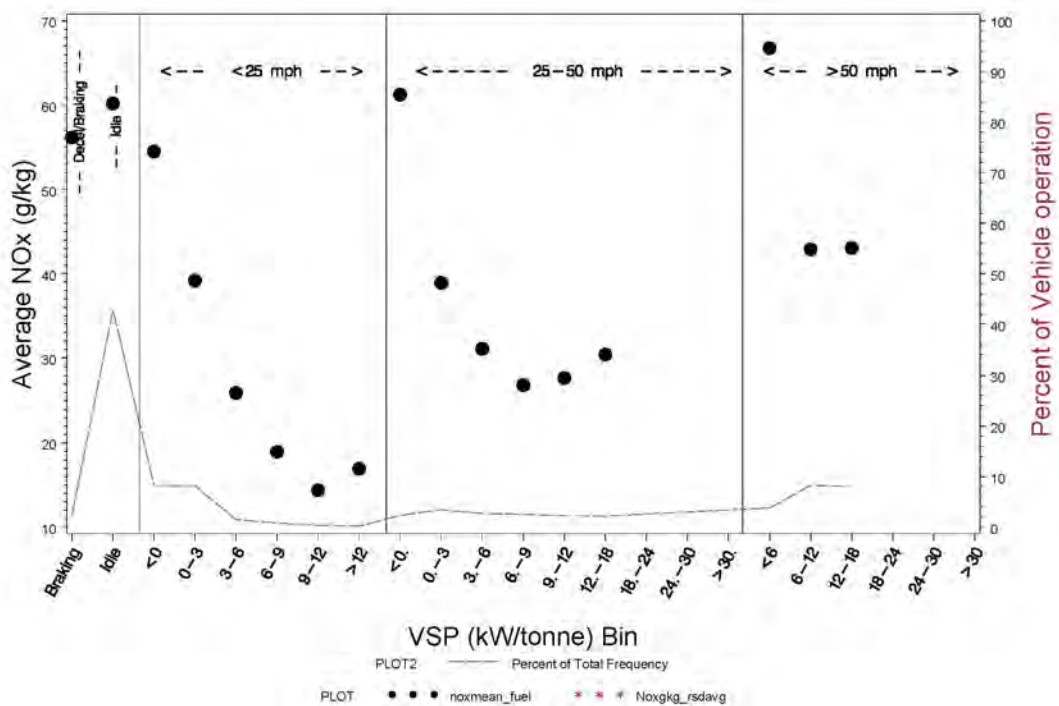


Figure 7.1-41 VSP-Based Activity And NO_x Emissions for 0182291-A

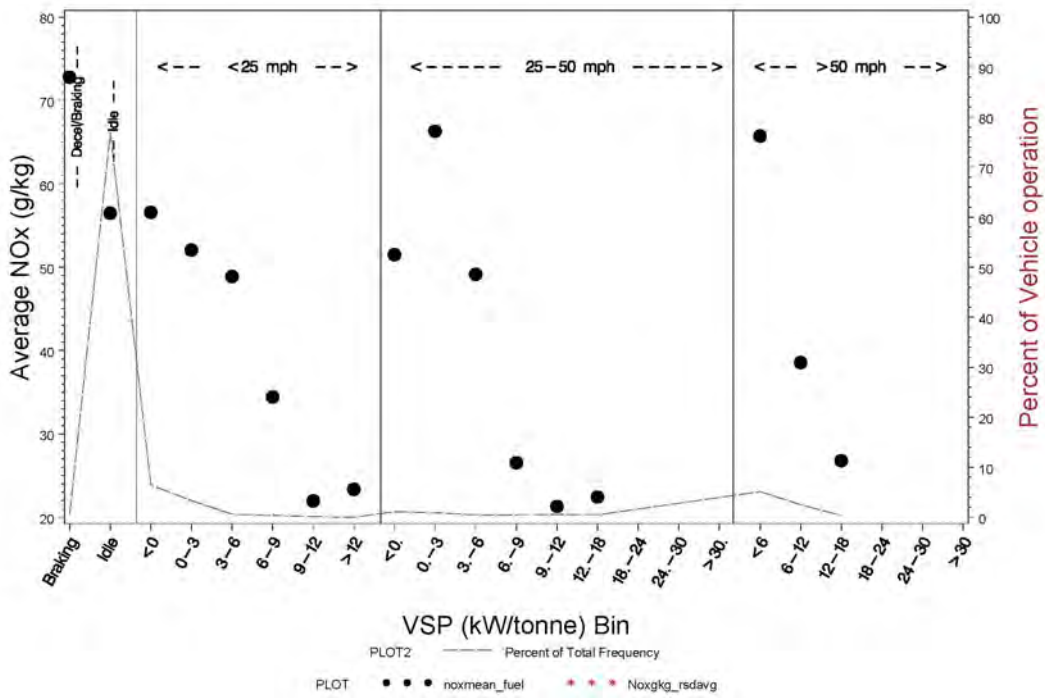


Figure 7.1-42 VSP-Based Activity And NO_x Emissions for 0183558-A

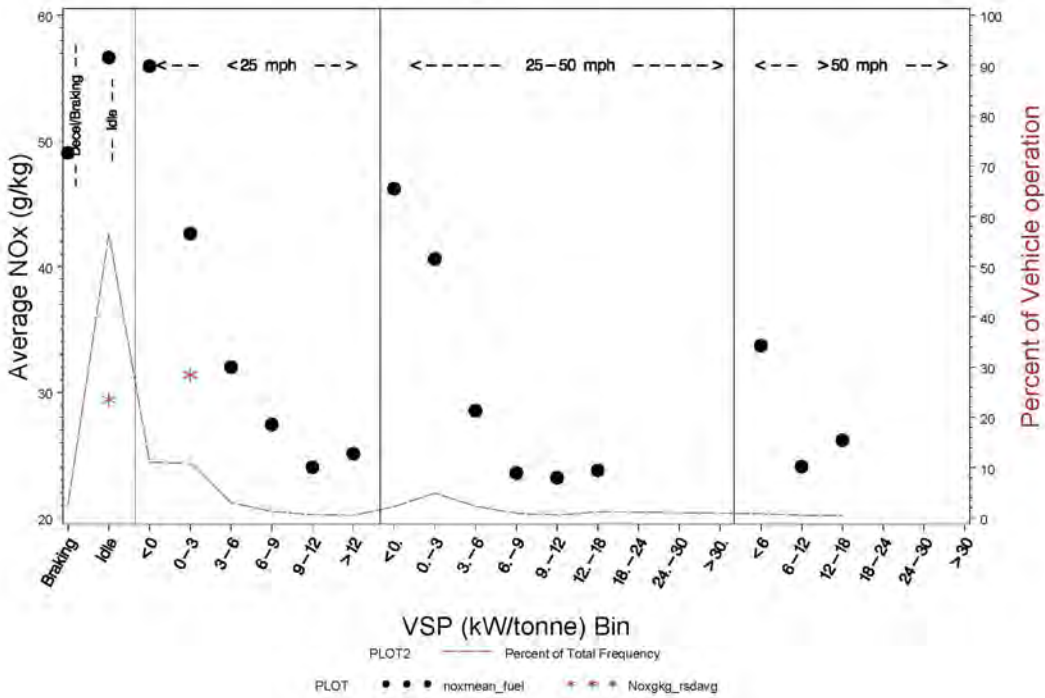


Figure 7.1-43 VSP-Based Activity And NO_x Emissions for 0183710-A

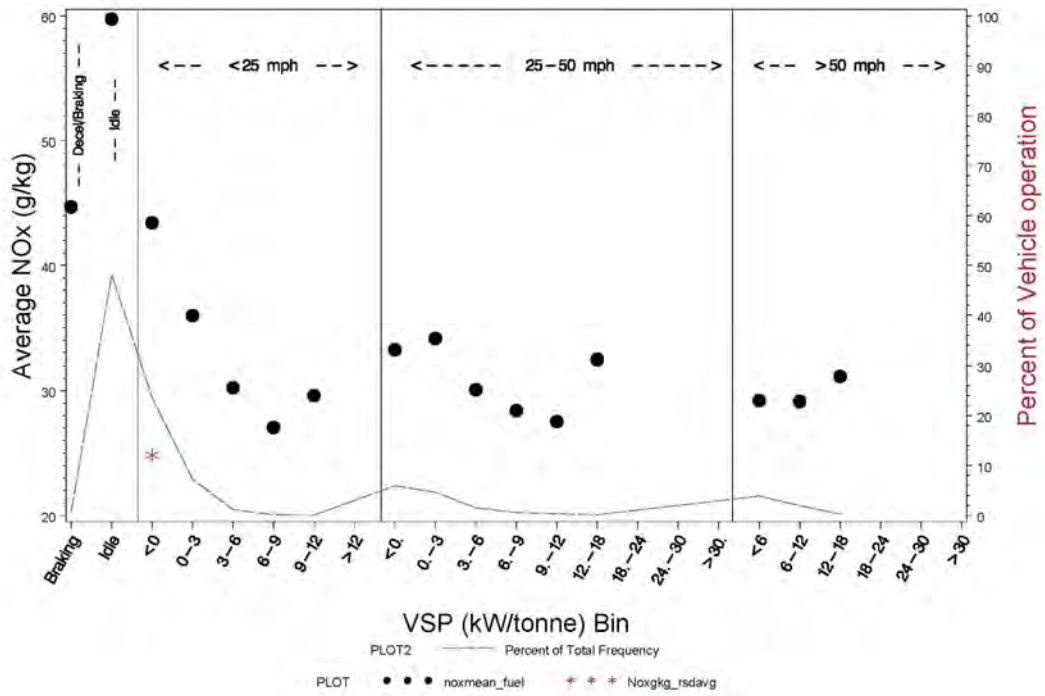


Figure 7.1-44 VSP-Based Activity And NO_x Emissions for 0183713-A

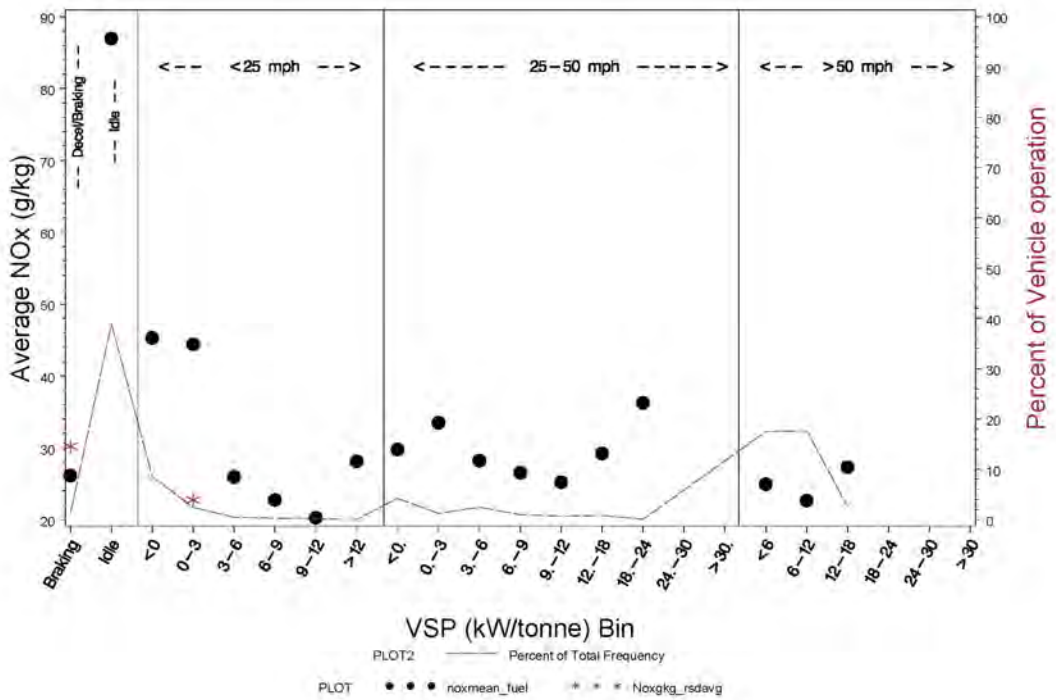


Figure 7.1-45 VSP-Based Activity And NO_x Emissions for 0183716-A

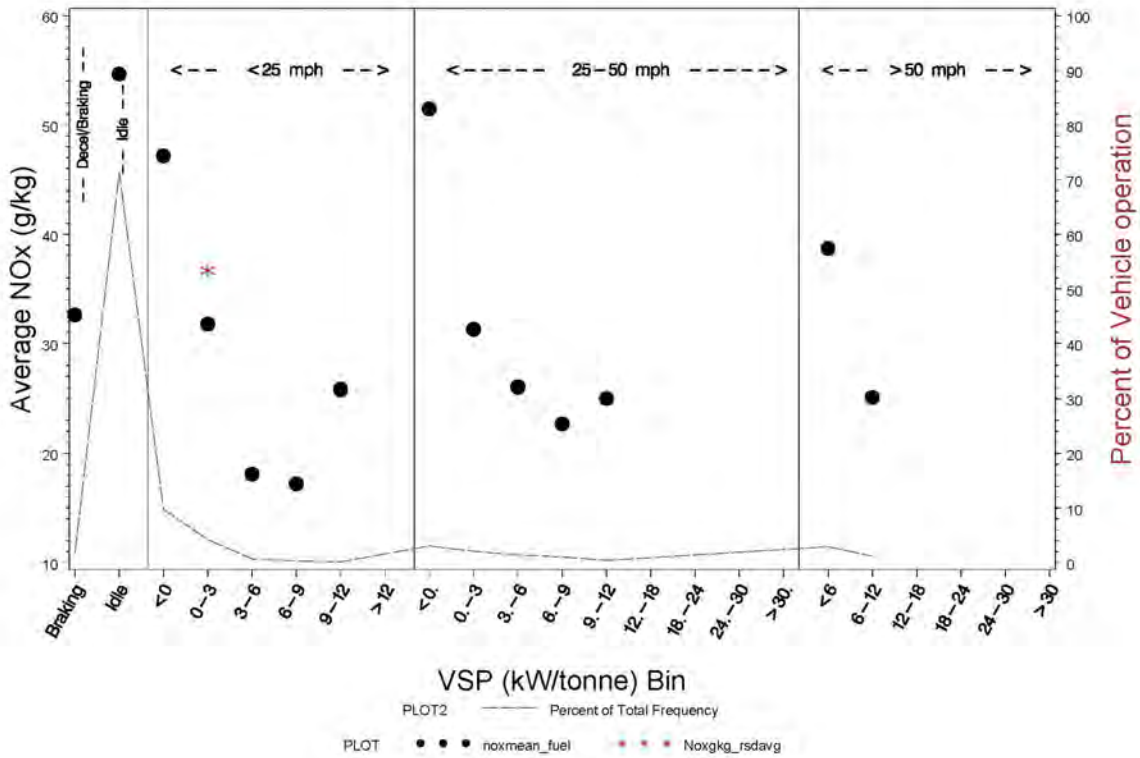


Figure 7.1-46 VSP-Based Activity And NO_x Emissions for 0183718-A

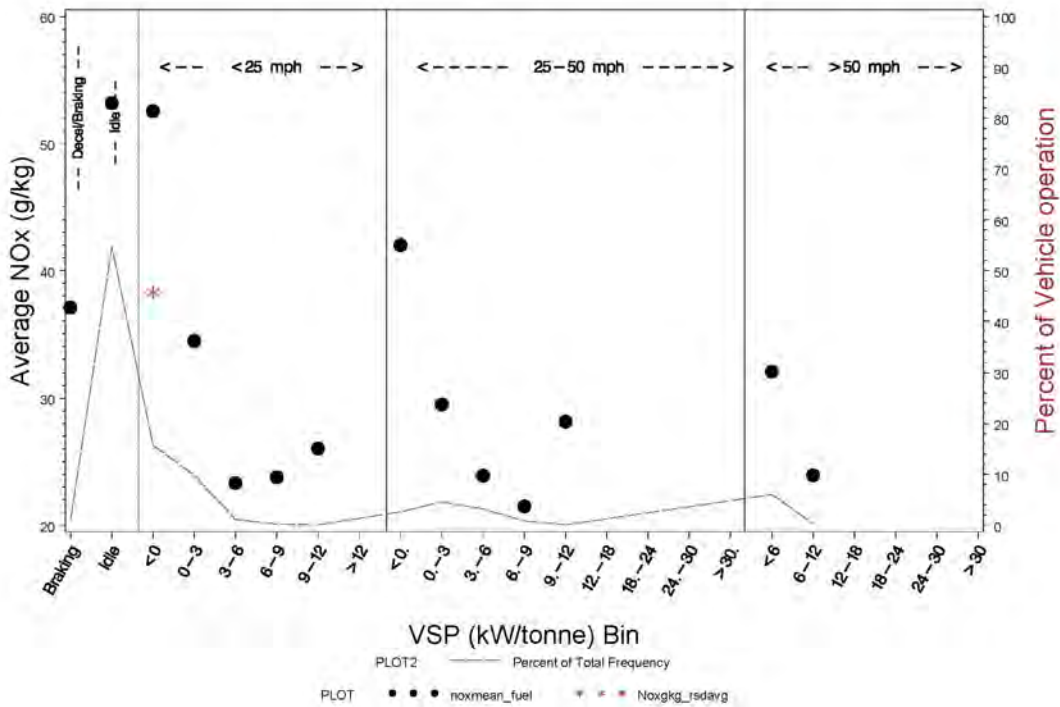


Figure 7.1-47 VSP-Based Activity And NO_x Emissions for 0184781-A

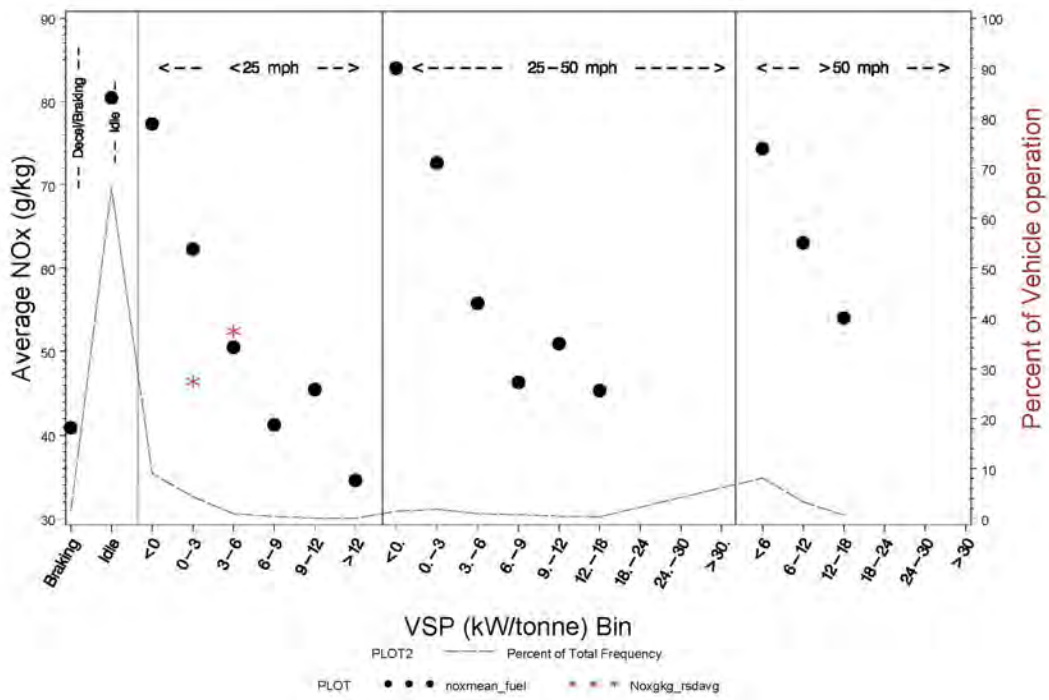


Figure 7.1-48 VSP-Based Activity And NO_x Emissions for 0185067-A

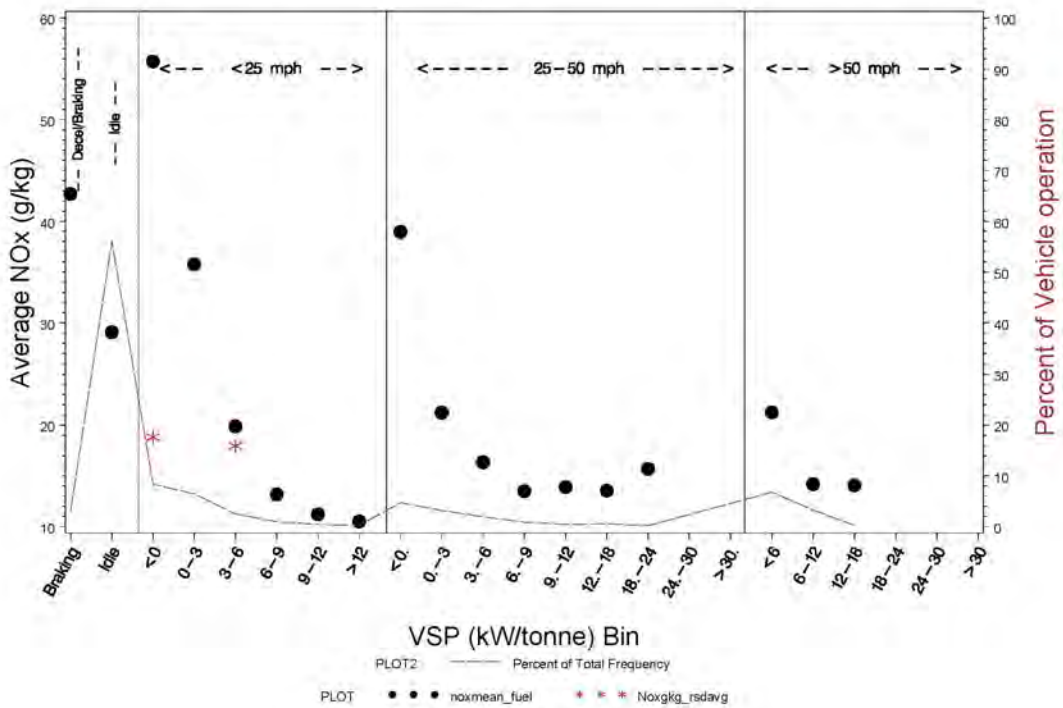


Figure 7.1-49 VSP-Based Activity And NO_x Emissions for 0185576-A

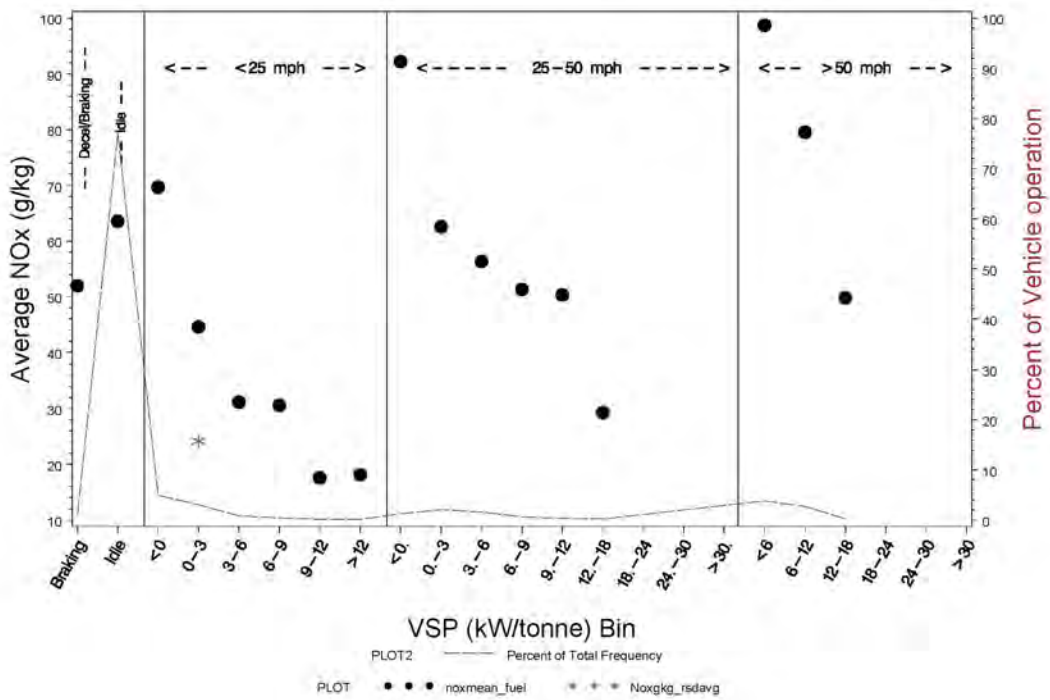


Figure 7.1-50 VSP-Based Activity And NO_x Emissions for 0185728-A

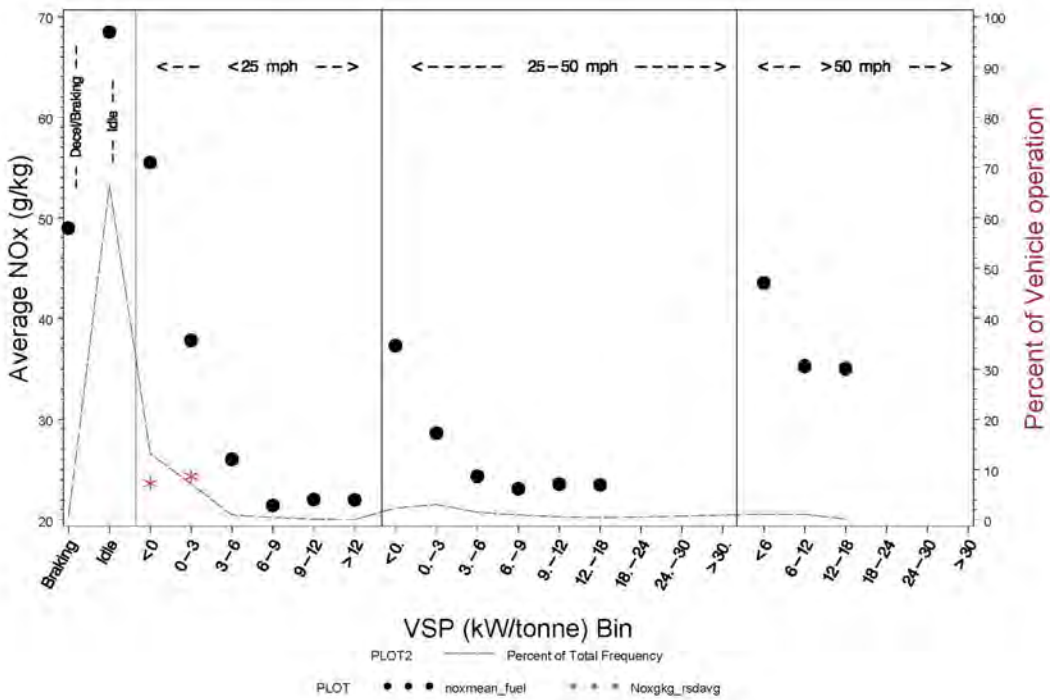


Figure 7.1-51 VSP-Based Activity And NO_x Emissions for 0185774-B

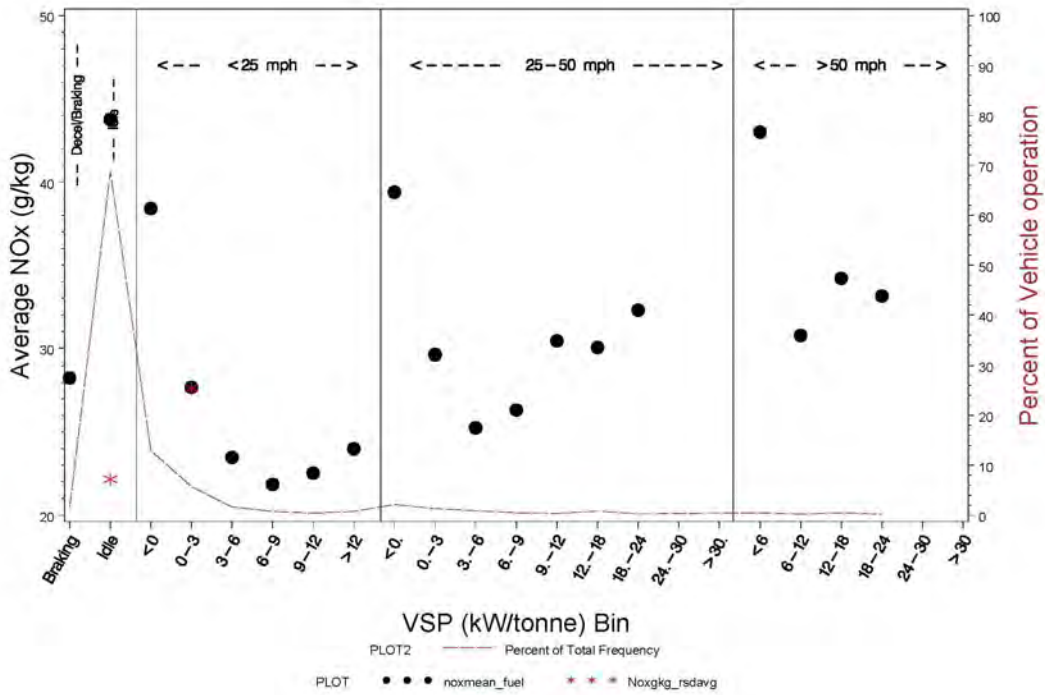


Figure 7.1-52 VSP-Based Activity And NO_x Emissions for 0186029-A

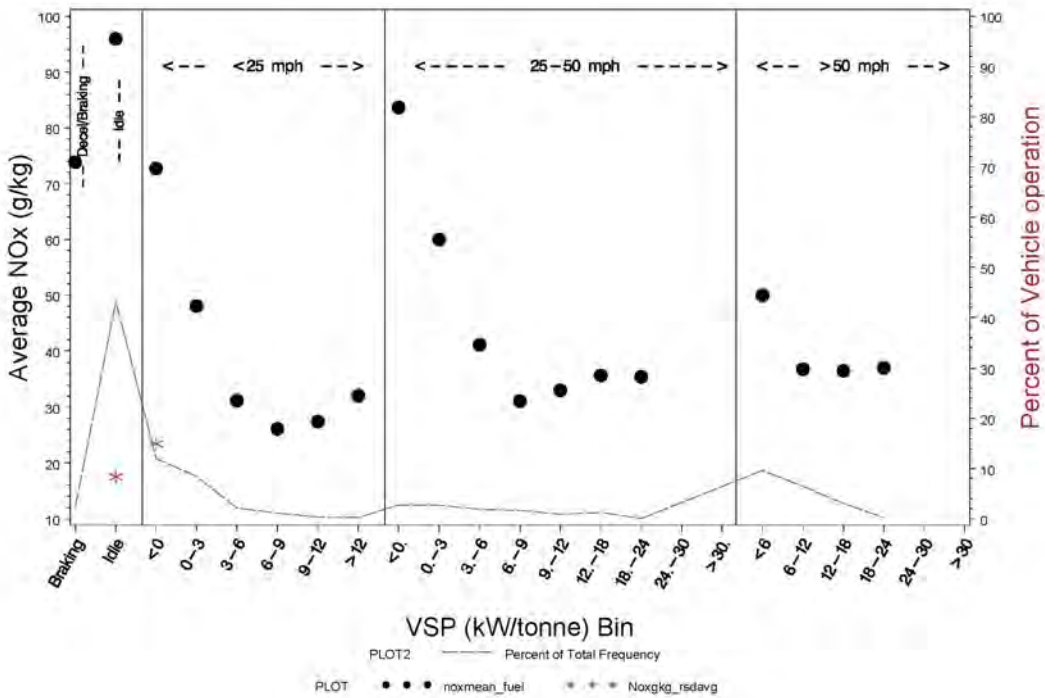


Figure 7.1-53 VSP-Based Activity And NO_x Emissions for 0188529-B

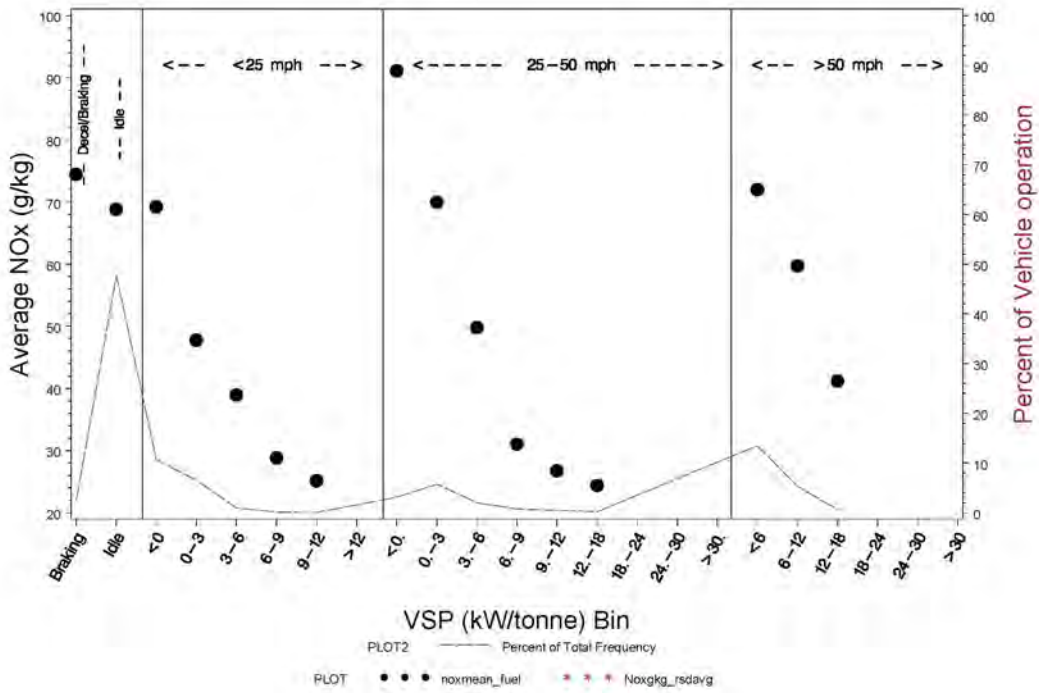


Figure 7.1-54 VSP-Based Activity And NO_x Emissions for 0189106-A

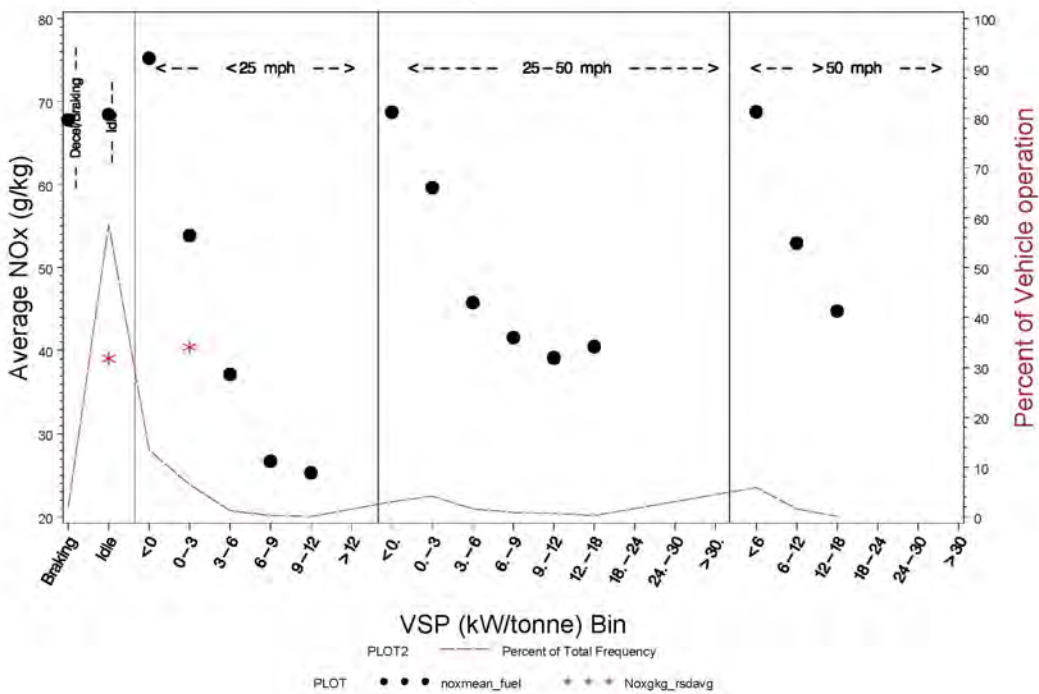


Figure 7.1-55 VSP-Based Activity And NO_x Emissions for 0190306-B

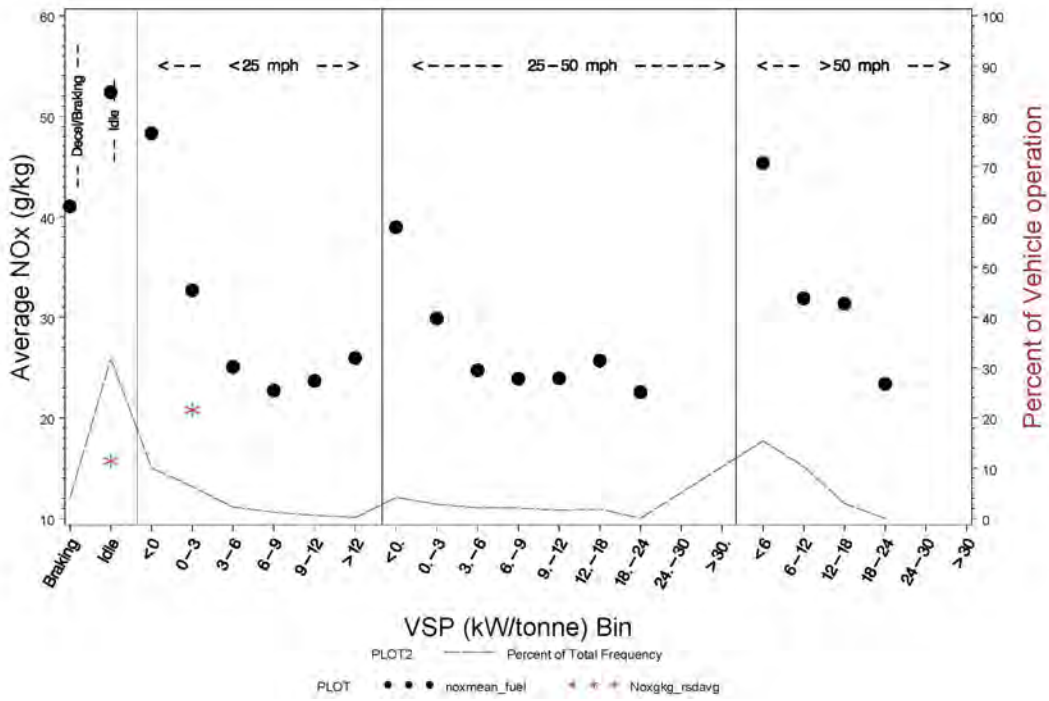


Figure 7.1-56 VSP-Based Activity And NO_x Emissions for 0190786-A

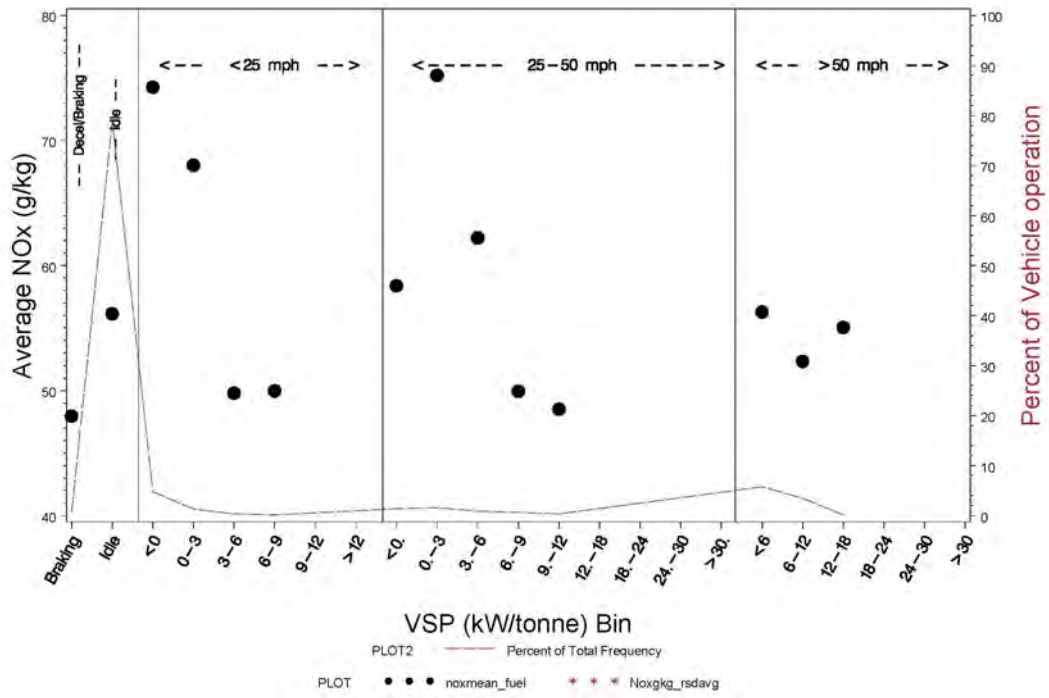


Figure 7.1-57 VSP-Based Activity And NO_x Emissions for 0190992-A

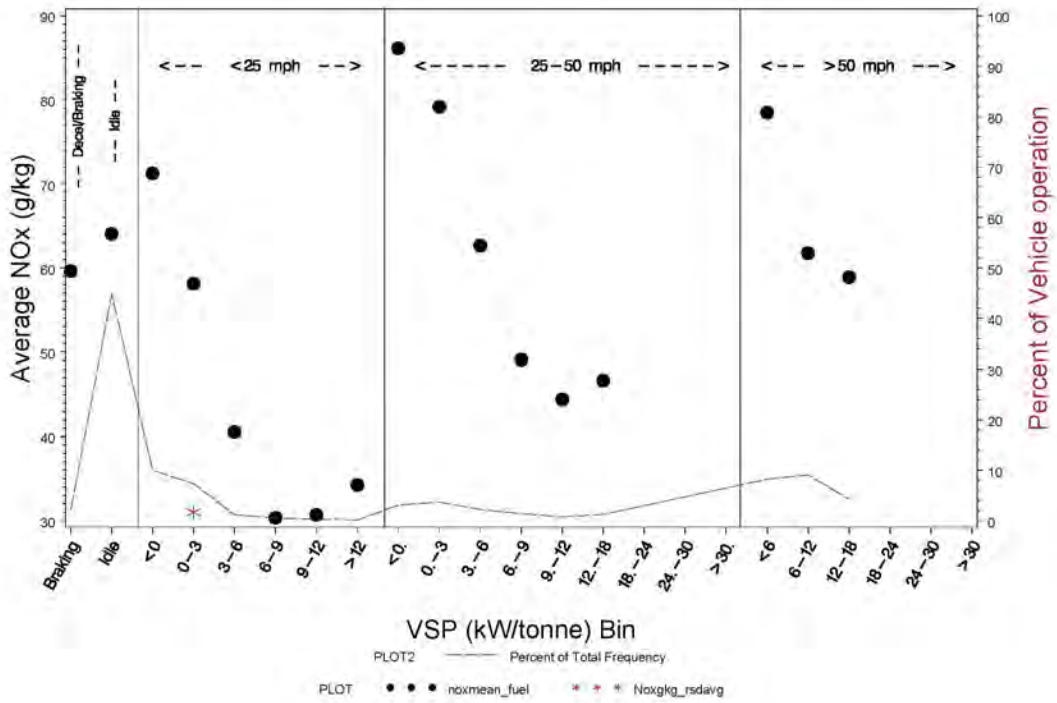


Figure 7.1-58 VSP-Based Activity And NO_x Emissions for 0218126-A

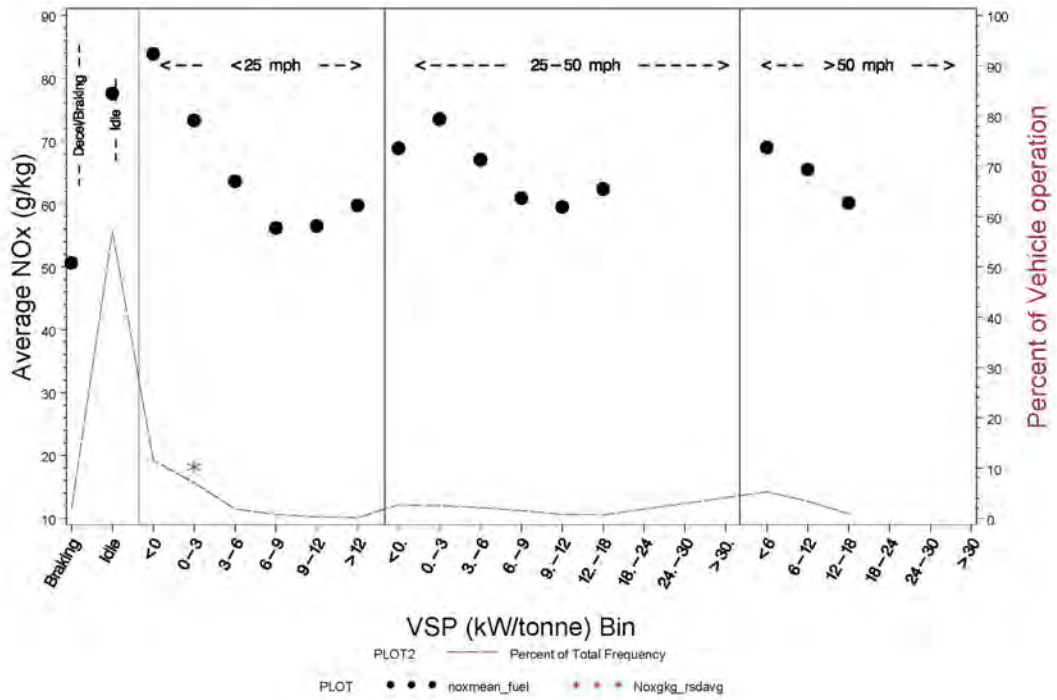


Figure 7.1-59 VSP-Based Activity And NO_x Emissions for 0267938-A

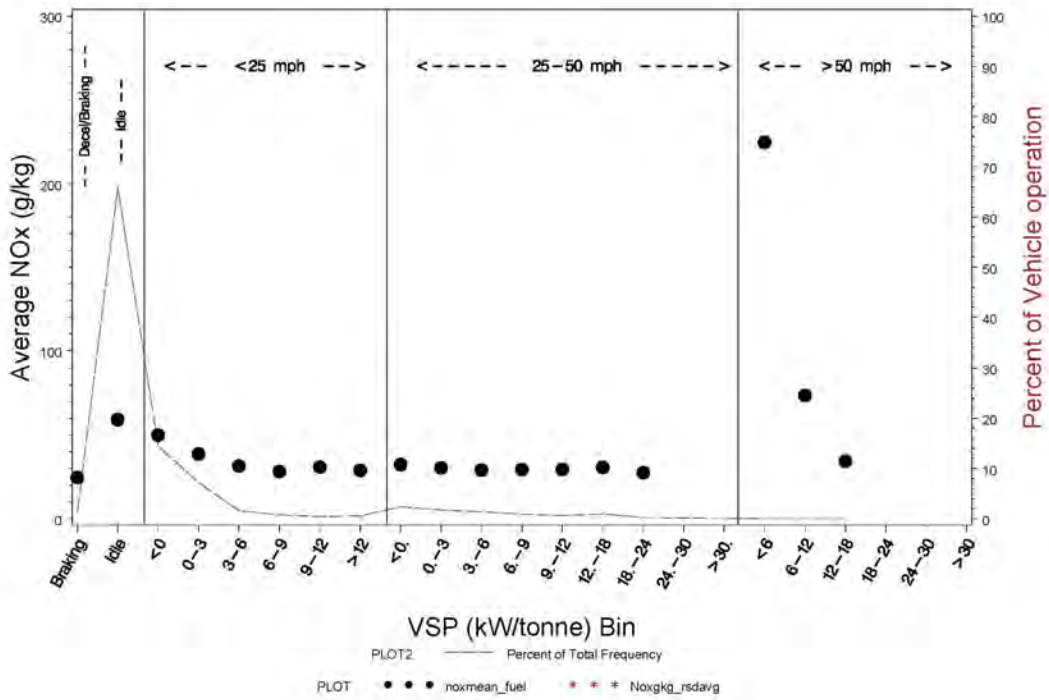


Figure 7.1-60 VSP-Based Activity And NO_x Emissions for 1095729-B

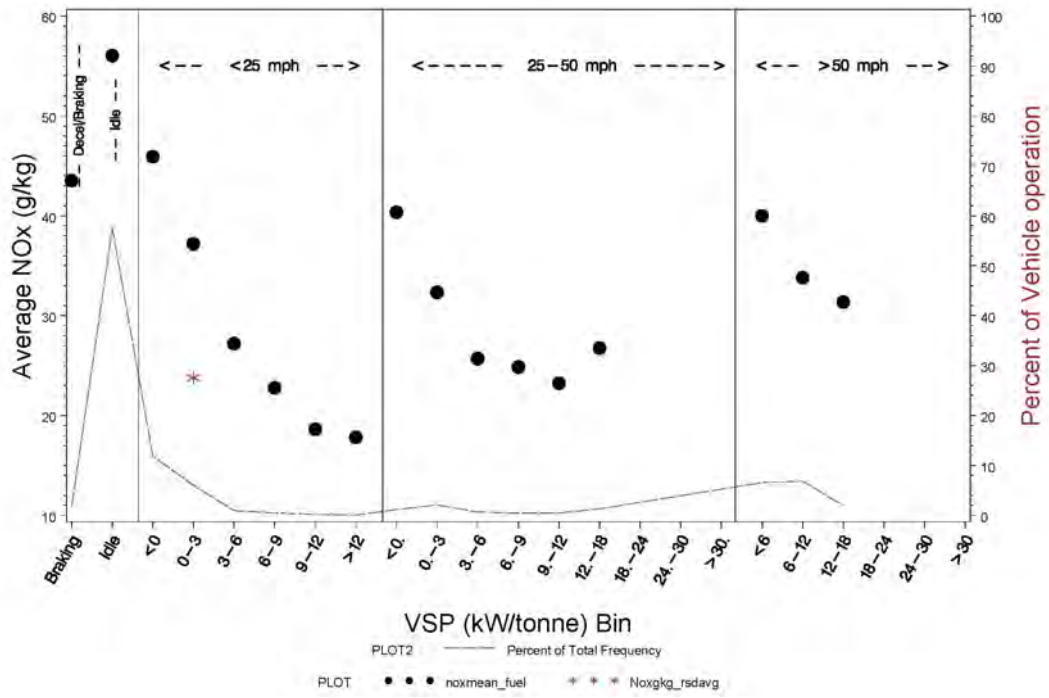


Figure 7.1-61 VSP-Based Activity And NO_x Emissions for 1095730-A

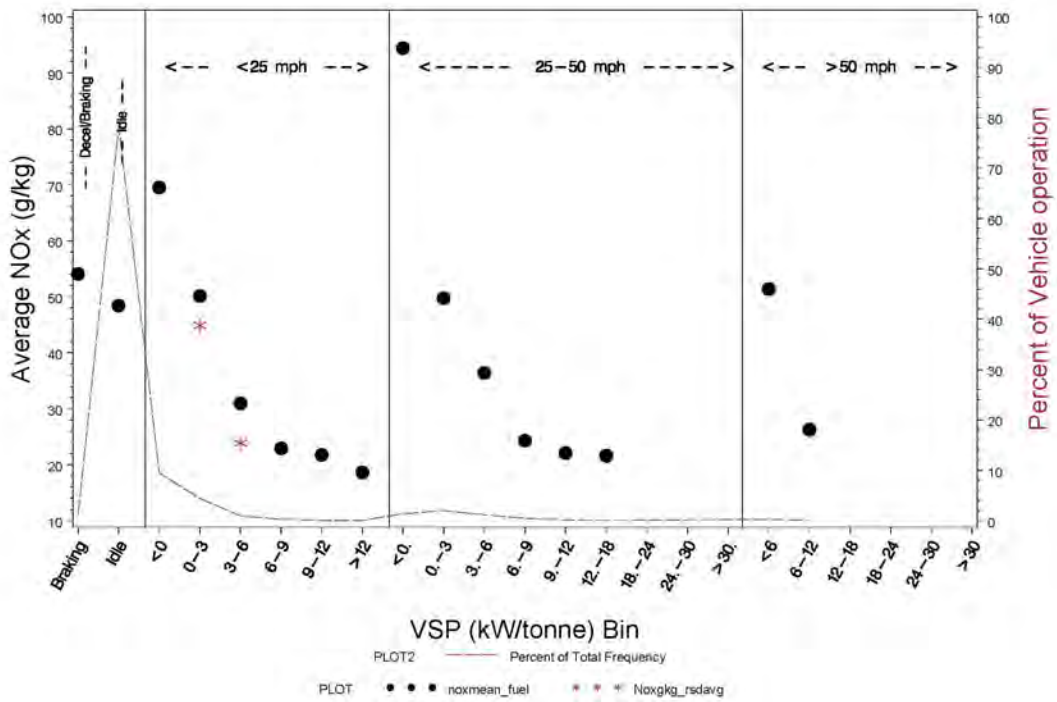


Figure 7.1-62 VSP-Based Activity And NO_x Emissions for 1144157-A

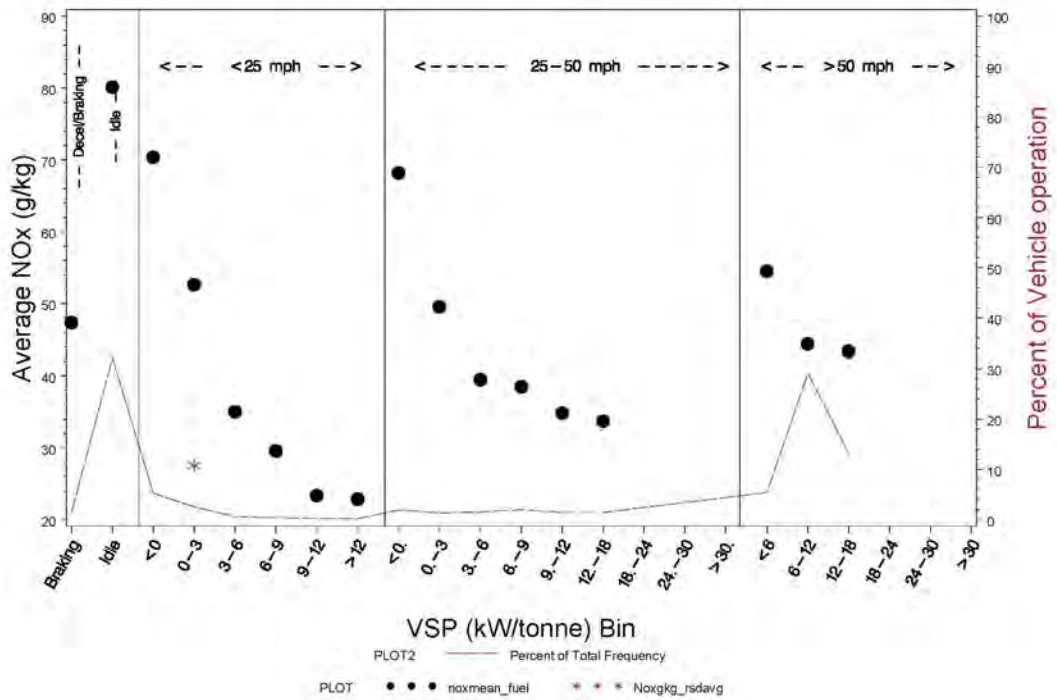


Figure 7.1-63 VSP-Based Activity And NO_x Emissions for 1157629-A

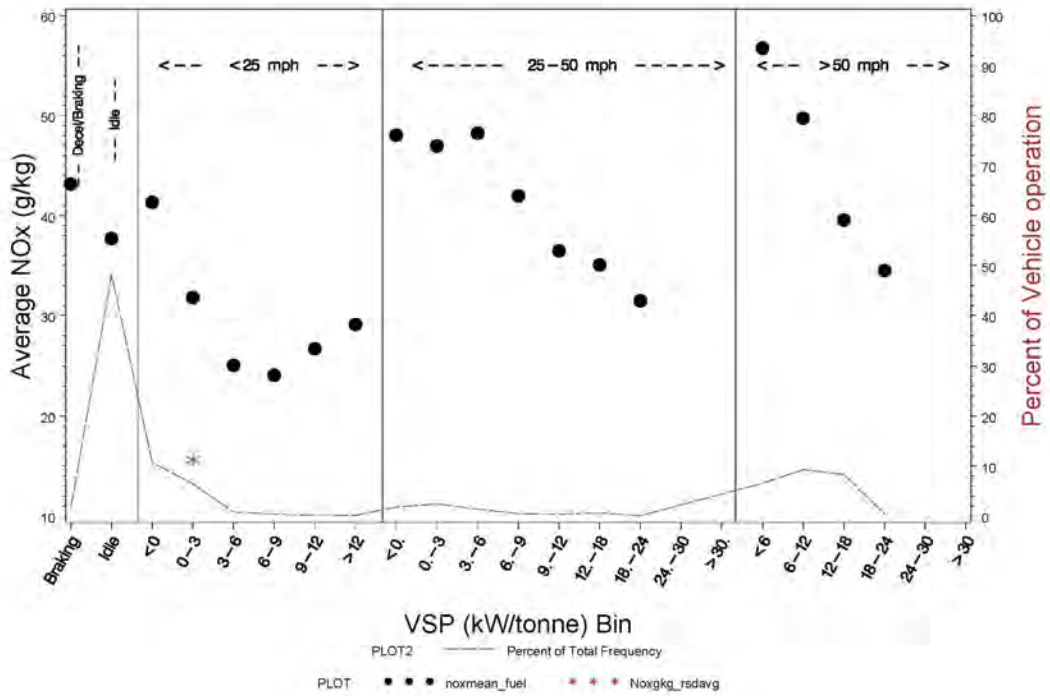


Figure 7.1-64 VSP-Based Activity And NO_x Emissions for 1190901-A

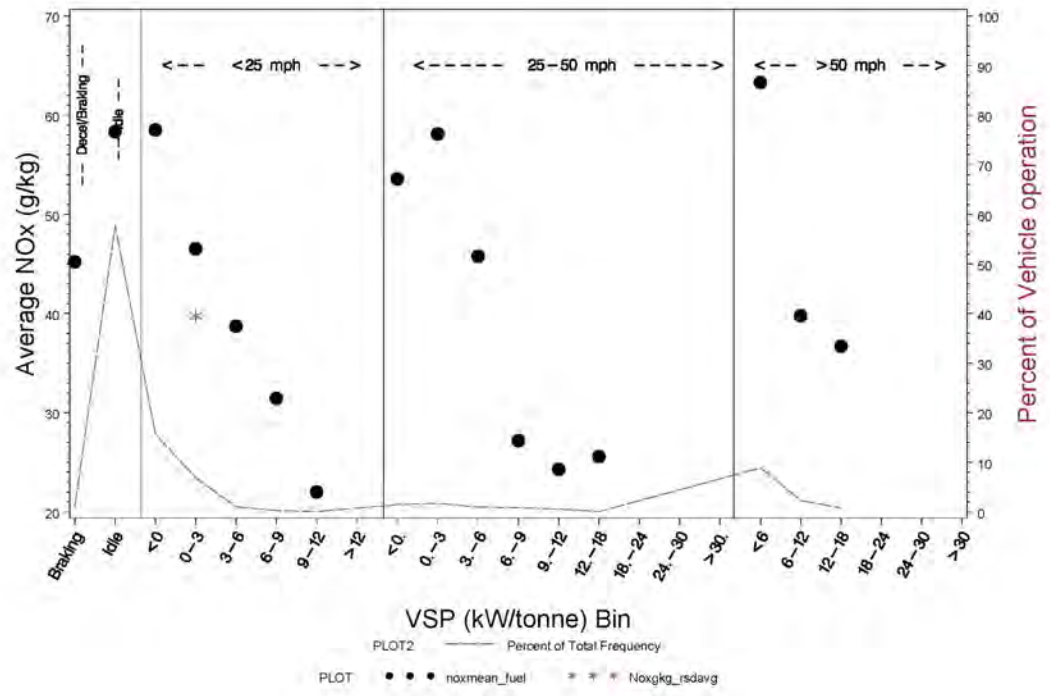


Figure 7.1-65 VSP-Based Activity And NO_x Emissions for 1191018-A

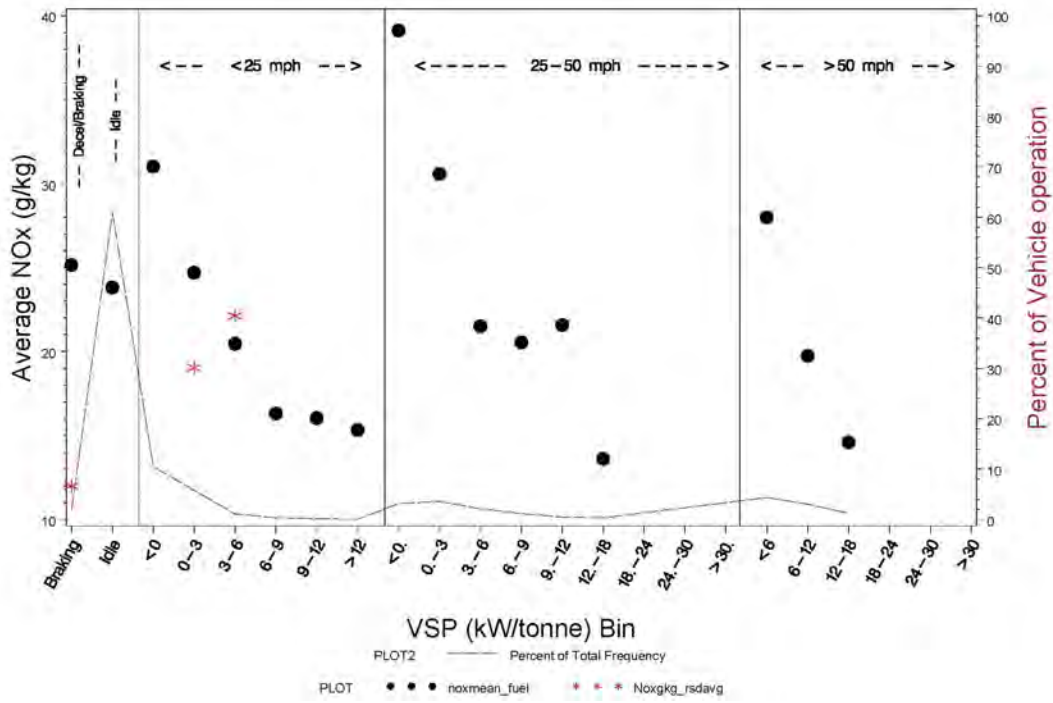
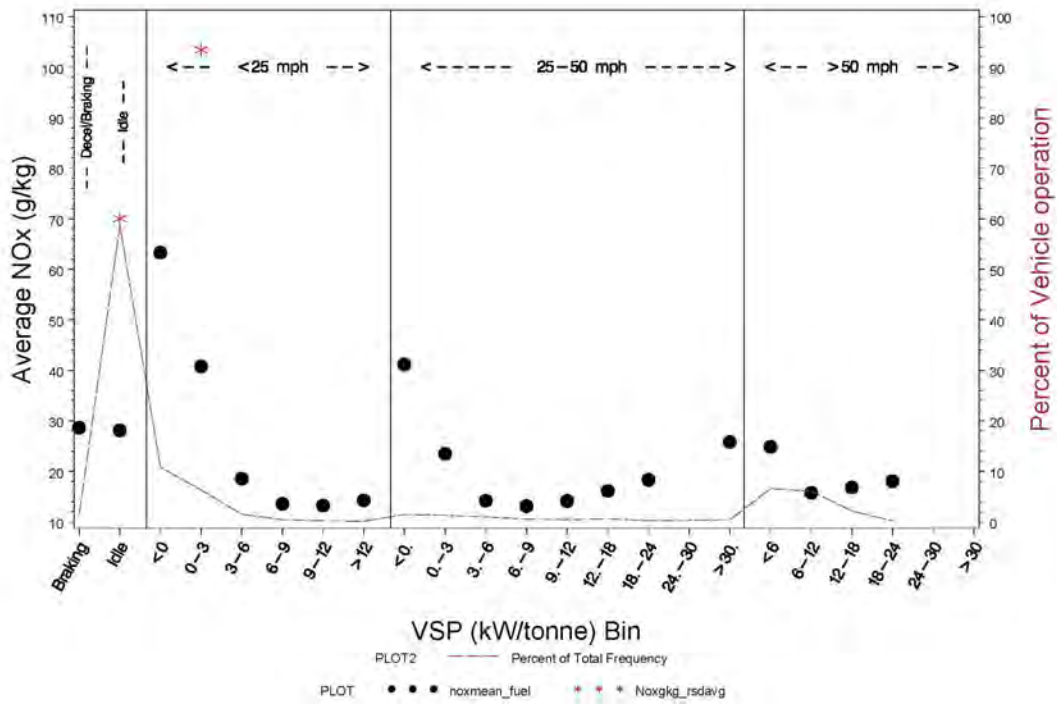


Figure 7.1-66 VSP-Based Activity And NO_x Emissions for 1191083-A



RSD vs. PEMS NO_x results shown in Figures 7.1-33 through 7.1-66 reveal some variability between the VSP-based RSD NO_x values used for sample stratification and the NO_x values actually measured during PEMS testing.

Figures 7.1.67 through 7.1.69 provide a comparison PEMS emissions vs. RSD emissions for trucks tested in this study. In these plots, each point represents an individual vehicle's cumulative PEMS average vs. cumulative RSD average within a specific VSP bin. Each axis presents VSP bin values, and a 1:1 line is provided on each plot. Reviewing these figures provides an indication of the amount of spread of HC, CO and NO_x PEMS vs. RSD results around the 1:1 line. Additional analysis of RSD and PEMS results from this study may be worthwhile to better understand the relationship between these two measurements.

Figure 7.1-67 PEMS vs. RSD HC Emissions Comparison, by VSP Bin

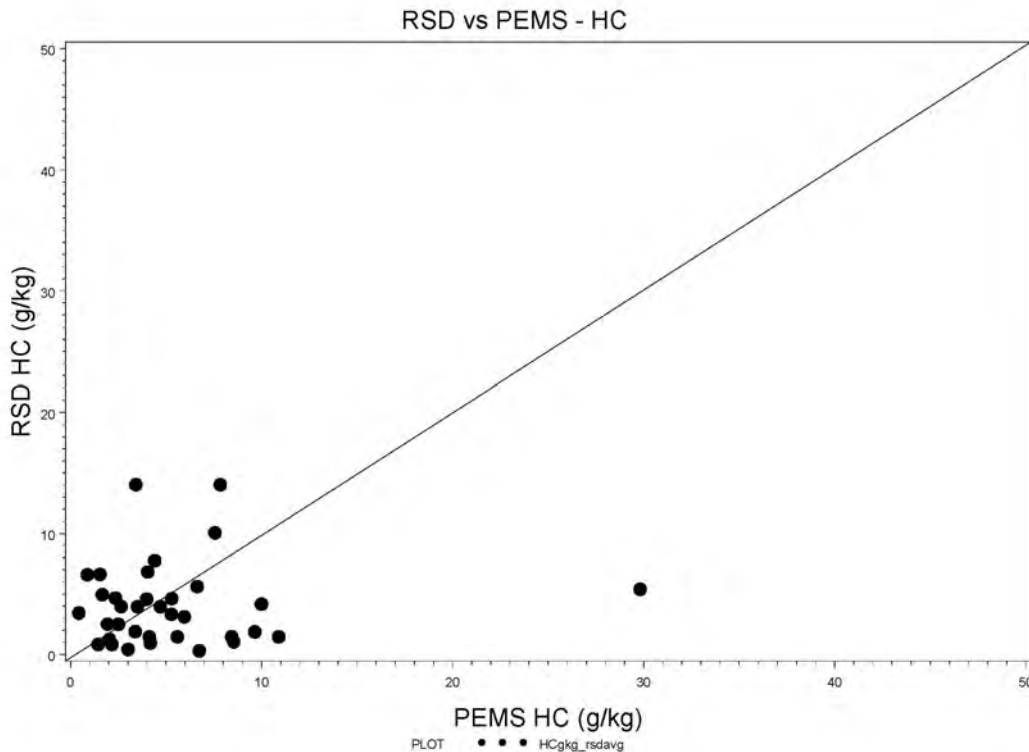


Figure 7.1-68 PEMS vs. RSD CO Emissions Comparison, by VSP Bin

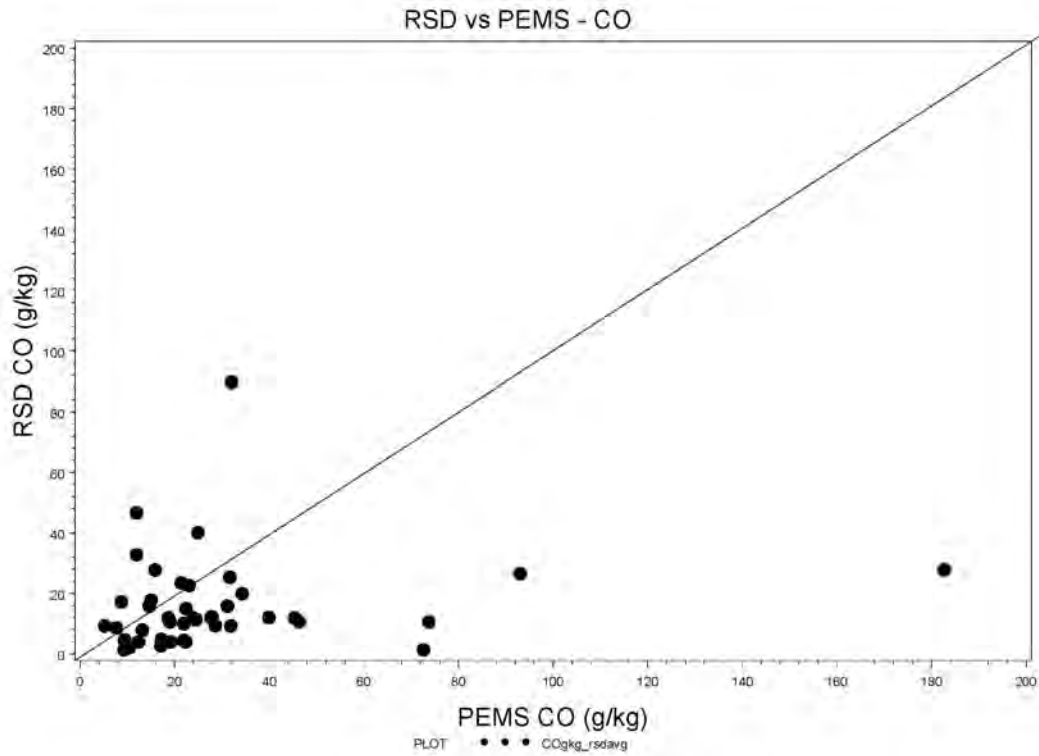


Figure 7.1-69 PEMS vs. RSD NO_x Emissions Comparison, by VSP Bin

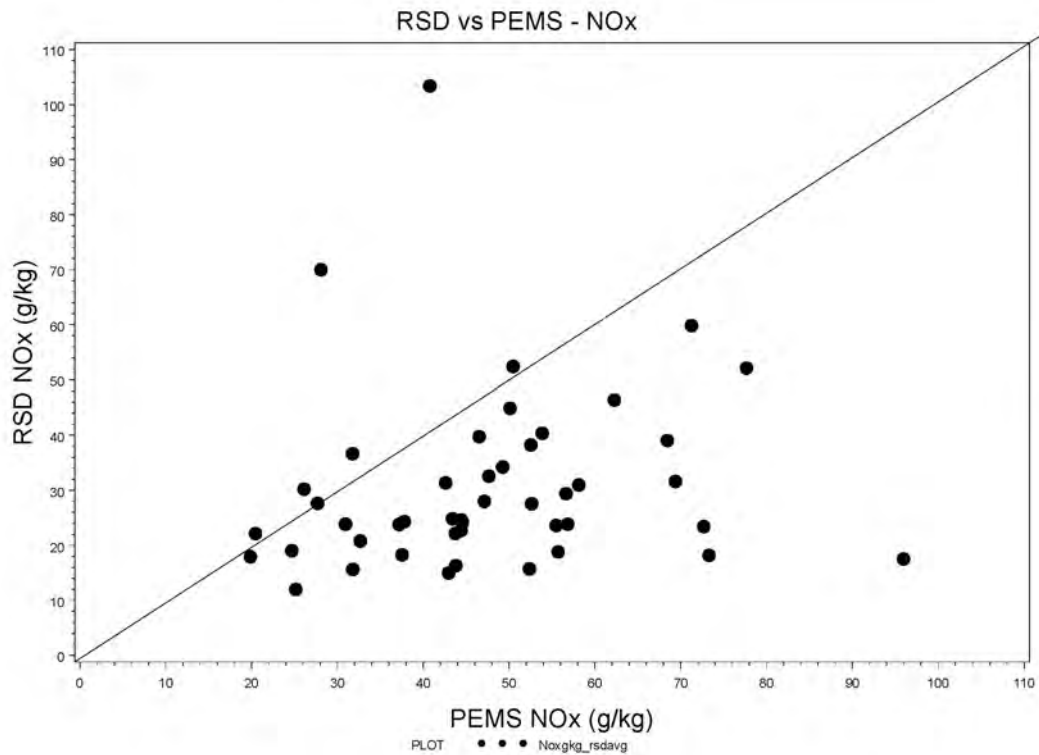
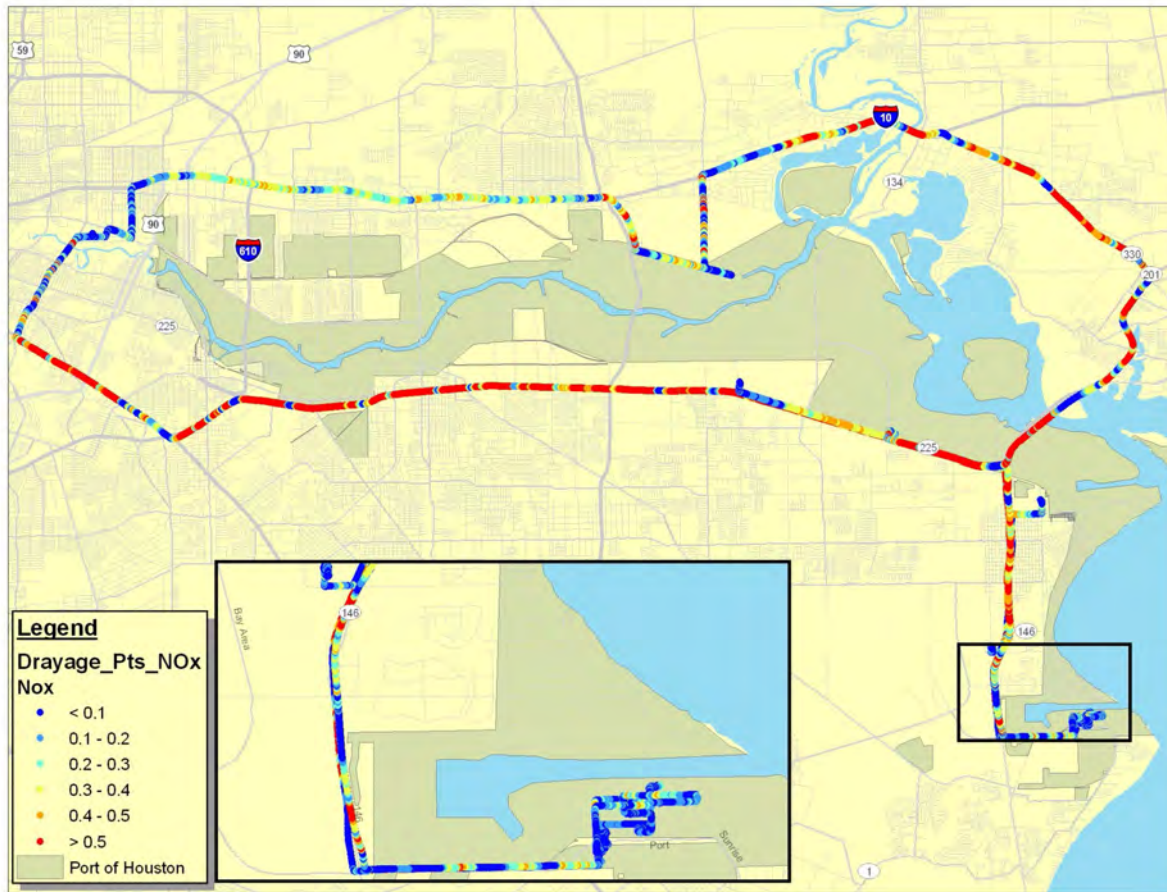


Figure 7.1-70 shows NO_x emissions graphically overlaid on a work route for one truck (0178515-B) as it performed operations on December 11, 2009. Port emissions are shown by the breakout box (Bayport Terminal in this case). In this particular test segment, NO_x emissions (g/second) appear to be lower in the port.

Tables 7.1-2 and 7.1-3 list work-based emissions, by port and by non-port operation, for each PEMS test conducted during the study. Units of work are on a grams per brake horsepower-hour (g/bhp-hr) basis, and results are cumulative for the overall test. Results in Tables 7.1-4 and 7.1-5 are provided on a distance basis (grams or kg/mile). Potentially invalid or “suspect” results are excluded from Tables 7.1-2 through 7.1-5.

Additional details regarding these results, including notes regarding data corrections and potentially invalid data that has been excluded from these summaries, are provided in Appendix J, Consolidated PEMS Review Results. A compilation of all emission results from this study is provided in Appendix M (including flagging of suspect or potentially invalid data). All emissions and activity data collected throughout the study will be provided as a deliverable accompanying this report (in raw form and in a MySQL database as described in Section 9.0).

Figure 7.1-70 NOx Emissions (g/s) for 0178515-B During a Day's Route



When reviewing Tables 7.1-2 through 7.1-5, it may be noted that work-based results are not listed for some tests which do have distance-based results listed. For these tests, no lug or maximum fuel consumption curve was available to develop work-based emission estimates. Appendix AC (Drayage Processing Parameters) provides details regarding lug curve availability and work-basis determinations for each test.

NOx in all emissions results refers to the total exhaust nitrogen oxides, corrected for humidity using methodology defined in 40CFR 1065.670. THC refers to the total hydrocarbon content of the exhaust, and CO and CO₂ refer to carbon monoxide and carbon dioxide exhaust content, respectively. PM refers to the total exhaust particulate matter, determined using dilution-corrected weight measurement results of heated 47mm gravimetric filters collected during testing.

Table 7.1-2 Drayage Average Work-Based Emissions, In-Port

| Test ID | Test Date | Truck Mfr | MY | Time (mins) | Dist (mi) | Idle (%) | Avg Spd (mph) | THC (g/bhp-hr) | CO (g/bhp-hr) | CO2 (kg/bhp-hr) | NOx (g/bhp-hr) | PM (g/bhp-hr) |
|-----------|-----------|-----------|------|-------------|-----------|----------|---------------|----------------|---------------|-----------------|----------------|---------------|
| 0160699-A | 20100316 | Frtlnr | 1997 | 299 | 17.4 | 56 | 3.5 | 3.39 | 5.32 | 1.51 | 21.64 | . |
| 0160910-A | 20100211 | Frtlnr | 2004 | 131 | 4.5 | 74 | 2.1 | 0.61 | 11.15 | 2.03 | 31.85 | . |
| 0178515-B | 20091210 | Frtlnr | 1994 | 59 | 2.4 | 65 | 2.4 | 18.30 | 12.39 | 1.12 | 19.45 | . |
| 0178515-B | 20091211 | Frtlnr | 1994 | 157 | 7.2 | 66 | 2.8 | 16.25 | 10.41 | 0.98 | 16.51 | 0.645 |
| 0180990-A | 20100211 | Frtlnr | 1999 | . | . | . | . | . | . | . | . | . |
| 0181021-A | 20091216 | Nav Intl | 1993 | 38 | 2.4 | 53 | 3.8 | . | . | . | . | . |
| 0181096-A | 20091217 | Frtlnr | 1993 | 47 | 2.3 | 54 | 2.9 | 1.29 | 8.75 | 0.55 | 10.08 | . |
| 0181096-A | 20100127 | Frtlnr | 1993 | 49 | 1.9 | 72 | 2.3 | 2.55 | 29.49 | 1.49 | 28.13 | . |
| 0181157-A | 20100317 | KW | 1996 | 211 | 12.9 | 57 | 3.7 | 1.62 | 3.68 | 1.20 | 18.89 | 0.128 |
| 0181276-B | 20091209 | KW | 1980 | 106 | 3.1 | 42 | 1.8 | . | . | . | . | . |
| 0181276-B | 20100125 | KW | 1980 | 69 | 3.0 | 63 | 2.6 | . | . | . | . | . |
| 0182003-A | 20100309 | Volvo | 1996 | 206 | 7.3 | 53 | 2.1 | 1.30 | 8.95 | 0.92 | 21.25 | . |
| 0182003-A | 20100310 | Volvo | 1996 | 307 | 11.6 | 62 | 2.3 | 2.08 | 15.23 | 1.31 | 31.87 | 0.236 |
| 0182022-A | 20100308 | Nav Intl | 1998 | 85 | 2.8 | 65 | 2.0 | 4.46 | 15.09 | 1.05 | 15.38 | . |
| 0182291-A | 20100210 | KW | 2000 | 147 | 1.4 | 82 | 0.6 | 19.18 | 25.13 | 5.98 | 88.49 | . |
| 0183558-A | 20100311 | Nav Intl | 1999 | 224 | 13.6 | 59 | 3.7 | 2.31 | 6.52 | 1.14 | 15.62 | 0.246 |
| 0183710-A | 20091215 | Frtlnr | 2003 | 121 | 7.9 | 45 | 3.9 | 8.38 | 31.81 | 4.74 | 66.98 | 1.259 |
| 0183713-A | 20091216 | Frtlnr | 2003 | 68 | 2.4 | 74 | 2.1 | 4.34 | 43.04 | 3.26 | 62.18 | . |
| 0183716-A | 20100125 | Frtlnr | 2003 | 77 | 1.4 | 87 | 1.1 | 3.28 | 28.09 | 3.33 | 51.64 | . |
| 0183718-A | 20091214 | Frtlnr | 2003 | 255 | 10.2 | 42 | 2.4 | 3.04 | 12.98 | 1.91 | 27.52 | 0.182 |
| 0184781-A | 20100203 | Frtlnr | 1997 | . | . | . | . | . | . | . | . | . |
| 0184781-A | 20100204 | Frtlnr | 1997 | 61 | 5.2 | 55 | 5.1 | 2.02 | 14.64 | 1.63 | 39.15 | . |
| 0185067-A | 20100205 | KW | 2004 | 76 | 4.4 | 64 | 3.4 | 1.31 | 21.77 | 0.92 | 8.80 | 0.391 |
| 0185576-A | 20100204 | Nav Intl | 1998 | . | . | . | . | . | . | . | . | . |
| 0185728-A | 20100312 | Frtlnr | 2001 | 146 | 2.4 | 83 | 1.0 | 3.41 | 22.49 | 3.24 | 62.20 | . |
| 0185774-B | 20100315 | KW | 2000 | 331 | 17.0 | 63 | 3.1 | 0.79 | 6.83 | 0.95 | 10.06 | 0.079 |
| 0186029-A | 20100316 | Frtlnr | 2000 | 98 | 6.6 | 52 | 4.1 | 1.06 | 7.60 | 1.13 | 22.14 | . |
| 0188529-B | 20100205 | Nav Intl | 1999 | 6 | 0.3 | 73 | 3.0 | 5.16 | 15.89 | 2.26 | 45.75 | . |
| 0189106-A | 20100208 | Frtlnr | 1998 | 92 | 3.6 | 71 | 2.4 | 2.28 | 33.34 | 2.05 | 43.72 | . |
| 0190306-B | 20100312 | Volvo | 2001 | 52 | 2.8 | 60 | 3.3 | 1.25 | 8.80 | 1.38 | 17.82 | 0.119 |
| 0190786-A | 20100209 | Frtlnr | 1997 | . | . | . | . | . | . | . | . | . |

| Test ID | Test Date | Truck Mfr | MY | Time (mins) | Dist (mi) | Idle (%) | Avg Spd (mph) | THC (g/bhp-hr) | CO (g/bhp-hr) | CO2 (kg/bhp-hr) | NOx (g/bhp-hr) | PM (g/bhp-hr) |
|-------------------|-----------|-----------|------|-------------|-----------|----------|---------------|----------------|---------------|-----------------|----------------|---------------|
| 0190992-A | 20100317 | Frtlnr | 1997 | 71 | 5.9 | 48 | 5.0 | 2.28 | 14.17 | 1.06 | 18.60 | . |
| 0218126-A | 20100126 | Frtlnr | 2000 | 81 | 13.7 | 31 | 10.2 | 0.30 | 2.71 | 0.63 | 14.07 | 0.041 |
| 0218126-A | 20100127 | Frtlnr | 2000 | 98 | 8.6 | 54 | 5.3 | 0.63 | 4.63 | 0.84 | 19.39 | 0.153 |
| 0267938-A | 20100310 | Frtlnr | 1997 | 102 | 3.4 | 0 | 2.0 | 1.60 | 8.65 | 1.64 | 27.38 | . |
| 1095729-B | 20100128 | Frtlnr | 2002 | 97 | 4.0 | 65 | 2.5 | 3.39 | 11.34 | 1.27 | 17.40 | . |
| 1095730-A | 20100201 | Frtlnr | 2001 | . | . | . | . | . | . | . | . | . |
| 1095730-A | 20100202 | Frtlnr | 2001 | . | . | . | . | . | . | . | . | . |
| 1144157-A | 20100308 | Nav Intl | 1999 | 42 | 1.6 | 58 | 2.2 | 1.48 | 10.75 | 1.72 | 34.73 | . |
| 1157629-A | 20100315 | Frtlnr | 2006 | 104 | 6.3 | 54 | 3.6 | 0.66 | 7.16 | 2.60 | 30.71 | . |
| 1190901-A | 20100208 | Nav Intl | 2003 | . | . | . | . | . | . | . | . | . |
| 1190901-A | 20100209 | Nav Intl | 2003 | 146 | 8.6 | 66 | 3.5 | 3.17 | 8.55 | 1.74 | 30.89 | 0.177 |
| 1191018-A | 20100210 | Frtlnr | 2004 | 44 | 9.5 | 30 | 12.8 | 0.25 | 2.97 | 0.91 | 6.33 | 0.174 |
| 1191083-A | 20100201 | KW | 2004 | 88 | 5.2 | 48 | 3.5 | 1.62 | 32.35 | 1.12 | 11.69 | 0.170 |
| 1191083-A | 20100202 | KW | 2004 | 146 | 5.3 | 66 | 2.2 | 2.39 | 56.12 | 1.47 | 16.98 | 0.188 |
| 1191084-A | 20100128 | KW | 2004 | . | . | . | . | . | . | . | . | . |
| | | | | | | | | | | | | . |
| Cumulative | | | | 4537 | 231 | 58 | 3.0 | 3.08 | 11.71 | 1.35 | 21.09 | 0.200 |

Table 7.1-3 Drayage Average Work-Based Emissions, Non-Port

| Test ID | Test Date | Truck Mfr | MY | Time (mins) | Dist (mi) | Idle (%) | Avg Spd (mph) | THC (g/bhp-hr) | CO (g/bhp-hr) | CO2 (kg/bhp-hr) | NOx (g/bhp-hr) | PM (g/bhp-hr) |
|-----------|-----------|-----------|------|-------------|-----------|----------|---------------|----------------|---------------|-----------------|----------------|---------------|
| 0160699-A | 20100316 | Frtlnr | 1997 | 254 | 57.5 | 38 | 13.6 | 0.89 | 1.64 | 0.73 | 11.75 | . |
| 0160910-A | 20100211 | Frtlnr | 2004 | 377 | 112.2 | 42 | 17.8 | 0.07 | 2.11 | 0.71 | 8.82 | . |
| 0178515-B | 20091210 | Frtlnr | 1994 | 410 | 71.1 | 44 | 10.4 | 4.59 | 4.06 | 0.66 | 11.55 | . |
| 0178515-B | 20091211 | Frtlnr | 1994 | 391 | 105.3 | 42 | 16.1 | 3.00 | 2.76 | 0.55 | 9.02 | 0.120 |
| 0180990-A | 20100211 | Frtlnr | 1999 | 510 | 140.8 | 0 | 16.6 | 0.08 | 1.16 | 0.64 | 10.78 | . |
| 0181021-A | 20091216 | Nav Intl | 1993 | 467 | 128.5 | 26 | 16.5 | . | . | . | . | . |
| 0181096-A | 20091217 | Frtlnr | 1993 | 137 | 62.0 | 27 | 27.2 | 0.32 | 3.88 | 0.55 | 8.81 | . |
| 0181096-A | 20100127 | Frtlnr | 1993 | 407 | 103.5 | 33 | 15.3 | 0.44 | 6.77 | 0.68 | 9.17 | . |
| 0181157-A | 20100317 | KW | 1996 | 302 | 37.9 | 57 | 7.5 | 1.09 | 2.61 | 0.88 | 12.95 | 0.111 |
| 0181276-B | 20091209 | KW | 1980 | 207 | 38.8 | 19 | 11.3 | . | . | . | . | . |
| 0181276-B | 20100125 | KW | 1980 | 379 | 91.0 | 27 | 14.4 | . | . | . | . | . |
| 0182003-A | 20100309 | Volvo | 1996 | 366 | 66.5 | 46 | 10.9 | 0.32 | 4.01 | 0.60 | 10.83 | . |
| 0182003-A | 20100310 | Volvo | 1996 | 210 | 35.8 | 37 | 10.2 | 0.52 | 4.37 | 0.63 | 12.63 | 0.095 |
| 0182022-A | 20100308 | Nav Intl | 1998 | 289 | 97.6 | 20 | 20.3 | 0.22 | 1.98 | 0.47 | 5.94 | . |
| 0182291-A | 20100210 | KW | 2000 | 501 | 71.8 | 19 | 8.6 | 0.68 | 1.69 | 0.74 | 10.95 | . |
| 0183558-A | 20100311 | Nav Intl | 1999 | 340 | 55.9 | 39 | 9.9 | 0.87 | 2.48 | 0.66 | 7.16 | 0.132 |
| 0183710-A | 20091215 | Frtlnr | 2003 | 513 | 107.8 | 33 | 12.6 | 1.55 | 5.99 | 1.63 | 18.13 | 0.292 |
| 0183713-A | 20091216 | Frtlnr | 2003 | 354 | 191.4 | 28 | 32.4 | 0.32 | 3.50 | 0.87 | 6.98 | . |
| 0183716-A | 20100125 | Frtlnr | 2003 | 230 | 32.4 | 60 | 8.5 | 1.02 | 9.28 | 1.12 | 12.94 | . |
| 0183718-A | 20091214 | Frtlnr | 2003 | 388 | 97.6 | 26 | 15.1 | 0.71 | 5.04 | 0.90 | 8.58 | . |
| 0184781-A | 20100203 | Frtlnr | 1997 | 314 | 42.4 | 44 | 8.1 | 0.56 | 4.07 | 0.73 | 14.82 | 0.023 |
| 0184781-A | 20100204 | Frtlnr | 1997 | 275 | 72.7 | 49 | 15.9 | 0.65 | 5.11 | 0.82 | 17.47 | 0.067 |
| 0185067-A | 20100205 | KW | 2004 | 336 | 84.3 | 32 | 15.0 | 0.39 | 4.34 | 0.62 | 4.15 | 0.631 |
| 0185576-A | 20100204 | Nav Intl | 1998 | 441 | 52.9 | 73 | 7.2 | 2.53 | 6.92 | 0.74 | 14.62 | . |
| 0185728-A | 20100312 | Frtlnr | 2001 | 432 | 59.1 | 47 | 8.2 | 0.65 | 3.43 | 0.80 | 9.44 | . |
| 0185774-B | 20100315 | KW | 2000 | 296 | 32.8 | 54 | 6.7 | 0.33 | 3.20 | 0.56 | 5.88 | 0.082 |
| 0186029-A | 20100316 | Frtlnr | 2000 | 443 | 157.9 | 39 | 21.4 | 0.18 | 1.85 | 0.55 | 7.22 | . |
| 0188529-B | 20100205 | Nav Intl | 1999 | 303 | 86.7 | 33 | 17.2 | 0.57 | 1.94 | 0.63 | 12.01 | . |
| 0189106-A | 20100208 | Frtlnr | 1998 | 428 | 79.0 | 39 | 11.1 | 0.46 | 6.23 | 0.74 | 12.96 | . |
| 0190306-B | 20100312 | Volvo | 2001 | 570 | 259.4 | 28 | 27.3 | 0.13 | 1.93 | 0.54 | 5.14 | 0.050 |
| 0190786-A | 20100209 | Frtlnr | 1997 | 505 | 55.6 | 45 | 6.6 | 0.93 | 7.24 | 0.79 | 14.59 | . |

| Test ID | Test Date | Truck Mfr | MY | Time (mins) | Dist (mi) | Idle (%) | Avg Spd (mph) | THC (g/bhp-hr) | CO (g/bhp-hr) | CO2 (kg/bhp-hr) | NOx (g/bhp-hr) | PM (g/bhp-hr) |
|-------------------|-----------|-----------|------|-------------|-----------|----------|---------------|----------------|---------------|-----------------|----------------|---------------|
| 0190992-A | 20100317 | Frtlnr | 1997 | 510 | 184.1 | 34 | 21.7 | 0.23 | 2.32 | 0.51 | 9.36 | . |
| 0218126-A | 20100126 | Frtlnr | 2000 | 454 | 102.8 | 53 | 13.6 | 0.26 | 2.05 | 0.55 | 11.28 | 0.036 |
| 0218126-A | 20100127 | Frtlnr | 2000 | 350 | 62.6 | 62 | 10.8 | 0.38 | 2.56 | 0.63 | 13.43 | 0.038 |
| 0267938-A | 20100310 | Frtlnr | 1997 | 484 | 43.5 | 0 | 5.4 | 0.33 | 4.64 | 0.62 | 7.16 | . |
| 1095729-B | 20100128 | Frtlnr | 2002 | 405 | 99.8 | 50 | 14.8 | 0.57 | 2.56 | 0.55 | 6.11 | . |
| 1095730-A | 20100201 | Frtlnr | 2001 | 533 | 12.6 | 18 | 1.4 | 3.82 | 20.12 | 1.28 | 20.78 | . |
| 1095730-A | 20100202 | Frtlnr | 2001 | 479 | 25.3 | 35 | 3.2 | 1.37 | 12.78 | 1.02 | 15.31 | . |
| 1144157-A | 20100308 | Nav Intl | 1999 | 684 | 427.3 | 23 | 37.5 | 0.04 | 0.88 | 0.49 | 6.64 | . |
| 1157629-A | 20100315 | Frtlnr | 2006 | 569 | 223.3 | 25 | 23.6 | 0.05 | 0.56 | 0.63 | 8.43 | . |
| 1190901-A | 20100208 | Nav Intl | 2003 | 272 | 33.4 | 69 | 7.4 | 1.76 | 5.08 | 1.14 | 17.98 | . |
| 1190901-A | 20100209 | Nav Intl | 2003 | 356 | 104.6 | 40 | 17.6 | 0.69 | 1.79 | 0.76 | 11.53 | 0.072 |
| 1191018-A | 20100210 | Frtlnr | 2004 | 591 | 106.2 | 28 | 10.8 | 0.11 | 1.68 | 0.69 | 5.17 | 0.157 |
| 1191083-A | 20100201 | KW | 2004 | 312 | 77.6 | 60 | 14.9 | 0.37 | 5.60 | 0.64 | 3.91 | 0.087 |
| 1191083-A | 20100202 | KW | 2004 | 298 | 101.0 | 48 | 20.3 | 0.21 | 4.28 | 0.58 | 3.73 | 0.102 |
| 1191084-A | 20100128 | KW | 2004 | 572 | 82.2 | 60 | 8.6 | . | . | . | . | . |
| Cumulative | | | | | | | | | | | | |
| | | | | 18246 | 4374 | 37 | 14.4 | 0.57 | 3.24 | 0.69 | 9.20 | 0.155 |

Table 7.1-4 Drayage Average Distance-Based Emissions, In-Port

| Test ID | Test Date | Truck Mfr | MY | Time (mins) | Dist (mi) | Idle (%) | Avg Spd (mph) | THC (g/mi) | CO (g/mi) | CO2 (kg/mi) | NOx (g/mi) | PM (g/mi) |
|-----------|-----------|-----------|------|-------------|-----------|----------|---------------|------------|-----------|-------------|------------|-----------|
| 0160699-A | 20100316 | Frtlnr | 1997 | 299 | 17.4 | 56 | 3.5 | 6.75 | 10.61 | 3.01 | 43.15 | . |
| 0160910-A | 20100211 | Frtlnr | 2004 | 131 | 4.5 | 74 | 2.1 | 1.65 | 30.04 | 5.46 | 85.82 | . |
| 0178515-B | 20091210 | Frtlnr | 1994 | 59 | 2.4 | 65 | 2.4 | 56.39 | 38.18 | 3.46 | 59.92 | . |
| 0178515-B | 20091211 | Frtlnr | 1994 | 157 | 7.2 | 66 | 2.8 | 57.30 | 36.71 | 3.47 | 58.21 | 2.339 |
| 0180990-A | 20100211 | Frtlnr | 1999 | . | . | . | . | . | . | . | . | . |
| 0181021-A | 20091216 | Nav Intl | 1993 | 38 | 2.4 | 53 | 3.8 | 9.54 | 25.21 | 2.99 | 49.35 | 0.433 |
| 0181096-A | 20091217 | Frtlnr | 1993 | 47 | 2.3 | 54 | 2.9 | 4.80 | 32.65 | 2.06 | 37.62 | . |
| 0181096-A | 20100127 | Frtlnr | 1993 | 49 | 1.9 | 72 | 2.3 | 7.27 | 83.95 | 4.25 | 80.06 | . |
| 0181157-A | 20100317 | KW | 1996 | 211 | 12.9 | 57 | 3.7 | 5.39 | 12.22 | 3.97 | 62.64 | 0.439 |
| 0181276-B | 20091209 | KW | 1980 | 106 | 3.1 | 42 | 1.8 | 31.21 | 35.31 | 3.11 | 20.98 | . |
| 0181276-B | 20100125 | KW | 1980 | 69 | 3.0 | 63 | 2.6 | 33.77 | 41.09 | 4.21 | 24.65 | . |
| 0182003-A | 20100309 | Volvo | 1996 | 206 | 7.3 | 53 | 2.1 | 2.90 | 19.94 | 2.04 | 47.33 | . |
| 0182003-A | 20100310 | Volvo | 1996 | 307 | 11.6 | 62 | 2.3 | 5.46 | 40.08 | 3.46 | 83.87 | 0.646 |
| 0182022-A | 20100308 | Nav Intl | 1998 | 85 | 2.8 | 65 | 2.0 | 13.45 | 45.47 | 3.16 | 46.33 | . |
| 0182291-A | 20100210 | KW | 2000 | 147 | 1.4 | 82 | 0.6 | 42.55 | 55.75 | 13.27 | 196.33 | . |
| 0183558-A | 20100311 | Nav Intl | 1999 | 224 | 13.6 | 59 | 3.7 | 9.23 | 26.04 | 4.57 | 62.41 | 0.927 |
| 0183710-A | 20091215 | Frtlnr | 2003 | 121 | 7.9 | 45 | 3.9 | 7.95 | 30.17 | 4.49 | 63.54 | 1.309 |
| 0183713-A | 20091216 | Frtlnr | 2003 | 68 | 2.4 | 74 | 2.1 | 6.62 | 65.61 | 4.98 | 94.79 | . |
| 0183716-A | 20100125 | Frtlnr | 2003 | 77 | 1.4 | 87 | 1.1 | 8.71 | 74.60 | 8.85 | 137.12 | . |
| 0183718-A | 20091214 | Frtlnr | 2003 | 255 | 10.2 | 42 | 2.4 | 5.12 | 21.89 | 3.23 | 46.39 | 0.387 |
| 0184781-A | 20100203 | Frtlnr | 1997 | . | . | . | . | . | . | . | . | . |
| 0184781-A | 20100204 | Frtlnr | 1997 | 61 | 5.2 | 55 | 5.1 | 3.51 | 25.48 | 2.84 | 68.14 | . |
| 0185067-A | 20100205 | KW | 2004 | 76 | 4.4 | 64 | 3.4 | 4.87 | 80.68 | 3.41 | 32.62 | 1.446 |
| 0185576-A | 20100204 | Nav Intl | 1998 | . | . | . | . | . | . | . | . | . |
| 0185728-A | 20100312 | Frtlnr | 2001 | 146 | 2.4 | 83 | 1.0 | 7.45 | 49.18 | 7.09 | 136.04 | . |
| 0185774-B | 20100315 | KW | 2000 | 331 | 17.0 | 63 | 3.1 | 3.36 | 29.08 | 4.03 | 42.83 | 0.373 |
| 0186029-A | 20100316 | Frtlnr | 2000 | 98 | 6.6 | 52 | 4.1 | 2.79 | 20.01 | 2.97 | 58.32 | . |
| 0188529-B | 20100205 | Nav Intl | 1999 | 6 | 0.3 | 73 | 3.0 | 5.79 | 17.82 | 2.53 | 51.31 | . |
| 0189106-A | 20100208 | Frtlnr | 1998 | 92 | 3.6 | 71 | 2.4 | 3.43 | 50.16 | 3.08 | 65.78 | . |
| 0190306-B | 20100312 | Volvo | 2001 | 52 | 2.8 | 60 | 3.3 | 2.96 | 20.89 | 3.28 | 42.30 | 0.284 |
| 0190786-A | 20100209 | Frtlnr | 1997 | . | . | . | . | . | . | . | . | . |

| Test ID | Test Date | Truck Mfr | MY | Time (mins) | Dist (mi) | Idle (%) | Avg Spd (mph) | THC (g/mi) | CO (g/mi) | CO2 (kg/mi) | NOx (g/mi) | PM (g/mi) |
|-------------------|-----------|-----------|------|-------------|-----------|----------|---------------|------------|-----------|-------------|------------|-----------|
| 0190992-A | 20100317 | Frtlnr | 1997 | 71 | 5.9 | 48 | 5.0 | 5.47 | 34.05 | 2.55 | 44.67 | . |
| 0218126-A | 20100126 | Frtlnr | 2000 | 81 | 13.7 | 31 | 10.2 | 0.84 | 7.63 | 1.77 | 39.56 | 0.116 |
| 0218126-A | 20100127 | Frtlnr | 2000 | 98 | 8.6 | 54 | 5.3 | 2.40 | 17.60 | 3.18 | 73.67 | 0.581 |
| 0267938-A | 20100310 | Frtlnr | 1997 | 102 | 3.4 | 0 | 2.0 | 4.71 | 25.43 | 4.81 | 80.50 | . |
| 1095729-B | 20100128 | Frtlnr | 2002 | 97 | 4.0 | 65 | 2.5 | 9.44 | 31.63 | 3.54 | 48.52 | . |
| 1095730-A | 20100201 | Frtlnr | 2001 | . | . | . | . | . | . | . | . | . |
| 1095730-A | 20100202 | Frtlnr | 2001 | . | . | . | . | . | . | . | . | . |
| 1144157-A | 20100308 | Nav Intl | 1999 | 42 | 1.6 | 58 | 2.2 | 2.78 | 20.12 | 3.22 | 65.01 | . |
| 1157629-A | 20100315 | Frtlnr | 2006 | 104 | 6.3 | 54 | 3.6 | 0.92 | 9.98 | 3.63 | 42.82 | . |
| 1190901-A | 20100208 | Nav Intl | 2003 | . | . | . | . | . | . | . | . | . |
| 1190901-A | 20100209 | Nav Intl | 2003 | 146 | 8.6 | 66 | 3.5 | 5.35 | 14.41 | 2.93 | 52.11 | 0.315 |
| 1191018-A | 20100210 | Frtlnr | 2004 | 44 | 9.5 | 30 | 12.8 | 0.50 | 5.93 | 1.81 | 12.63 | 0.348 |
| 1191083-A | 20100201 | KW | 2004 | 88 | 5.2 | 48 | 3.5 | 4.75 | 94.74 | 3.28 | 34.24 | 0.504 |
| 1191083-A | 20100202 | KW | 2004 | 146 | 5.3 | 66 | 2.2 | 6.40 | 150.19 | 3.93 | 45.43 | 0.533 |
| 1191084-A | 20100128 | KW | 2004 | . | . | . | . | . | . | . | . | . |
| Cumulative | | | | 4537 | 230.6 | 58 | 3.0 | 7.97 | 30.29 | 3.49 | 54.53 | 0.591 |

Table 7.1-5 Drayage Average Distance-Based Emissions, Non-Port

| Test ID | Test Date | Truck Mfr | MY | Time (mins) | Dist (mi) | Idle (%) | Avg Spd (mph) | THC (g/mi) | CO (g/mi) | CO2 (kg/mi) | NOx (g/mi) | PM (g/mi) |
|-----------|-----------|-----------|------|-------------|-----------|----------|---------------|------------|-----------|-------------|------------|-----------|
| 0160699-A | 20100316 | Frtlnr | 1997 | 254 | 57.5 | 38 | 13.6 | 2.07 | 3.81 | 1.69 | 27.35 | . |
| 0160910-A | 20100211 | Frtlnr | 2004 | 377 | 112.2 | 42 | 17.8 | 0.19 | 5.81 | 1.96 | 24.31 | . |
| 0178515-B | 20091210 | Frtlnr | 1994 | 410 | 71.1 | 44 | 10.4 | 12.06 | 10.66 | 1.74 | 30.33 | . |
| 0178515-B | 20091211 | Frtlnr | 1994 | 391 | 105.3 | 42 | 16.1 | 9.51 | 8.74 | 1.74 | 28.61 | 0.490 |
| 0180990-A | 20100211 | Frtlnr | 1999 | 510 | 140.8 | 0 | 16.6 | 0.25 | 3.69 | 2.03 | 34.33 | . |
| 0181021-A | 20091216 | Nav Intl | 1993 | 467 | 128.5 | 26 | 16.5 | 1.60 | 5.27 | 1.61 | 21.55 | 0.179 |
| 0181096-A | 20091217 | Frtlnr | 1993 | 137 | 62.0 | 27 | 27.2 | 0.81 | 9.71 | 1.36 | 22.03 | . |
| 0181096-A | 20100127 | Frtlnr | 1993 | 407 | 103.5 | 33 | 15.3 | 1.22 | 18.60 | 1.86 | 25.22 | . |
| 0181157-A | 20100317 | KW | 1996 | 302 | 37.9 | 57 | 7.5 | 2.90 | 6.94 | 2.35 | 34.46 | 0.297 |
| 0181276-B | 20091209 | KW | 1980 | 207 | 38.8 | 19 | 11.3 | 7.19 | 20.06 | 1.68 | 18.10 | . |
| 0181276-B | 20100125 | KW | 1980 | 379 | 91.0 | 27 | 14.4 | 3.38 | 25.11 | 1.97 | 22.32 | 2.536 |
| 0182003-A | 20100309 | Volvo | 1996 | 366 | 66.5 | 46 | 10.9 | 0.74 | 9.36 | 1.40 | 25.30 | . |
| 0182003-A | 20100310 | Volvo | 1996 | 210 | 35.8 | 37 | 10.2 | 1.73 | 14.55 | 2.09 | 42.06 | 0.330 |
| 0182022-A | 20100308 | Nav Intl | 1998 | 289 | 97.6 | 20 | 20.3 | 0.92 | 8.24 | 1.96 | 24.72 | . |
| 0182291-A | 20100210 | KW | 2000 | 501 | 71.8 | 19 | 8.6 | 1.78 | 4.43 | 1.94 | 28.63 | . |
| 0183558-A | 20100311 | Nav Intl | 1999 | 340 | 55.9 | 39 | 9.9 | 3.18 | 9.04 | 2.42 | 26.08 | 0.527 |
| 0183710-A | 20091215 | Frtlnr | 2003 | 513 | 107.8 | 33 | 12.6 | 2.42 | 9.34 | 2.55 | 28.26 | 0.375 |
| 0183713-A | 20091216 | Frtlnr | 2003 | 354 | 191.4 | 28 | 32.4 | 0.79 | 8.62 | 2.13 | 17.18 | . |
| 0183716-A | 20100125 | Frtlnr | 2003 | 230 | 32.4 | 60 | 8.5 | 1.90 | 17.36 | 2.09 | 24.21 | . |
| 0183718-A | 20091214 | Frtlnr | 2003 | 388 | 97.6 | 26 | 15.1 | 1.18 | 8.38 | 1.50 | 14.27 | . |
| 0184781-A | 20100203 | Frtlnr | 1997 | 314 | 42.4 | 44 | 8.1 | 1.66 | 12.05 | 2.16 | 43.88 | 0.068 |
| 0184781-A | 20100204 | Frtlnr | 1997 | 275 | 72.7 | 49 | 15.9 | 1.33 | 10.52 | 1.69 | 35.98 | 0.182 |
| 0185067-A | 20100205 | KW | 2004 | 336 | 84.3 | 32 | 15.0 | 0.97 | 10.69 | 1.53 | 10.21 | 1.558 |
| 0185576-A | 20100204 | Nav Intl | 1998 | 441 | 52.9 | 73 | 7.2 | 6.76 | 18.48 | 1.97 | 39.02 | . |
| 0185728-A | 20100312 | Frtlnr | 2001 | 432 | 59.1 | 47 | 8.2 | 1.72 | 9.09 | 2.13 | 25.04 | . |
| 0185774-B | 20100315 | KW | 2000 | 296 | 32.8 | 54 | 6.7 | 1.42 | 13.85 | 2.42 | 25.48 | 0.394 |
| 0186029-A | 20100316 | Frtlnr | 2000 | 443 | 157.9 | 39 | 21.4 | 0.56 | 5.96 | 1.77 | 23.28 | . |
| 0188529-B | 20100205 | Nav Intl | 1999 | 303 | 86.7 | 33 | 17.2 | 1.18 | 4.03 | 1.31 | 24.94 | . |
| 0189106-A | 20100208 | Frtlnr | 1998 | 428 | 79.0 | 39 | 11.1 | 0.94 | 12.87 | 1.53 | 26.79 | . |
| 0190306-B | 20100312 | Volvo | 2001 | 570 | 259.4 | 28 | 27.3 | 0.40 | 5.80 | 1.63 | 15.43 | 0.149 |
| 0190786-A | 20100209 | Frtlnr | 1997 | 505 | 55.6 | 45 | 6.6 | 2.03 | 15.78 | 1.72 | 31.80 | . |

| Test ID | Test Date | Truck Mfr | MY | Time (mins) | Dist (mi) | Idle (%) | Avg Spd (mph) | THC (g/mi) | CO (g/mi) | CO2 (kg/mi) | NOx (g/mi) | PM (g/mi) |
|-------------------|-----------|-----------|------|-------------|-----------|----------|---------------|------------|-----------|-------------|------------|-----------|
| 0190992-A | 20100317 | Frtlnr | 1997 | 510 | 184.1 | 34 | 21.7 | 0.75 | 7.44 | 1.64 | 29.95 | . |
| 0218126-A | 20100126 | Frtlnr | 2000 | 454 | 102.8 | 53 | 13.6 | 0.70 | 5.61 | 1.51 | 30.91 | 0.098 |
| 0218126-A | 20100127 | Frtlnr | 2000 | 350 | 62.6 | 62 | 10.8 | 1.13 | 7.58 | 1.86 | 39.73 | 0.110 |
| 0267938-A | 20100310 | Frtlnr | 1997 | 484 | 43.5 | 0 | 5.4 | 1.52 | 21.48 | 2.85 | 33.17 | . |
| 1095729-B | 20100128 | Frtlnr | 2002 | 405 | 99.8 | 50 | 14.8 | 1.85 | 8.23 | 1.77 | 19.64 | . |
| 1095730-A | 20100201 | Frtlnr | 2001 | 533 | 12.6 | 18 | 1.4 | 8.03 | 42.26 | 2.70 | 43.64 | . |
| 1095730-A | 20100202 | Frtlnr | 2001 | 479 | 25.3 | 35 | 3.2 | 3.10 | 28.86 | 2.29 | 34.57 | . |
| 1144157-A | 20100308 | Nav Intl | 1999 | 684 | 427.3 | 23 | 37.5 | 0.18 | 3.64 | 2.01 | 27.36 | . |
| 1157629-A | 20100315 | Frtlnr | 2006 | 569 | 223.3 | 25 | 23.6 | 0.16 | 1.93 | 2.18 | 29.15 | . |
| 1190901-A | 20100208 | Nav Intl | 2003 | 272 | 33.4 | 69 | 7.4 | 2.54 | 7.33 | 1.64 | 25.95 | . |
| 1190901-A | 20100209 | Nav Intl | 2003 | 356 | 104.6 | 40 | 17.6 | 1.59 | 4.13 | 1.75 | 26.63 | 0.150 |
| 1191018-A | 20100210 | Frtlnr | 2004 | 591 | 106.2 | 28 | 10.8 | 0.30 | 4.39 | 1.80 | 13.56 | 0.413 |
| 1191083-A | 20100201 | KW | 2004 | 312 | 77.6 | 60 | 14.9 | 1.19 | 17.96 | 2.04 | 12.55 | 0.308 |
| 1191083-A | 20100202 | KW | 2004 | 298 | 101.0 | 48 | 20.3 | 0.61 | 12.34 | 1.68 | 10.76 | 0.262 |
| 1191084-A | 20100128 | KW | 2004 | 572 | 82.2 | 60 | 8.6 | 1.17 | 23.75 | 2.31 | 19.73 | 0.384 |
| Cumulative | | | | | | | | | | | | |
| | | | | 18246 | 4375 | 37 | 14.4 | 1.55 | 8.78 | 1.88 | 24.95 | 0.383 |

As would be expected, Tables 7.1-2 through 7.1-5 show a higher overall percentage of idle operation (58% vs. 37%) for port operation vs. non-port operation. Similarly, average speed within a port (3 mph) was lower than average speed outside of ports (14.4 mph). These trends conform to the trends shown in the PAMS summaries provided in Section 7.2. Comparing cumulative emission results from Tables 7.1-2 and 7.1-3 shows work-based emissions are higher for in-port operation than for non-port operation, likely due to the high amount of low-speed and low-load (i.e., idle and creep) operation. This same trend of higher “in-port” vs. “non-port” emissions is seen for distance-based cumulative emissions presented in Tables 7.1-4 and 7.1-5.

At some time during each test day (once the engine was warmed up), each truck was idled while a PM filter was collected. Results of each of these “idle” filters are presented in Table 7.1-6. This table gives an estimate of the dilution-corrected full-exhaust PM emission rate for each truck, during idle-only operation. Since proportionality was generally low during idle operation, most filters in Table 7.1-6 have low proportionality. Only filters deemed “suspect” as a result of other sampling issues noted during testing are excluded from Table 7.1-6.

Table 7.1-6 Drayage Idle PM Emission Rates

| Test ID | Test Date | Truck Mfr | MY | Filter # | Seq | Duration (seconds) | Total PM (grams) | PM Rate (grams/sec) |
|-----------|-----------|-----------|------|----------|-----|--------------------|------------------|---------------------|
| 0178515-B | 20091211 | Frtlnr | 1994 | 9047745 | 1 | 590 | 0.1234 | 0.0023838 |
| 0181021-A | 20091216 | Nav Intl | 1993 | 9047478 | 8 | 1023 | 0.0195 | 0.0002656 |
| 0181157-A | 20100317 | KW | 1996 | 9051929 | 13 | 1264 | 0.0286 | 0.0002494 |
| 0183558-A | 20100311 | Nav Intl | 1999 | 9047590 | 1 | 1571 | 0.095 | 0.0004235 |
| 0183718-A | 20091214 | Frtlnr | 2003 | 9047463 | 12 | 987 | 0.0213 | 0.0003898 |
| 0184781-A | 20100203 | Frtlnr | 1997 | 9051899 | 2 | 1213 | 0.0332 | 0.0004670 |
| 0190306-B | 20100312 | Volvo | 2001 | 9054986 | 6 | 466 | 0.0171 | 0.0002896 |
| 0190306-B | 20100312 | Volvo | 2001 | 9055037 | 11 | 711 | 0.0237 | 0.0002700 |
| 0218126-A | 20100126 | Frtlnr | 2000 | 9051407 | 2 | 2720 | 0.0319 | 0.0001984 |
| 0218126-A | 20100126 | Frtlnr | 2000 | 9051416 | 11 | 894 | 0.0235 | 0.0003985 |
| 0218126-A | 20100126 | Frtlnr | 2000 | 9051419 | 14 | 972 | 0.8397 | 0.0134872 |
| 0218126-A | 20100127 | Frtlnr | 2000 | 9051430 | 10 | 1199 | 0.0406 | 0.0004474 |
| 1191084-A | 20100128 | KW | 2004 | 9051843 | 7 | 1102 | 0.0271 | 0.0004523 |
| 1191084-A | 20100128 | KW | 2004 | 9051844 | 8 | 2961 | 0.0369 | 0.0002223 |

The results presented in this report and in the appendices have been validated, but uncertainties in the results have not been quantified. Future effort placed on estimating the various uncertainties would be of benefit. These uncertainties include exhaust and sample flow measurement error, instrument drift, time alignment errors, temperature measurement errors, bench errors (errors in measuring specific pollutants) and errors associated with PM collection and measurement, including filter contamination and lab procedures, proportionality and sample

flow control, sample loss and collection efficiency, as these will all affect overall emission results. Some focus should also be placed on determining the cause of several negative filter masses measured during this study. Suspect data, including negative filter masses, have been excluded from the overall emission results presented in this report but are included in the detailed emission results presented in Appendix M.

7.2 PAMS Data

Summary results from compiled PAMS data follow. These results do not include data from the instrumentation of truck 1191097-A, since this instrumentation collected over-the-road (OTR) data. Although this OTR data does include port work, the predominant activity is OTR activity and does not represent operational patterns of local drayage operations. In addition, VSP reporting does not include results from 0181276-B, as no load measurements were available for this instrumentation.

Figures 7.2-1 and 7.2-2 show the overall time and day of the week for drayage truck activity, as collected using PAMS. Columns to the right of each of these figures show statistics on frequency of distribution. These figures present cumulative activity both for in-port and non-port operation. The numerical values are based on the number of seconds of operation, and the times on the left axis indicate the midpoint of each one hour time bin in Figure 7.2-1, and the day of the week in Figure 7.2-2.

Figure 7.2-1 Drayage Truck Activity by Hour of Day

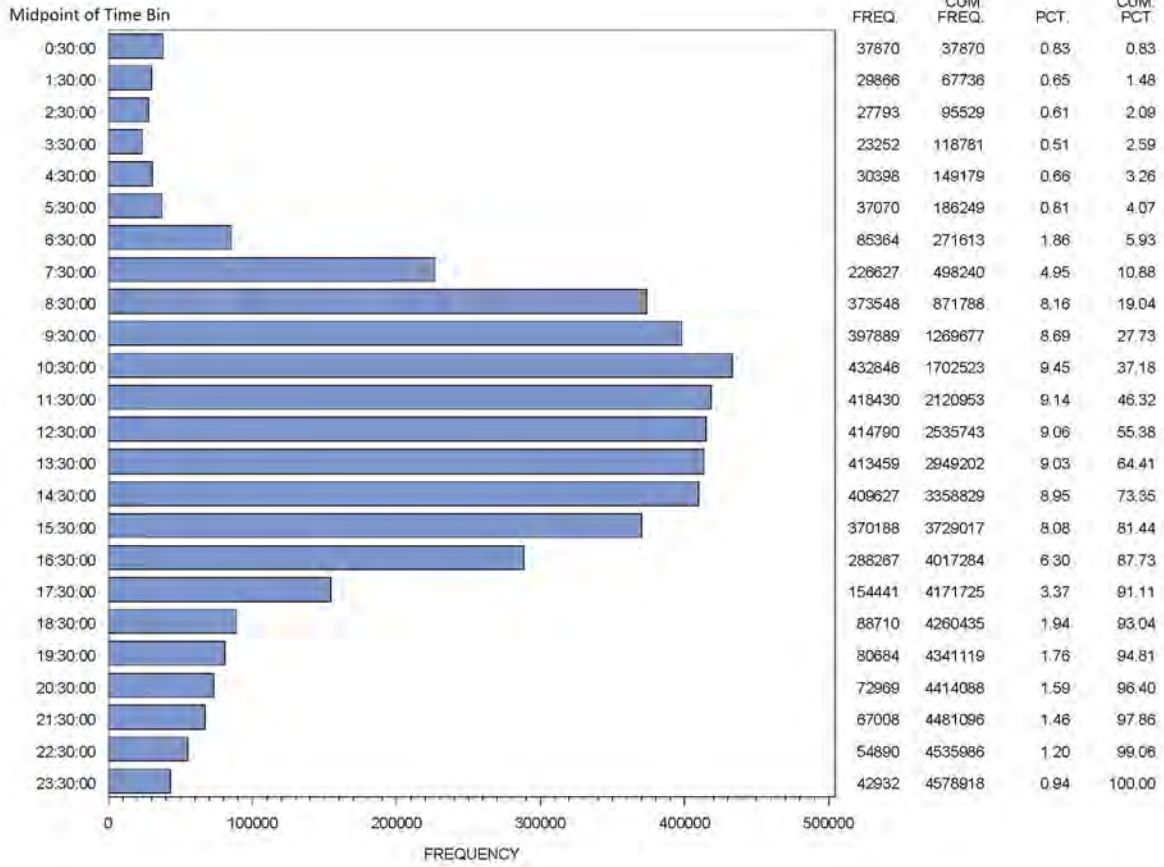
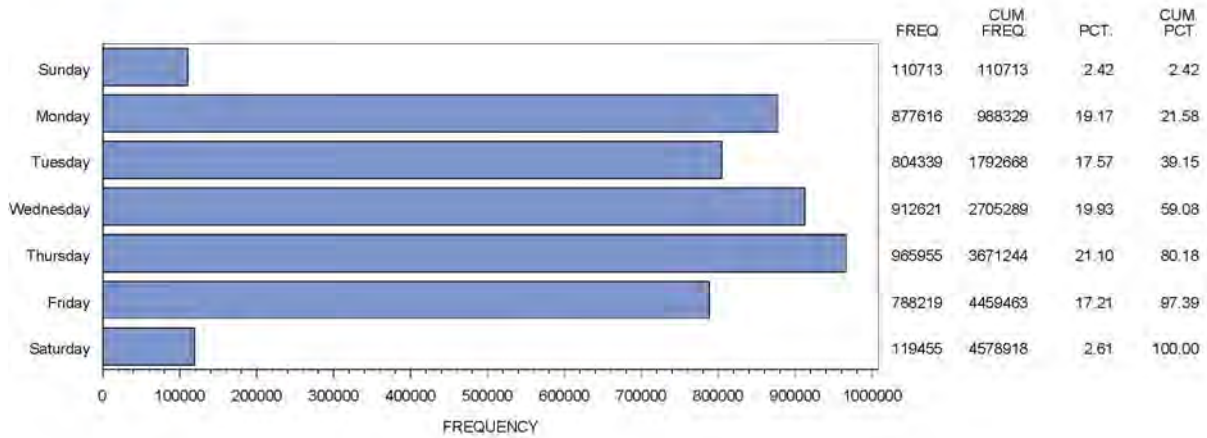


Figure 7.2-2 Drayage Truck Activity by Day of Week



Figures 7.2-3 and 7.2-4 show operation of drayage trucks by vehicle speed, for in-port activities (Figure 7.2-3) and non-port activities (Figure 7.2-4). Each of these figures shows a predominant amount of activity at speeds under 3 mph, with the non-port histogram showing a secondary trend of non-port speed predominance above 47 mph.

Figure 7.2-3 Drayage Truck Speeds for In-Port Activity

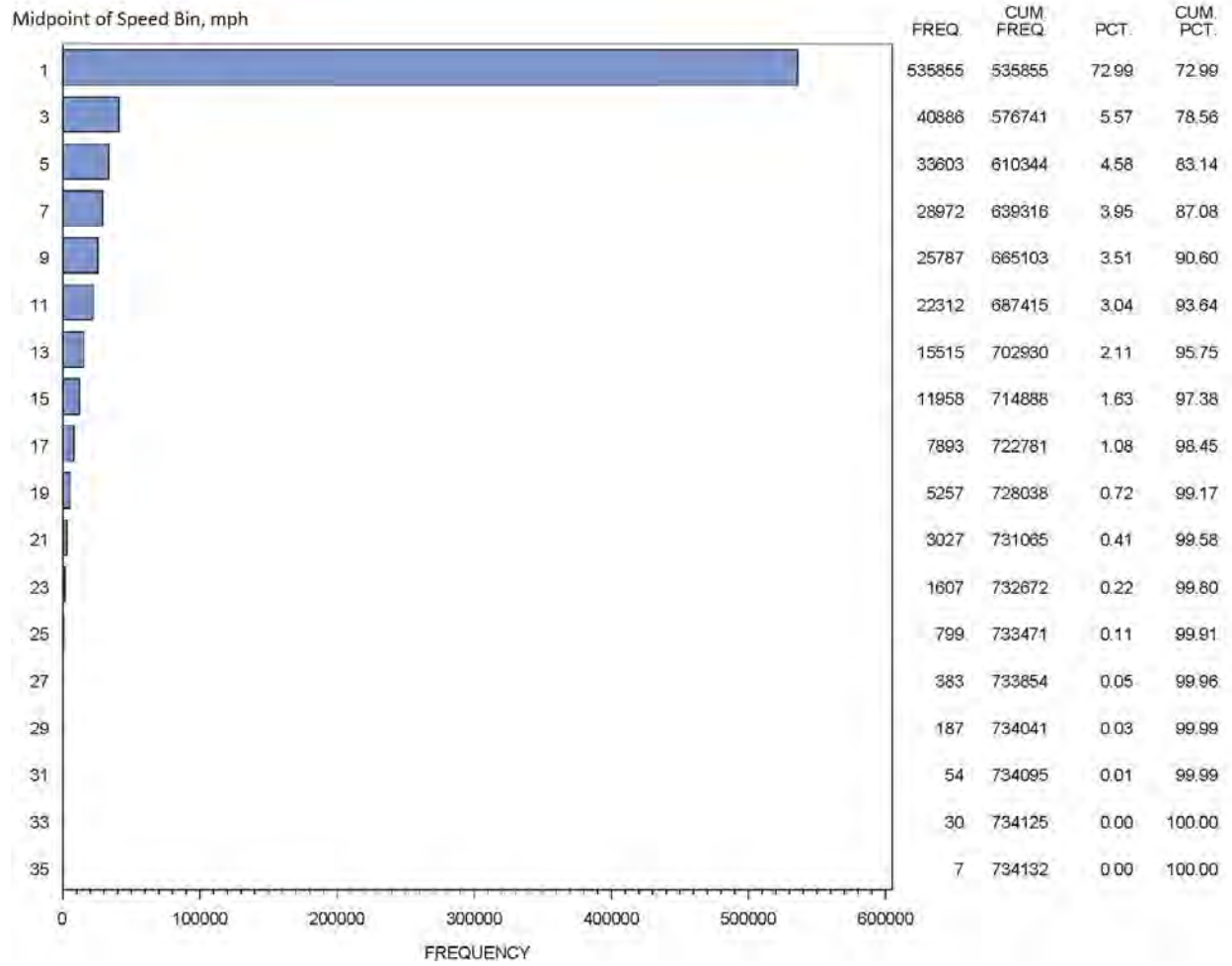
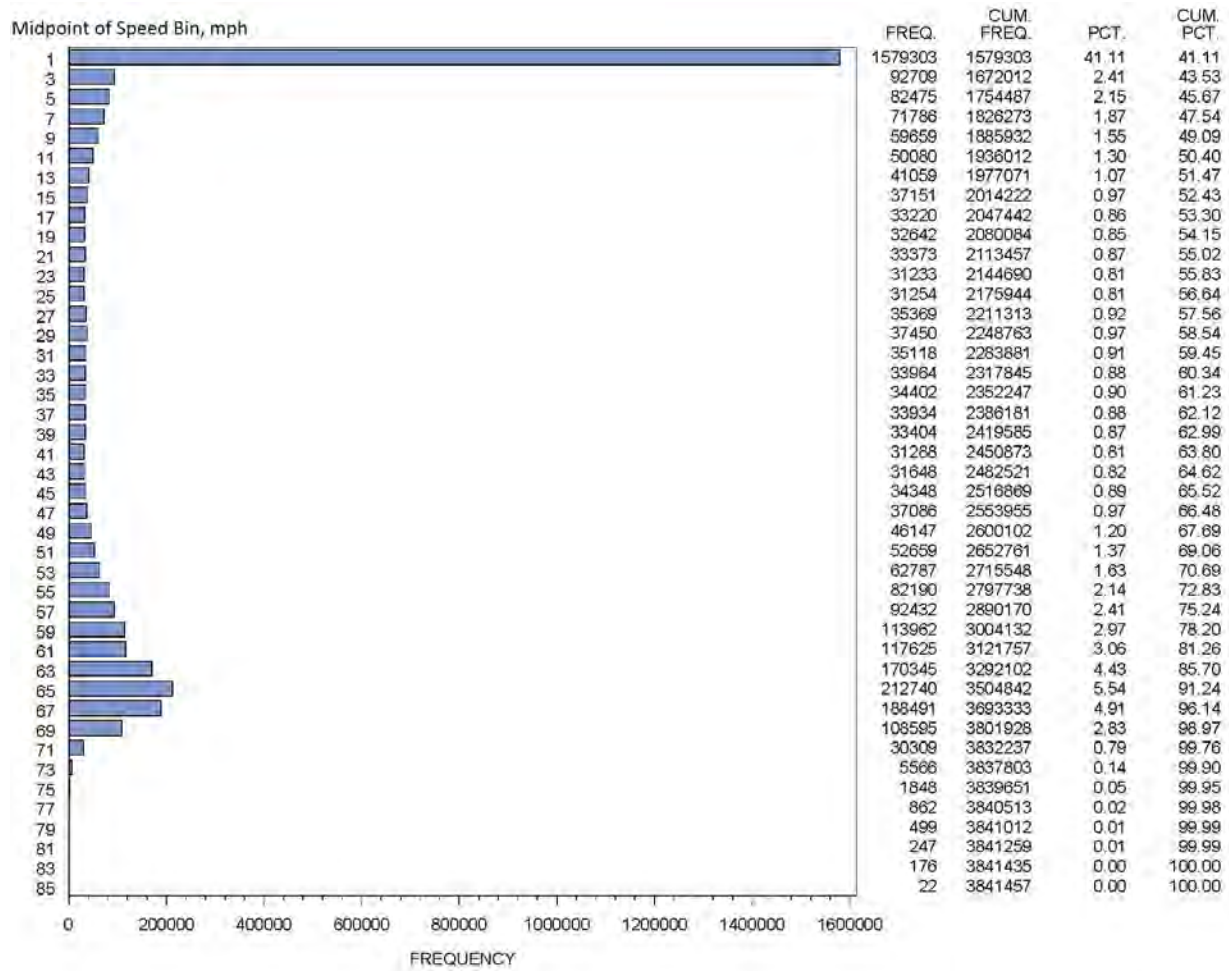


Figure 7.2-4 Drayage Truck Speeds for Non-Port Activity



Figures 7.2-5 and 7.2-6 show operation by vehicle load, again for both in-port and non-port activity.

Figure 7.2-5 Drayage Truck Percent Engine Load for In-Port Activity

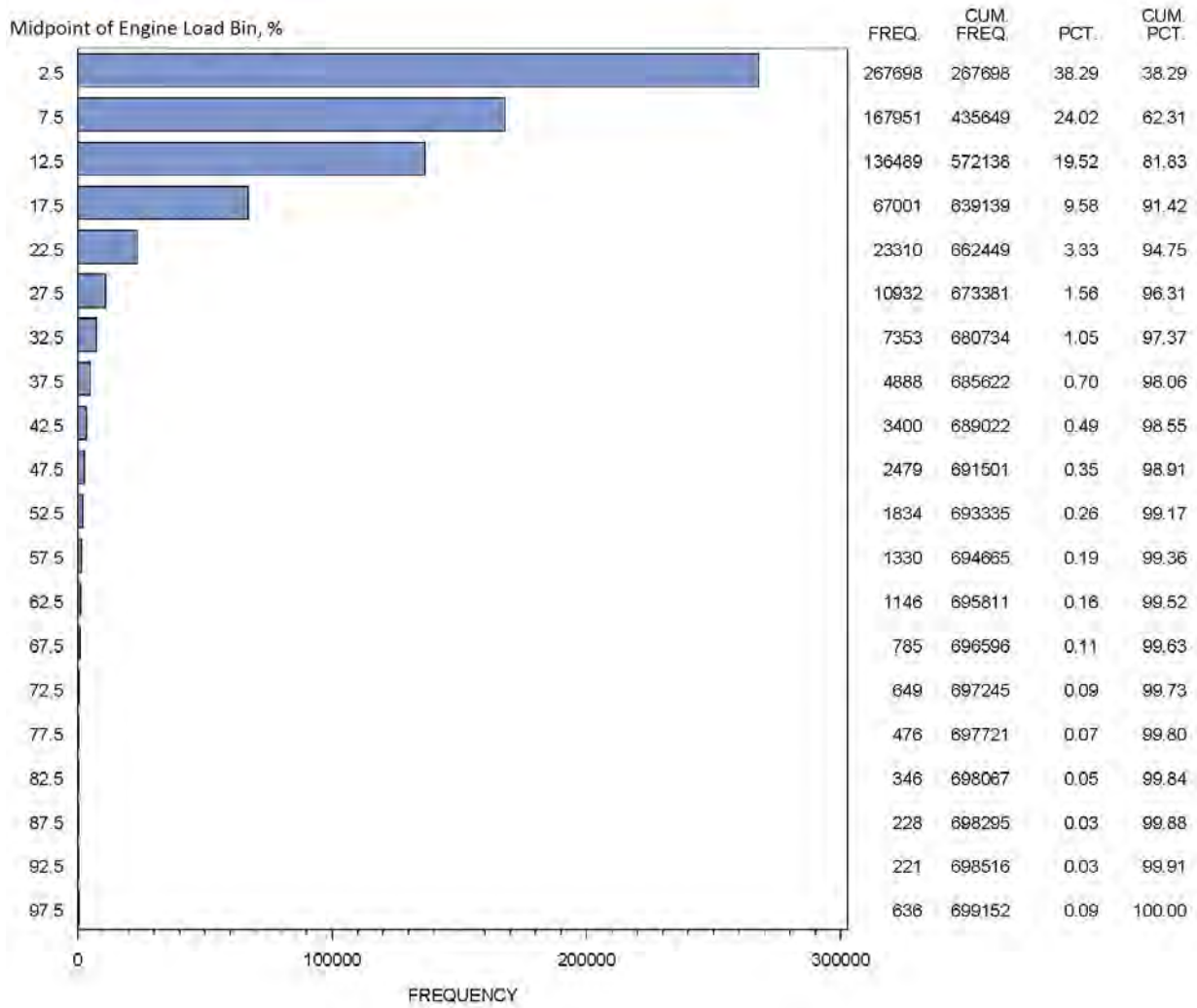
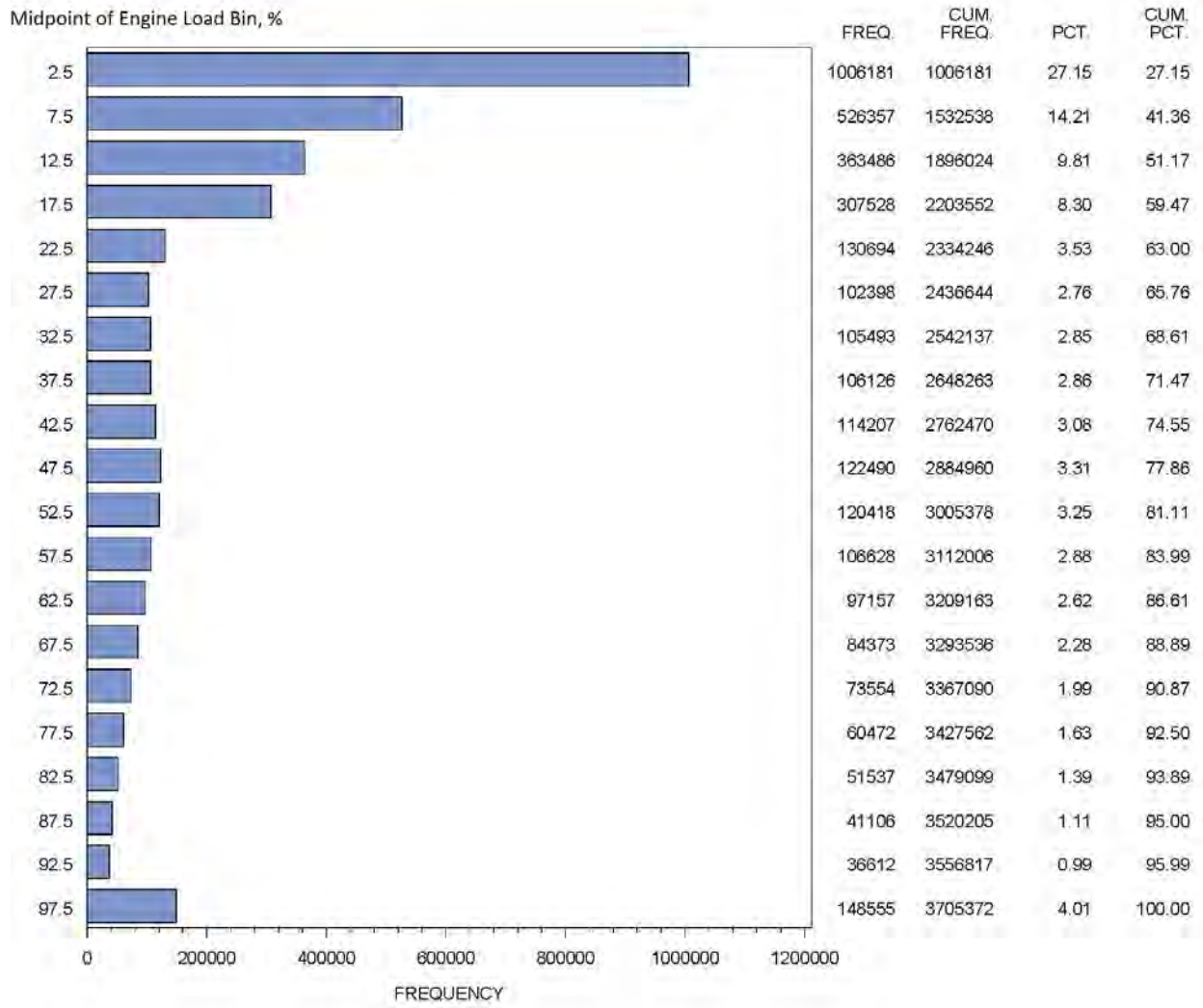


Figure 7.2-6 Drayage Truck Percent Engine Load for Non-Port Activity



Figures 7.2-7 and 7.2-8 show drayage truck operation by MOVES Operating Mode bin, for both in-port and non-port activity.

Figure 7.2-7 Drayage Truck Operation by MOVES Operating Mode Bin, In-Port

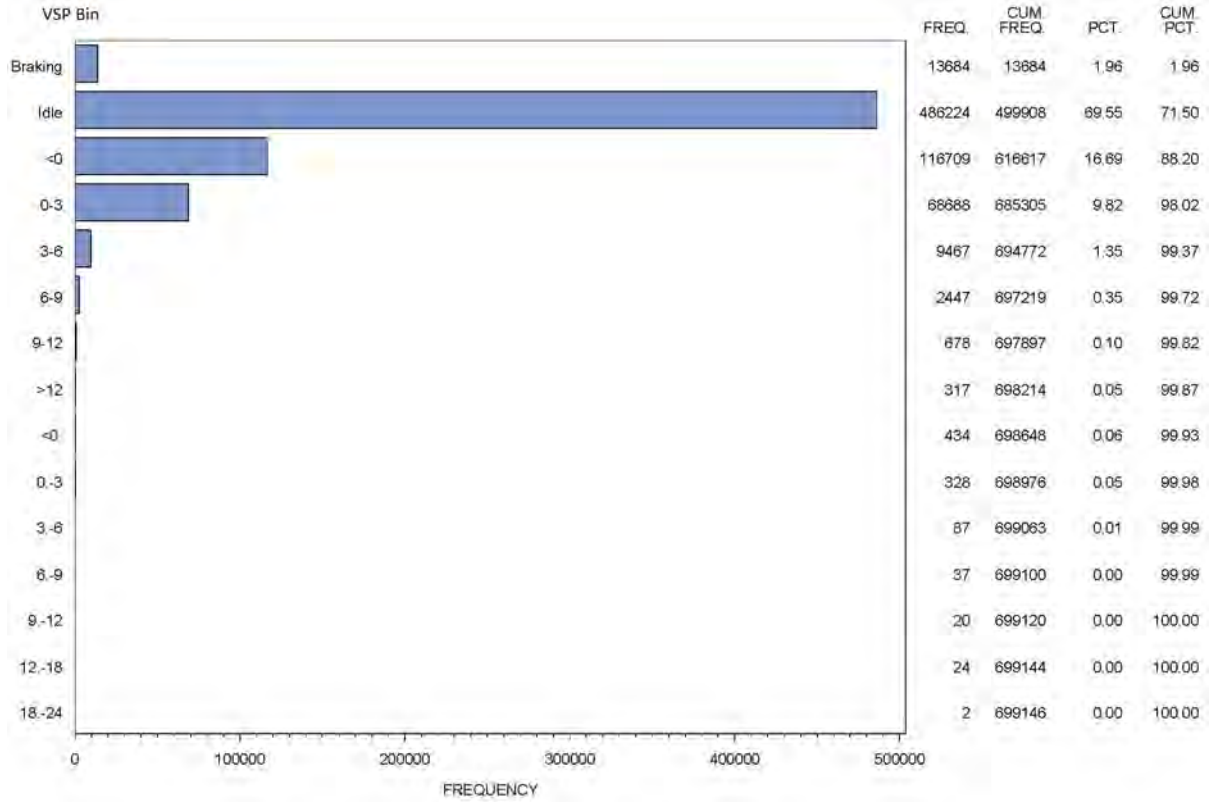
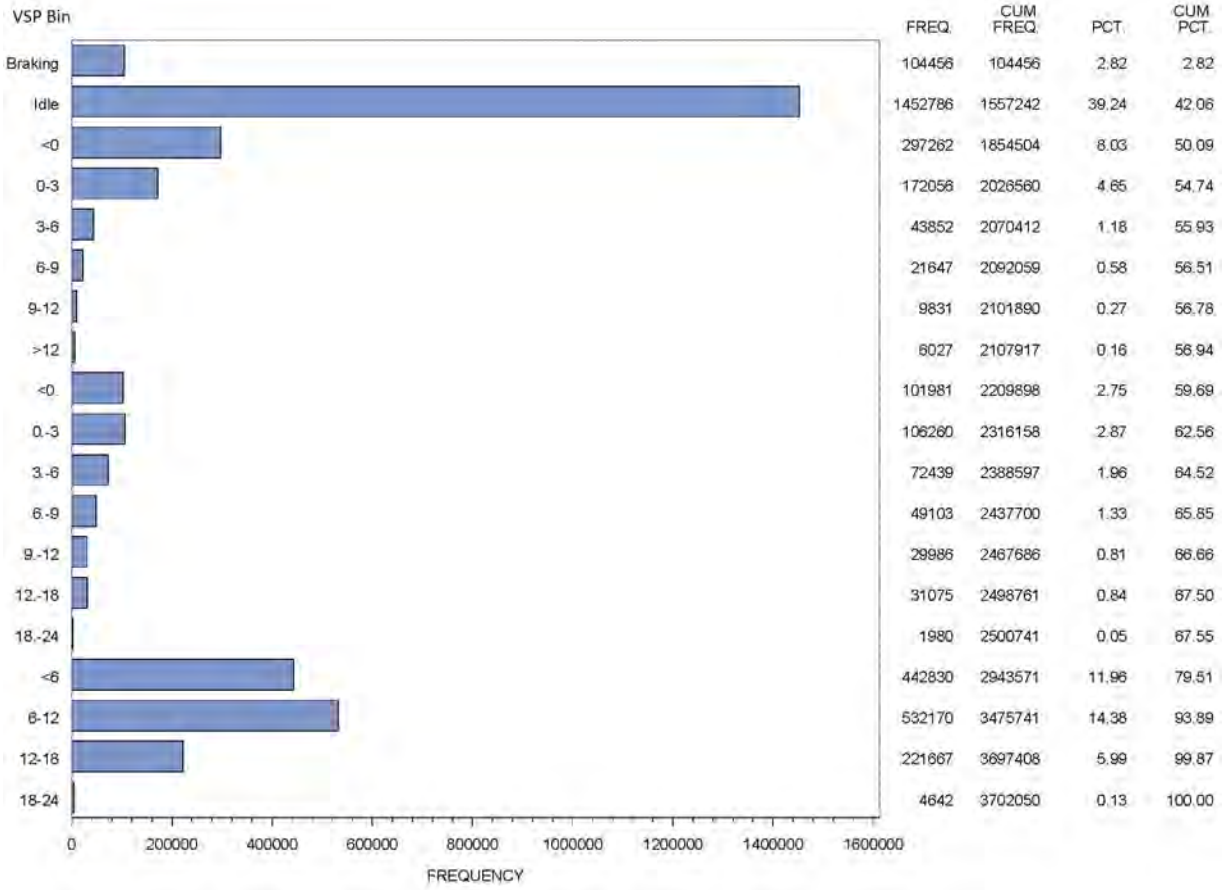


Figure 7.2-8 Drayage Truck Operation by MOVES Operating Mode Bin, Non-Port



Tables 7.2-1 and 7.2-2 provide a summary of PAMS activity data collected throughout the study, both in-port and non-port.

Table 7.2-1 Activity Measurement Result Summary, In-Port

| Truck ID | Test Dates | Truck Mfr | MY | Time (mins) | Dist (miles) | Idle (%) | Avg Spd (mph) | Avg Load (%) |
|------------------------|-------------------|---------------|------|--------------|--------------|--------------|---------------|--------------|
| 0178515-B | 12/6/09-12/17/09 | Freightliner | 1994 | 659.0 | 29.66 | 63.94 | 2.70 | 6.60 |
| 0181276-B ¹ | 12/9/09-12/17/09 | Kenworth | 1980 | 583.1 | na | na | 2.68 | na |
| 0182003-A | 3/6/10-3/17/10 | Volvo | 1996 | 1604.1 | 63.89 | 62.44 | 2.39 | 12.49 |
| 0182022-A | 3/6/10-3/17/10 | International | 1998 | 1068.8 | 35.45 | 70.45 | 1.99 | 3.84 |
| 0183438-A | 3/6/10-3/16/10 | International | 2002 | 1052.7 | 39.12 | 71.92 | 2.23 | 7.37 |
| 0183439-A | 3/6/10-3/16/10 | Freightliner | 2003 | 142.3 | 6.64 | 67.17 | 2.80 | 7.93 |
| 0183710-A | 12/10/09-12/18/09 | Freightliner | 2003 | 635.0 | 24.87 | 66.22 | 2.35 | 11.01 |
| 0183713-A | 12/9/09-12/18/09 | Freightliner | 2003 | 616.7 | 25.59 | 65.49 | 2.49 | 13.01 |
| 0183716-A | 1/24/10-2/1/10 | Freightliner | 2003 | 545.7 | 18.73 | 70.80 | 2.06 | 11.78 |
| 0183718-A | 12/10/09-12/18/09 | Freightliner | 2003 | 541.4 | 25.90 | 57.76 | 2.87 | 11.37 |
| 0185067-A | 2/3/10-2/11/10 | Kenworth | 2004 | 335.3 | 16.48 | 67.55 | 2.95 | 3.58 |
| 0185576-A | 2/3/10-2/11/10 | International | 1998 | 257.4 | 14.93 | 59.16 | 3.48 | 11.87 |
| 0186809-A | 12/10/09-12/17/09 | Freightliner | 2003 | 740.6 | 30.74 | 69.10 | 2.49 | 10.59 |
| 0186844-A | 2/2/10-2/11/10 | Freightliner | 2001 | 92.8 | 1.55 | 76.82 | 1.00 | 3.20 |
| 0190758-A | 3/9/10-3/15/10 | Freightliner | 1997 | 566.3 | 24.63 | 67.93 | 2.61 | 19.05 |
| P-0000001 | 2/2/10-2/11/10 | Freightliner | 2000 | 145.7 | 7.65 | 65.20 | 3.15 | 16.68 |
| 1075087-A | 3/6/10-3/17/10 | Peterbilt | 2000 | 380.5 | 14.97 | 62.44 | 2.36 | 1.98 |
| 1095729-B | 1/20/10-2/1/10 | Freightliner | 2002 | 533.1 | 18.48 | 71.83 | 2.08 | 5.77 |
| 1095730-A | 1/22/10-2/2/10 | Freightliner | 2001 | 150.9 | 7.39 | 60.05 | 2.94 | 8.71 |
| 1190370-A | 1/21/10-2/1/10 | International | 2000 | 408.6 | 13.28 | 70.48 | 1.95 | 16.88 |
| 1190901-A | 2/2/10-2/11/10 | International | 2003 | 200.8 | 7.60 | 67.11 | 2.27 | 2.40 |
| 1191083-A | 1/20/10-2/2/10 | Kenworth | 2004 | 975.1 | 35.10 | 68.44 | 2.16 | 2.07 |
| 1191097-A ² | 1/20/10-2/5/10 | Freightliner | 2003 | 343.1 | 6.18 | 83.99 | 1.08 | 8.76 |
| Average | | | | 556.2 | 22.03 | 66.78 | 2.45 | 8.96 |

1 This truck did not have an ECU from which to collect engine load.

2 This was a long haul truck, not a drayage truck. The data from this truck is not used in the calculation of the average values presented in this table.

Table 7.2-2 Activity Measurement Result Summary, Non-Port

| Truck ID | Test Dates | Truck Mfr | MY | Time (mins) | Dist (miles) | Idle (%) | Avg Spd (mph) | Avg Load (%) |
|------------------------|-------------------|------------------|-----------|--------------------|---------------------|-----------------|----------------------|---------------------|
| 0178515-B | 12/6/09-12/17/09 | Freightliner | 1994 | 1722.3 | 543.39 | 41.24 | 18.93 | 20.15 |
| 0181276-B ¹ | 12/9/09-12/17/09 | Kenworth | 1980 | 2323.5 | na | na | 19.53 | na |
| 0182003-A | 3/6/10-3/17/10 | Volvo | 1996 | 2997.8 | 743.46 | 39.37 | 14.88 | 19.5 |
| 0182022-A | 3/6/10-3/17/10 | International | 1998 | 4250.0 | 2103.03 | 35.27 | 29.69 | 35.96 |
| 0183438-A | 3/6/10-3/16/10 | International | 2002 | 2767.1 | 784.92 | 42.29 | 17.02 | 17.87 |
| 0183439-A | 3/6/10-3/16/10 | Freightliner | 2003 | 4087.8 | 2888.74 | 23.58 | 42.4 | 34.09 |
| 0183710-A | 12/10/09-12/18/09 | Freightliner | 2003 | 2598.4 | 663.90 | 45.78 | 15.33 | 21.65 |
| 0183713-A | 12/9/09-12/18/09 | Freightliner | 2003 | 3156.6 | 1232.13 | 37.36 | 23.42 | 29.2 |
| 0183716-A | 1/24/10-2/1/10 | Freightliner | 2003 | 2725.4 | 943.89 | 44.57 | 20.78 | 29.38 |
| 0183718-A | 12/10/09-12/18/09 | Freightliner | 2003 | 1986.9 | 717.93 | 31.22 | 21.68 | 31.93 |
| 0185067-A | 2/3/10-2/11/10 | Kenworth | 2004 | 1527.6 | 464.63 | 44.86 | 18.25 | 11.99 |
| 0185576-A | 2/3/10-2/11/10 | International | 1998 | 2013.7 | 513.50 | 53.03 | 15.3 | 19.22 |
| 0186809-A | 12/10/09-12/17/09 | Freightliner | 2003 | 1576.6 | 568.87 | 34.47 | 21.65 | 21.24 |
| 0186844-A | 2/2/10-2/11/10 | Freightliner | 2001 | 2447.8 | 983.21 | 43.45 | 24.1 | 19.94 |
| 0190758-A | 3/9/10-3/15/10 | Freightliner | 1997 | 1612.2 | 402.51 | 47.33 | 14.98 | 24.33 |
| P-0000001 | 2/2/10-2/11/10 | Freightliner | 2000 | 1141.5 | 662.04 | 26.61 | 34.8 | 35.42 |
| 1075087-A | 3/6/10-3/17/10 | Peterbilt | 2000 | 6056.5 | 4297.06 | 22.46 | 42.57 | 34.77 |
| 1095729-B | 1/20/10-2/1/10 | Freightliner | 2002 | 3557.9 | 1627.15 | 41.14 | 27.44 | 24.74 |
| 1095730-A | 1/22/10-2/2/10 | Freightliner | 2001 | 2385.6 | 1264.76 | 30.32 | 31.81 | 29.67 |
| 1190370-A | 1/21/10-2/1/10 | International | 2000 | 5160.9 | 1882.02 | 50.48 | 21.88 | 32.85 |
| 1190901-A | 2/2/10-2/11/10 | International | 2003 | 3743.7 | 1961.06 | 34.71 | 31.43 | 20.59 |
| 1191083-A | 1/20/10-2/2/10 | Kenworth | 2004 | 4240.0 | 1838.75 | 45.8 | 26.02 | 16.95 |
| 1191097-A ² | 1/20/10-2/5/10 | Freightliner | 2003 | 8598.6 | 5471.60 | 35.66 | 38.18 | 40.37 |
| Average | | | | 2912.7 | 1289.86 | 38.83 | 24.27 | 25.31 |

1 This truck did not have an ECU from which to collect engine load.

2 This was a long haul truck, not a drayage truck. The data from this truck is not used in the calculation of the average values presented in this table.

8.0 Lessons Learned and Program Observations

8.1 General Lessons and Recommendations

This study demonstrated the effectiveness of federal, state and local collaboration in a large-scale measurement study such as this. All partners were instrumental in the successful outcome of this work.

Fieldwork for this study was heavily staffed by EPA (ASD and LOD) personnel. Having a large number of staff performing dedicated tasks (as described in Section 5.1.2) allowed team members to perform installations within the relatively short timeframe available in this study (since installations were generally performed during the evenings when trucks were not in use). Sufficient staff with dedicated tasks reduced installation times and also reduced the likelihood of missed steps. Both PEMS and PAMS installations were generally performed during non-working hours, and equipment rotation allowed equipment maintenance to be performed during times when testing was underway. This project showed that the number of personnel that was used did not result in the project being overstaffed. Future work of this kind should maintain this level of staffing,

Trucks were assigned “priorities” for recruiting purposes. These priorities were based on the truck’s NO_x emission level, the total number and variability of RSD NO_x measurements for each truck, and the total number of trucks within a bin (based on the sample of 1877 trucks). Hierarchies were assigned based on recruiting criteria described in Section 3.2, and “rare” trucks were assigned higher recruiting priorities than common trucks in order to maximize the number of recruiting bins completed. Using these criteria, the team found that recruiting “rare” trucks could be problematic, in particular when working with large drayage companies. As described in Section 5.1.1, a number of factors such as trucks scheduled for non-port work, incompatible usage shifts and employment (driver/truck) changes would prevent the team from being able to instrument (or even locate) certain trucks. With larger companies, an additional obstacle was encountered when trying to access specific trucks, since several steps (involving multiple people) would typically be required in order to simply identify the owner/operators of specific trucks. With smaller companies, ERG’s recruiting team members were frequently able to talk directly with dispatch personnel, who generally knew each driver personally and would contact the driver about testing (as long as other requirements were met). In addition, it was simply more challenging to integrate our activities into the operations of larger, hierarchical, streamlined operations. Smaller companies seemed to have a higher degree of flexibility in their operations which more easily accommodated a test program such as this. In future work of this type, personnel working on recruiting and scheduling should plan to make every attempt to create a

rapport with each company's dispatcher, as that can be just as effective as the incentive in terms of success in scheduling trucks and preventing downtime.

As previously noted, a high in-field participation rate was seen with the incentives described in Section 3.3. Recruitment was initially met with some skepticism at new facilities (often both from the facility as well as the independent owners/operators), but after a day or so of testing, much of this skepticism diminished, and in fact many drivers would seek the recruiter in order to determine if their truck was eligible for participation in the program. Word of mouth seems to have had a strong influence on recruitment in this study, in particular at smaller companies where most of the drivers knew one another. The level of incentive used in this project resulted in an increased participation rate which, in this type of project, resulted in less downtime and a larger number of test performed per personnel hour by eliminating downtime due to not having a vehicle to test.

This study shows that regions can take advantage of the flexibility of the MOVES emission model by collecting and using local data and targeted field work to enhance emissions and activity information within MOVES to reflect local conditions. For example, preliminary results from this study suggest that due to different load, speed, idle and creep operation, in-port emissions and activity differ from on road emissions and activity and are therefore important to characterize uniquely within MOVES. Data collected during this study can be used to help define emissions from drayage truck port operations within MOVES, and the methodologies applied throughout this study may be used to obtain data for characterizing other source types in future studies.

8.2 PEMS Lessons Learned

Depending on the type of truck being instrumented, the field team consisting of five to seven members were typically able to perform all installation, sampling and data collection activities necessary for a full PM / gaseous PEMS test and a gaseous-only PEMS test within three to five hours the evening prior to testing, with an additional two hours of warm-up and system verification required on the day of testing (prior to the start of emissions testing).

In order to maintain accurate proportional sampling, it was necessary to remove, disassemble, clean and calibrate the MPS unit after each day's test. Therefore, in order to perform back-to-back PM testing, a minimum of two MPS units were needed to rotate into service every other test day. ASD and Sensors staff would perform all required MPS service activities during the test day, when the alternate MPS unit was in use.

In addition to two MPS units being rotated throughout the study, four SEMTECH-DS PEMS units and two gravimetric sampling units were also rotated in and out of service, as needed. A reserve backup of equipment was essential in order to continue testing operations when equipment failed or required service. Other backup equipment included heated gaseous and PM sampling lines, MPS communication boxes, and auxiliary devices such as ECU interface communication boxes and connectors, weather probes and GPS antennas. During the project, project staff found that this level of spares was appropriate and we could have, at times, been able to benefit from having an even greater number of spares and parts on hand. Due to the size and weight of the SEMTECH-DS and the gravimetric sampling box, and also due to the height of most cabs, moving equipment into and out of the cabs was physically challenging and required multiple personnel. Generally, only one person could be in the cab (because of limited space), with one or two people outside of the cab lifting the equipment up. The use of stepladders during this process (and other installation activities) was very beneficial.

Due to both exhaust system rust and damage which occurred as a result of trying to remove the exhaust stack, a number of exhaust system repairs and muffler/stack replacements were necessary throughout the study. Often, the prospect of a stack replacement (with a new chrome unit) served as an additional incentive for participation, especially with independent owners/operators. Occasionally, replacement exhaust system components were not available, so ASD technologists repaired damaged exhaust systems by welding or brazing the damaged areas, as shown in Figure 8.2-1. The damage shown in Figure 8.2-1 occurred prior to the study, but was repaired by ASD technologists in order to prevent any exhaust flow loss or dilution which could affect emission measurement results. In future studies, researchers should expect to have a need to maintain common exhaust system spares, and also can use exhaust system repair or replacement as a part of the test incentive.

One of the scheduling challenges of this study was our frequent inability to schedule trucks for testing in advance. Many establishments did not notify ERG of which truck(s) would be available for testing until the day of the installation. Therefore, little preparation time was typically available for any particular installation. In order to be able to install on a variety of different trucks, it was helpful to have an overstock of replacement stacks, exhaust tubing and deck plates available for upcoming installations (rather than buying materials “as needed”).

Figure 8.2-1 Exhaust System Repairs Performed During Study



Because of the problems encountered in prior studies with burning and melting of silicon boot and hoses, ASD technologists used metal exhaust lines rather than silicon boots and hoses when fabricating all exhaust connections, as shown in Figures 5.1-15 and 5.1-16. Custom exhaust systems were fabricated for each PM/gaseous installation by cutting and welding five-inch diameter metal tubing (equivalent to each truck's exhaust diameter), and attachments were made via welding, compression clamps and band clamps. When needed, flexible five-inch metal tubing unions were used to accommodate the relative motion between the truck and sampling equipment, and this flexible tubing withstood the rigors of testing relatively well, especially compared to the flexible silicon hoses. Future testing should continue with the use of steel exhaust parts.

PEMS testing was limited to trucks with single exhaust stacks, which fortunately were prevalent in drayage activities. Dual-stack testing was discussed but would have required either routing both stacks into a "Y" shaped exhaust collection system or capping one stack and collecting the sample from the remaining open stack. Due to their prevalence, limiting sampling to single-stack trucks did not have a large impact on the trucks which were tested in this study, but could affect other studies targeting truck fleets with a larger prevalence of dual stacks (such as fleets of over-the-road trucks). In addition, trucks with side stacks (such as that shown in Figure 8.2-2) were not eligible for PM/gaseous testing during this study, due to the challenges in routing the metal sample line from the muffler to the MPS/flowmeter. Again, these were not common in drayage activities, so relatively few trucks were rejected from testing on this basis. The great prevalence of single exhaust stacks in drayage trucks means that future projects directed at drayage are unlikely to need to have provisions for dual or side stack trucks.

Figure 8.2-2 Side Stack Trucks Not Tested During Drayage Study



Since this was an “in-use” study designed to collect activity, gaseous and PM emission data from “in-use” drayage trucks without interfering with everyday operations, it was imperative to not interfere with the operations of the drayage facility. Consequently, extremely flexible test scheduling was necessary, and scheduling was tailored to each company’s operations (and downtime). Off-hour access (nights/weekends) to job sites and trucks was essential in order to perform the study. This was coordinated independently with each establishment where testing took place.

As with prior studies, sampling in rain or wet conditions was problematic. Despite efforts to seal the micro-proportional sampler, PM testing generally could not be performed in rainy weather, because water and dirt would inevitably enter the MPS. Even with light rain, PM testing was not possible, because the area around the rear deck on which the MPS was placed would become saturated with water sprayed up from the roadway, and efforts undertaken to seal the MPS box were not sufficient to prevent water incursion into the micro-proportional sampler. Consequently, the team eventually limited testing on rainy days to gaseous-only testing (since the majority of sampling equipment could be stored inside the dry cab). All weather capability would increase the productivity of future projects of this type. It may be of value to invest in further more permanent weatherproofing of the components, especially the MPS cabinet.

As much as possible, equipment failures during testing were addressed by the ride-along personnel, with remote (telephone) assistance from onsite EPA or Sensors staff. Ride-along personnel also performed general testing and tasks such as system and gravimetric filter changes, eliminating condensation from the FID drain lines and generator refueling. Gaseous system zero calibrations were performed when operations permitted (such as when the truck was temporarily parked). Having a person riding with the equipment seemed to greatly improve testing success rates and data quality (over non-accompanied testing), as real-time monitoring and hands-on correction of issues was possible. Future projects of this type should include provisions for ride-alongs to increase the productivity of testing and reduce the possibility of lost data or downtime.

Significant time was spent during each installation connecting the exhaust system, securing the PEMS rack, installing the RPM pickup device, gas bottles, generator and power lines, calibrating the gaseous sampling system and MPS system, and ensuring all systems were functioning prior to the start of each test. Maintaining, calibrating and operating the PM and gaseous PEMS system is complex and requires equipment expertise and a significant amount of attention to detail. While certainly a manageable task, staff with adequate training and experience are required, and the above challenges should be considered when planning test programs (especially “in-use”, “real world” test programs). Sufficient staff with dedicated duties should be available for testing support, with heavy use of SOPs, guidelines and checklists to ensure safety and proper test preparation and procedures take place. Dedicating knowledgeable staff for repairs and addressing problems was worthwhile and did not result in the project being overstaffed. Another personnel benefit was that relating to the EPA technologists with commercial drivers licenses and/or experience driving heavy duty trucks. There were a number of times in which being able to move trucks around establishment sites presented a benefit to productivity for reasons such as weather protection or proximity to amenities such as an electrical outlet for shore power access to keep equipment operational overnight. The ability to move the test trucks benefitted the program.

8.3 PAMS Lessons Learned

Installation of PAMS units was relatively straightforward, and few obstacles were encountered.

All installations were within the cabs of the tested trucks, so element exposure was not an issue. Occasionally, the length of the wiring harness from the truck’s ECU connector limited the areas where the PAMS could be placed, but a suitable location was always identified. There was not a problem with tampering or drivers inadvertently disabling or disconnecting the units. It is

possible the loggers could have been left on even longer without being checked, and still work well. The combination of Isaac loggers with the ECU connection proved robust with little evidence of any lost data, in spite of being left unchecked by project staff.

No issues were encountered with the relatively few installations requiring the use of optical sensors for RPM acquisition. However, for these non-ECU installations, a supplemental data stream (such as an analog signal proportional to the rack or throttle position) would be required in order to convert the activity data into a work basis. All ECU data was converted to a work basis, but as described in Section 6.2, due to variations in data provided by different protocols and different manufacturers, some analysis was required to ensure all activity data was presented on a common (brake-specific) work basis.

The use of standardized datalogger configuration files (based on the truck computer's communication protocol or optical RPM detection) helped minimize installation times and ensured consistent PAMS configuration settings were used, including collection of standardized parameters. Standardizing datalogger input formats before beginning the project reduces time spent setting up the logger as well as time spent during the data analysis part of the project.

9.0 MSOD Data Conversion and Data Delivery

Data from this study was provided in the following formats:

- All raw PAMS data files were provided in csv format, along with the SAS code used to import and process the PAMS data
- All raw PEMS data files (containing continuous gaseous emission rates) were provided in both unprocessed xml and processed csv formats, along with the SAS code used to import and process the PEMS data
- All scanned PEMS and PAMS instrumentation forms were provided in PDF format
- The project's comprehensive MySQL database was also provided. This deliverable is described in the sections that follow.

9.1 MySQL Database Delivery

The data deliverable provided to EPA as part of this project consisted of a standalone MySQL database. The database was designed based on a structure similar to previous ERG data submittals of PEMS and PAMS data, and includes tables, relationships, field names, field formats, and descriptors consistent with EPA standards.

The following text describes the design of the database and the process of its creation.

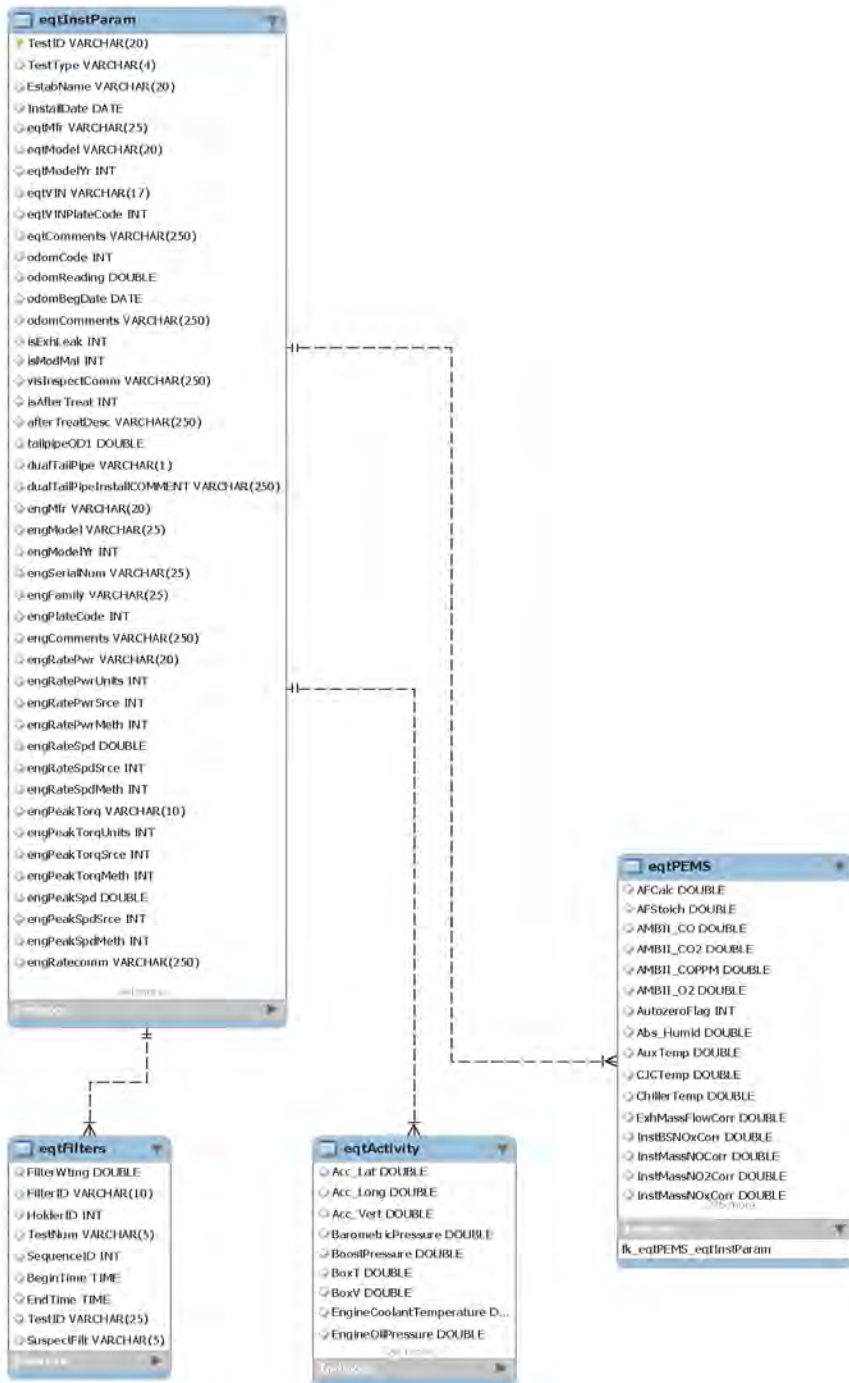
9.1.1 Creation and Population of Database

ERG used the MySQL Workbench tool to create tables, fields, format, and descriptive information. Figure 9.1-1 presents an entity-relationship diagram (ERD) detailing the structure of the database, which consists of four separate tables.

With the design of the database complete, ERG began gathering raw data collected over the course of the project, and copying it into Microsoft Excel spreadsheets modeled after each individual table in the database. This data was obtained from a variety of sources, including logs of sites and equipment visited in the field, filter logs, and PEMS/PAMS data. A separate spreadsheet was created for each table to be input into the database, and was populated accordingly using the data described above. Where applicable, data fields were populated with specific codes consistent with previous ERG database submittals (and described in detail in the MySQL schema report present in Appendix AG).

Having populated these spreadsheets, corrections were made to the data in order for it to be readable by the database. Examples of the corrections made here include changes to date and time formats, filling of nulls, addition of fields for clarity, and removal of fields no longer

Figure 9.1-1 Entity-Relationship Diagram for MySQL Database



applicable to the project. Once the spreadsheets were fully populated with the appropriate data, they were exported in tab-delimited format in order for each file to be directly imported into the database. In the case of PEMS and PAMS data collected via instrumentation, SAS programs were written at this point to export the previously quality checked data to tab-delimited files that could be read directly into the database. Additional edits were then made to correct line endings and to remove extraneous data characters introduced by the export from Microsoft Excel.

Once the tab-files containing the data had been created, we executed a MySQL script generated by the Workbench tool to create a blank database within a MySQL instance. Separate scripts were then used to load the information contained in the tab-delimited files into the newly created database structure. Some iteration took place at this point to ensure that all of the data loaded into the database without errors related to table relationship integrity, primary key violations or field format errors. Once the data loaded successfully, we compressed the MySQL database files and transmitted them to EPA via secure FTP.

9.1.2 Table List

This section list the tables contained in the MySQL database submitted to EPA. A comprehensive list of all fields included in these tables is presented in the database schema report provided in Appendix AH. The format for these tables were not explicitly specified in the work assignment, so they were created to comprehensively include all of the data contained in the QC'd SAS datasets from which they were derived consistent with past ERG database submittals of this type.

- **Table *eqtInsParam*:** This table includes descriptive equipment information as well as instrumentation parameters. It is related to its child tables *eqtActivity*, *eqtPEMS*, and *eqtFilters* by the *testID* field.
 - **Table *eqtActivity*.** This table includes QC'ed PAMS information collected in the field via datalogger. It has no child tables.
 - **Table *eqtPEMS*.** This table includes QC'ed PEMS information collected in the field via SEMTECH. It has no child tables.
 - **Table *eqtFilters*.** This table includes QC'ed PM filter information collected in the field with weights measured in EPA's lab. It has no child tables.

10.0 References

- (1) “Development of Emission Rates for Heavy-Duty Vehicles in the Motor Vehicle Emissions Simulator (MOVES2009)”, Draft Report, EPA-420-P-09-005, August 2009.
- (2) Personal conversation between Sandeep Kishan (ERG) and James Warila (US EPA, OTAQ, ASD), February 2010.
- (3) <http://www.tceq.state.tx.us/implementation/air/sip/cleandiesel.html>, accessed March 10, 2010
- (4) Clark, N., Wayne, W.S., Gautam, M., Thompson, G., Lyons, D., “World Energy B20 Envirodiesel® Evaluation as a TCEQ Alternative Fuel Formulation”, Report, West Virginia University, OSP Ref. 05-704.
- (5) Durbin, T., Jung, H., Cocker, D., Johnson, K., “PM PEM’s Pre-Measurement Allowance-On-Road Evaluation and Investigation”, Final Report to Measurement Allowance Steering Committee, University of California CE-CERT.
- (6) Kishan, S., Fincher, S., Sabisch, M., Santos, R., Zmud, M., Sen, S., Amen, S., Ensfield, C., “Populations, Activity and Emissions of Diesel Nonroad Equipment in EPA Region 7”, Final Report, EPA Contract # EP-C-06-080.

11.0 Index of Appendices

Appendices will be provided electronically. The following is a list of the appendices to be provided. Page counts for those appendices formatted for printing are given in parenthesis.

- Appendix A - Drayage QAPP_V3 (448 pages)
- Appendix B - RSD Stratification Results (31 pages) **Confidential-Not for Release**
- Appendix C – Drayage recruiting materials (6 pages)
- Appendix D – Drayage PEMS and PAMS Equipment (11 pages)
- Appendix E – Drayage PEMS SOPs_20100123 (56 pages)
- Appendix F – Drayage PAMS SOPs_20091105 (16 pages)
- Appendix G - Drayage Preliminary Visit Forms (2 pages)
- Appendix H - Instrumentation Data Collection Forms (11 pages)
- Appendix I – Consolidated Instrumentation Data (156 pages) **Confidential-Not for Release**
- Appendix J– Consolidated PEMS Review Results (148 pages) **All Confidential-Not for Release**
 - Appendix J-1 - PEMS Data QC Guidelines
 - Appendix J-2 - Sensors Drayage PEMS Data Review Notes
 - Appendix J-3 - Sensors / ERG dialog on chiller temps, exhaust BP, ExFM error on PM sampling, & ExFM data corrections
 - Appendix J-4 - ERG Drayage PEMS Data Review Notes
 - Appendix J-5 -SAS Corrections Performed on Drayage PEMS Data
- Appendix K – Sensors PEMS Data QC Results Detail (94 pages)
- Appendix L – Test and payment log (3pages) **Confidential-Not for Release**
- Appendix M – Drayage Emissions Measurement Results (86 pages) **Confidential-Not for Release**
 - Appendix M-1 – Drayage Emissions Measurement Results (86 pages) (Anonymized Copy of M)
- Appendix N – Drayage Fuel Sampling SOPs_20091203 (1 page)
- Appendix O – Consolidated Drayage Fuel Analysis Results (35 pages) **Confidential-Not for Release**
- Appendix P – Drayage PEMS Checklist_20100129 (6 pages)
- Appendix Q – Drayage Filter Data Collection Form (4 pages)
- Appendix R – Gravimetric Filter Handling SOPs (2 pages)
- Appendix S – Drayage Ridealong Checklist_20100130 (5pages)
- Appendix T – Drayage Filter Log (90 pages)
- Appendix U – Port Activity From Ride Along Logs (8 pages)
- Appendix V – PDFs of Drayage Ride-Along Notes (zip file containing 57 pages when extracted) **Confidential-Not for Release**
- Appendix W – PDFs of Drayage Filter Forms (zip file containing 73 pages when extracted) **Confidential-Not for Release**
- Appendix X – PDFs of Dray Instrumentation Forms (zip file containing 864 pages extracted) **Confidential-Not for Release**
- Appendix Y – PDFs of Preliminary Visit Data Collection Forms (28 pages) **Confidential-Not for Release**
- Appendix Z – Filter System User Manual rev1.04 (25 pages)
- Appendix AA – MPS User Manual rev1.01 (38 pages)
- Appendix AB - Port Definitions in Drayage Study (8 pages)

Appendix AC – Drayage Processing Parameters (24 pages) **Confidential-Not for Release**
Appendix AC-1 – Drayage Processing Parameters (24 pages) (Anonymized Copy of AC)
Appendix AD – Drayage Torque Curves (7 pages)
Appendix AE - PAMS Data QC Results (1 page)
Appendix AF- MPS to Exhaust Flow Proportionality Plots (44 pages) **Confidential-Not for Release**
Appendix AG - MySQL SchemaReport (17 pages)