

Class-8 Heavy Truck Duty Cycle Project Final Report

December 2008

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R&D Staff

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Vehicle Systems Program

CLASS-8 HEAVY TRUCK DUTY CYCLE PROJECT FINAL REPORT

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Date Published: December 2008

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Oak Ridge, Tennessee 37831-6283
managed by
UT-BATTELLE, LLC
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

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ACRONYMNS AND ABBREVIATIONS

Term	Definition
ADAMS	Automatic Dynamic Analysis of Mechanical Systems
ANL	Argonne National Laboratory
API	Application Programming Interface
APU	Auxiliary Power Unit
CAN	Controller Area Network
Dana	Dana Corporation
DAS	Data Acquisition System
DCGenT	Duty Cycle Generation Tool
DOE	U.S. Department of Energy
DTF	Dana Truck Fleet
Dyno	Dynamometer
FMCSA	Federal Motor Carrier Safety Administration
EPA	Environmental Protection Agency
FOT	Field Operational Test
GAWR	Gross Axle Weight Rating
GVWR	Gross Vehicle Weight Rating
HTDC	Heavy Truck Duty Cycle
LLNL	Lawrence Livermore National Laboratory
Michelin	Michelin Americas Research Company
MOU	Memorandum of Understanding
NGSWBTs	New Generation Single Wide-Based Tires
NTRC	National Transportation Research Center
ORNL	Oak Ridge National Laboratory
OVT	Office of Vehicle Technologies
PSAT	Powertrain Systems Analysis Toolkit
PTO	Power Take-Off
Schrader	Schrader Trucking
SDC	Synthetic Duty Cycle
SDOD	System Design and Operations Document
SOP	Standard Operating Procedure(s)
UDDS	Urban Dynamometer Driving Schedule
UT	The University of Tennessee
Vehicle	Test Vehicle Including Tractor and/or Trailer Unit(s)
VehSim	Mechanical Simulation Corporation's Vehicle Simulation Software
VIN	Vehicle Identification Number
WVU	West Virginia University

ACKNOWLEDGEMENTS

The Oak Ridge National Laboratory (ORNL) would like to thank Dana Corp. of Kalamazoo, Michigan for their tremendous contributions in support of the pilot testing efforts of this Program. Dana's generosity in providing access to a dedicated tractor, box-trailer, driver, engineering expertise, ride-along engineer and wheel-end torque sensors is greatly appreciated.

We would also like to thank the Michelin Americas Research Company (MARC) in Greenville, South Carolina for their technical contributions to the project, provision of tires for the test vehicles, and assistance in locating a suitable fleet partner. MARC's support and encouragement were critical for the success of this project.

ORNL would like to thank Schrader Trucking for making available their trucks to serve as test vehicles for this project. They provided necessary access to vehicles for the smooth conduct of the Field Operational Test as well as providing fueling and routing information to the project team for incorporation into the test data. Without the support of Schrader's owners, drivers, and technicians, this project would not have been possible.

The involvement of Fleet Tire of Knoxville is also much appreciated for their work to get the test tires to the fleet partner.

ORNL would also like to thank Commercial Carrier Consultants for their invaluable assistance in providing the necessary contracting for the pilot testing and dynamometer testing.

We would also like to thank Joe Massimini (Purdue University), Mary Beth Lascurain (Pensacola Christian College), Fiona Dunne (University of California, Santa Barbara), Randall Plate (Cedarville University), and Amanda Blagg (Pensacola Christian College) for their contributions to the project in its various stages through internships with the DOE Office of Science and the Oak Ridge Institute for Science and Education.

The project team would also like to thank instrumentation suppliers SoMat, VBox USA, Air-Weigh, and Vaisala for their support throughout the project. Representatives from SoMat provided tremendous assistance in the installation of their equipment on the first test vehicle and provided technical support throughout the project. Their assistance was crucial in the early stages of the sensor suite development when the project team first interacted with a vehicle data bus. The team would also like to express appreciation to VBOX USA for conducting product demonstrations prior to the start of this project and providing technical support through the various stages of the project. Air-Weigh representatives provided hours of technical expertise in the sensor development stage, enabling the data acquisition unit to interact with their system, and also installed their units in the test vehicle. Representatives from Vaisala also assisted the project team greatly, particularly during the pilot test, but also providing support as needed throughout the FOT, working to limit down-time due to difficulties with the units.

Finally, the project team would like to thank Mr. Lee Slezak (DOE's Vehicle Technologies Program) for his continued support of this important project. Mr. Slezak's encouragement, guidance and enthusiasm for this work; along with the financial support for its conduct were the foundation which allowed this project to be conducted. We are indebted to Mr. Slezak for his support.

ORNL Project Team: Gary Capps, Oscar Franzese, Bill Knee, Mary Beth Lascurain and Pedro Otaduy

EXECUTIVE SUMMARY

The Heavy Truck Duty Cycle (HTDC) Project is sponsored by the U.S. Department of Energy's (DOE's) Office of Vehicle Technologies (OVT). It involved efforts to collect, analyze and archive data and information related to Class-8 heavy-truck operation in real-world highway environments. Such data and information is useful to support technology evaluation efforts, and to provide a means of accounting for real-world driving performance within heavy truck analyses. The Project was led by the Oak Ridge National Laboratory (ORNL), involves three industry partners (Dana Corporation (Dana) of Kalamazoo, Michigan; Michelin Americas Research Company (Michelin) of Greenville, South Carolina; and Schrader Trucking (Schrader) of Jefferson City, Tennessee), and supports the Argonne National Laboratory (ANL) with regard to Class-8 data and information for the development and evaluation of their Powertrain Systems Analysis Toolkit (PSAT). The Project was conducted in three phases:

Phase 1 – Pilot Test: Efforts in this phase involved the design, evaluation, and field testing of a duty cycle data collection system. This phase was initiated in early CY2005 and was completed in March 2006.

Phase 2 – Field Operational Test Launch: Efforts in this phase involved identification of a field operational test (FOT) Class-B fleet, fleet Instrumentation, initiation of field testing that included initial data collection, development of a data management system, and quality assurance and verification of the collected data. These efforts were in direct follow-on to Phase 1 efforts and were initiated in February 2006. Phase 2 was completed at the end of CY2006.

Phase 3 – Field Operational Test: Efforts in this phase involved continuation and completion of the FOT, the conduct of data analyses, completion of the data management system, development of specialized data handling tools, completion of a Duty Cycle Generation Tool (DCGenT) prototype, and the production of a final report. These efforts were initiated in October 2006 and were completed in April, 2008.

Overall, the conduct of the Phase 1 Pilot Test activities allowed the research team to be better prepared for the conduct of the FOT, in both the analysis of the data generated and in envisioning capabilities for providing tools for generating custom duty cycle profiles and information. Phase 1 efforts were concluded in March 2006 (a Phase 1 final report was prepared and submitted to DOE) and Phase 2 was initiated in April 2006. An initial assessment of the fuel efficiency benefits of the New Generation single wide-based tires (NGSWBTs) was determined to be 6%. Since data involved only two cross-country data collection efforts, the fuel savings benefit was not conclusive.

Phase 2 was an eighteen-month effort that began in April 2006 and was concluded in September 2007. Phase 2 involved the development of the FOT sensor suite and the instrumentation of six Class-B long-haul heavy trucks. Initial data collection and verification were performed during this phase and were concluded in Phase 3. A major milestone of Phase 2 efforts was the formal launch of the FOT. This launch was marked by the signing of a memorandum of understanding (MOU) between Schrader, UT-Battelle, and DOE on October 23, 2006.

Phase 3 was a seven-month effort which began in October 2007 and concluded in April 2008. Major Phase 3 efforts involved the completion of the data collection efforts, completion of the prototype DCGenT, and the conduct of dynamometer testing. The FOT data was archived in a DOE heavy vehicle data archive system located at ORNL. Data analyses of operational characteristics were also conducted under Phase 3, and the data archive system was made accessible for use by the research community and others (with permission from DOE).

Sixty channels of data were collected at 5 Hz from six instrumented tractors and ten instrumented trailers for more than one year during the FOT. Much of the data, including fuel consumption was collected from the vehicles databus. Other instrumentation included a GPS system which provided three dimensional location; a real-time vehicle weight system; a weather station to obtain precipitation, wind direction and wind velocity data; and a system to collect road condition data. A data acquisition system was developed, hardened in the pilot testing, and utilized in the FOT. In addition, there was interest on the part of Michelin to collect real-world performance data related to the performance of their NGSWBTs in comparison to standard tandem dual tires which is used predominantly in the industry.

The volunteer fleet that partnered with ORNL was Schrader Trucking of Jefferson City, Tennessee. Their operation includes the eastern portion of the U.S., and covers a broad range of topology from mountainous to flat, and from rural to metropolitan. Seasonal data was collected and data on idling behavior was captured. No aerodynamics, emissions, or driver performance data was gathered. More than 200 Gigabytes of compressed data were collected on nearly 700,000 miles of Class-8 long-haul performance. The collected data was quality assured and archived for use in various data analyses. Two software tools were developed to support data analyses. The first involves the ability to identify data files within the database that conform (in a Boolean “OR” sense) to performance criteria selected by the user. The identified files can then be downloaded and utilized by the user. A second software program is the Duty Cycle Generation Tool (DCGenT) prototype. This prototype will allow a user to identify files (in a Boolean “AND” sense) corresponding to a set of user designated criteria. These files are then statistically decomposed into histograms of speed and acceleration, and used to generate a synthetic duty cycle of user-designated duration, that is characteristic of the segments from which it was derived. The tool is currently a prototype and still requires some additional effort before it is released. The data will be made available to researchers and the industry with approval from DOE.

The data analyses of the collected FOT data was accomplished through the study of the fuel efficiencies associated with NGSWBTs vs. standard dual tires. Overall, the NGSWBTs outperformed the standard dual tires when the entire database was studied; when payload weight increased; and for most speeds traveled by the tractor-trailers. Improvements in the fuel economy of about 9-10% were seen. In addition, as the payload weight of the tractor-trailer increased, so did the marginal benefit over the dual tires and for “heavy” loads, the percentage increased to 10.2%.

Lastly, a comparison of the NGSWBTs to the dual tires was made with respect to vehicle speed. For all speed categories, the NGSWBTs outperformed the dual tires with respect to fuel efficiency.

Future efforts will involve the collection of similar data and information on selected Class-6 and Class-7 vocations (to begin in CY-2009); completion of the DCGenT for general use; as possible, supporting the Environmental Protection Agency’s (EPA’s) SmartWay Program by providing access to, and analysis of the Class-8 data collected in this project; support for evaluating and validating DOE’s Powertrain Systems Analysis Toolkit (PSAT); and if possible a study of duty cycles most appropriate for Medium – and Heavy – Truck hybrid drivetrains.

1. PROJECT OVERVIEW

This U.S. Department of Energy (DOE) Project is sponsored by the Office of Vehicle Technologies (OVT), and involves efforts to collect, analyze and archive data and information related to heavy-truck operation in real-world highway environments. Such data and information is useful to support technology evaluation efforts, and to provide a means of accounting for real-world driving performance within heavy truck analyses. The Project is led by the Oak Ridge National Laboratory (ORNL), involves three industry partners (Dana Corporation (Dana) of Kalamazoo, Michigan; Michelin Americas Research Company (Michelin) of Greenville, South Carolina; and Schrader Trucking (Schrader) of Jefferson City, Tennessee), and supports the Argonne National Laboratory (ANL) with regard to Class-8 data and information for the development and evaluation of their Powertrain Systems Analysis Toolkit (PSAT). Dana provided the tractor and trailer used for the Pilot Test. Michelin provided tires for the Program in the interest of gathering data regarding the long-term real-world performance of their New-Generation Single Wide-Based Tires (NGSWBTs) – especially with regard to the fuel savings aspect of NGSWBTs. Schrader provided six tractors and ten trailers for use in the Field Operational Test (FOT). The Program was conducted in three phases:

Phase 1 – Pilot Test: Efforts in this phase involved the design, evaluation, and field testing of a duty cycle data collection system. This phase was initiated in early CY2005 and was completed in March 2006.

Phase 2 – Field Operational Test Launch: Efforts in this phase involved identification of a FOT fleet, fleet Instrumentation, initiation of field testing that includes initial data collection, development of a data management system, and quality assurance and verification of the collected data. These efforts were in direct follow-on to Phase 1 efforts and were initiated in February 2006. Phase 2 was completed at the end of CY2006.

Phase 3 – Field Operational Test Conduction: Efforts in this phase involved continuation and completion of the FOT, the conduct of data analyses, completion of the data management system, development of specialized data handling tools, completion of a Duty Cycle Generation Tool (DCGenT), and the production of a final report. These efforts were initiated in October 2006 and were completed in April 2008.

Phase 1 was a 15-month effort that was completed in March 2006. Within Phase 1, pilot testing was conducted to evaluate the prototype data collection system that was to be used to capture relevant vehicle data. The data collected during the Pilot Test was analyzed and example duty cycles based on this data were developed. The efforts engaged in during Pilot Testing were extremely valuable. Failure to invest in pilot testing activities prior to a field test creates a strong potential for having something go wrong during the field test. Field hardening of instrumentation or data collection systems, familiarity with such instrumentation and systems, optimal calibration, and general pilot testing lessons learned, protocols and procedures are ways of ensuring that once a field test has been initiated, that down-time is kept to a minimum.

The research team obtained considerable experience with the sensors and data acquisition systems (DASs) utilized during the pilot test. A more optimal data collection frequency rate was determined, and attention was focused on the need for better time stamping and data synchronicity.

The handling of the enormous amount of data that was generated in the Pilot Test was discovered to be very resource-intensive. The adjustment of data collection rates, the collection of data at the same frequency for all performance measures, and the need to develop some automated data handling/management tools were identified to be necessary.

The data analyses performed in Phase 1 indicated that duty cycle data could be generated from the data that was collected during the Pilot Test. A characteristic data analysis task indicated that for NGSWBTs, a fuel savings in the range of 2.9 percent to 9.0 percent might be experienced.

Overall, the conduct of the Phase 1 Pilot Test activities allowed the research team to be better prepared for the conduct of the FOT, in both the analysis of the data generated and in envisioning capabilities for providing tools for generating custom duty cycle profiles and information. Phase 1 efforts were concluded in March 2006 (a Phase 1 final report was prepared and submitted to DOE) and Phase 2 was initiated in April 2006.

Phase 2 was an eighteen-month effort that began in April 2006 and was concluded in September 2007. Phase 2 involved the development of the FOT sensor suite and the instrumentation of six long-haul heavy trucks. Initial data collection and verification were performed during this phase and were concluded in Phase 3. A major milestone of Phase 2 efforts was the formal launch of the FOT. This launch was marked by the signing of a memorandum of understanding (MOU) between Schrader, UT-Battelle, and DOE on October 23, 2006.

Phase 3 was a seven-month effort which began in October 2007 and concluded in April 2008. Major Phase 3 efforts involved the completion of the data collection efforts, completion of the DCGenT, and the conduct of dynamometer testing. The FOT data was archived in a DOE heavy vehicle data archive system located at ORNL. Data analyses of operational characteristics were also conducted under Phase 3, and the data archive system was made accessible for use by the research community and others (with permission from DOE).

1.1 DUTY CYCLE NEEDS OF INDUSTRY/GOVERNMENT

1.1.1 Overview of Duty Cycles

In their simplest form vehicle-based duty cycles have traditionally represented a mapping of a vehicle's velocity over time. Duty cycles are also referred to as emission test cycles or drive cycles and are utilized in conjunction with engine or chassis dynamometers to measure and compare emissions for engines or vehicles operating with exactly the same duty cycle. In theory, in order to assess the real-world impact of engines and vehicles, and for the purposes of setting emissions and fuel efficiency standards, duty cycles should ideally reflect characteristics of real-world vehicle usage patterns. Many existing duty cycles resemble portions of real-world driving, but were developed for emissions testing and the evaluation of technologies on a common duty cycle basis. Many real-world duty-cycles are highly dependent on the specific vocational applications which oftentimes do not resemble existing duty cycles.

A number of emission test cycles used internationally (including the European Union and Japan) and in the US are presented at: <http://www.dieselnet.com/standards/cycles/#us>. Such duty cycles have associated measures such as:

- cycle duration
- average speed
- maximum speed
- maximum acceleration
- maximum deceleration
- distance traveled
- the number of stops per mile

- total kinetic energy
- total idling time

Three of the four speed-time modes of the Heavy Heavy-Duty Diesel Truck (HHDDT) Cycle (obtained from: <http://www.dieselnet.com/standards/cycles/hhddt.html>) are presented below. They are: 1) the HHDDT Creep Mode, 2) HHDDT Transient Mode, and 3) HHDDT Cruise mode, and are respectively presented as Fig. 1 through Fig. 3. While these plots represent driving profiles from five to over 35 minutes, they are not representative of all heavy-duty diesel truck operations. Certainly the operation of Class-8 tractor-trailers in long-haul operations and operation in urban areas are significantly different (see Chapters X and 6 of this report for some examples). As such, duty cycles such as the HHDDT are well suited for benchmarking engine performance for setting vehicle standards, and comparing engine and emission performance, but are not necessarily reflective of comprehensive real-world operations. For the most part, no existing single, or even a few duty cycles can reflect the comprehensive behavior of long-haul operations. One of the goals of this project was to collect sufficient data on long-haul operations to allow interested parties to generate a characteristic duty cycle for specified operational characteristics based on real-world operational segments that match those characteristics.

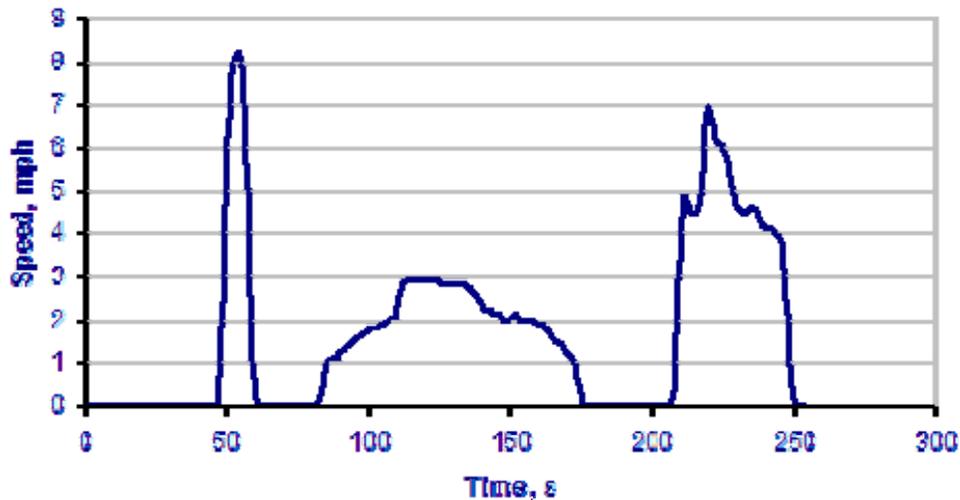


Fig. 1. HHDDT Creep Mode

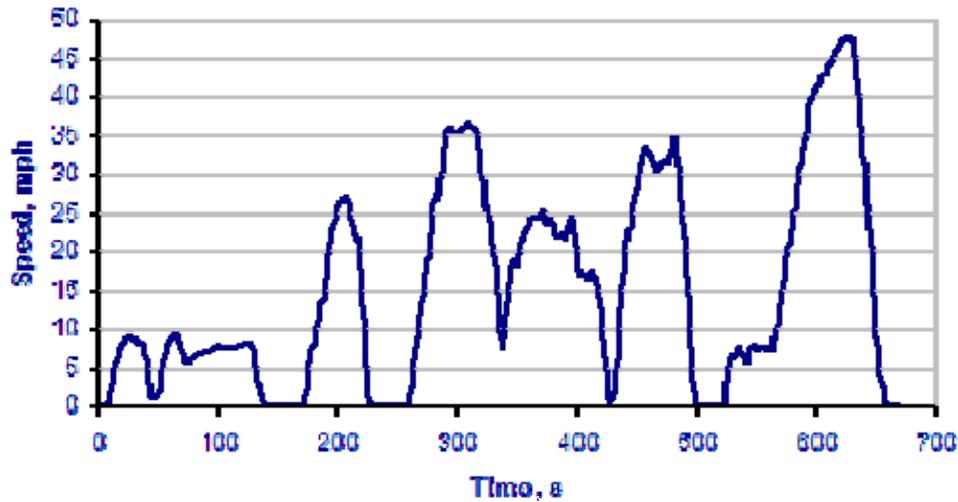


Fig. 2. HHDDT Transient Mode

In addition to collecting data specific to the formation of duty cycles, this project also collected situational data associated with the duty cycle data. That is, information regarding a vehicle’s payload, the road grade over which it travels, the type of roadway, the time of day (relates to congestion), weather conditions, road conditions, etc. were also collected. For the purposes of modeling real-world performance, such duty-cycle situational data allows for the calibration and validation of models that simulate engine or vehicle performance on duty cycle information gathered within this project.

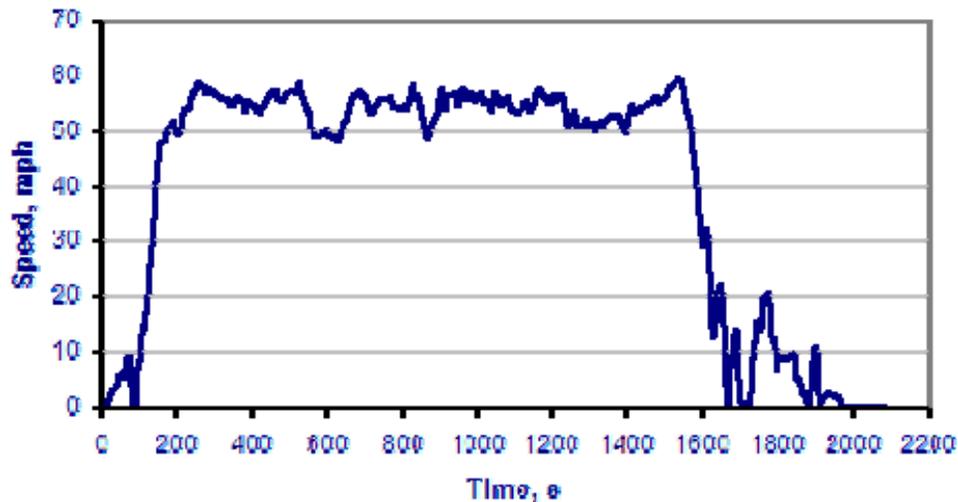


Fig. 3. HHDDT Cruise Mode

1.1.2 Heavy Truck Long-Haul Operations

Heavy truck-based long-haul operations (i.e., operations in areas beyond 300-to-500 miles of a garaging area) have typically been stereo-typed as long-periods of driving many miles with few stops. However, when considering refueling, topography, congestion, size/weight/safety inspections, anti-idling laws and hours-of-service, there is considerably more stop-and-go behavior than is popularly believed. In long-haul operations, the drivers usually do not return to their home terminal each

evening and they maintain a daily logbook of operation statistics. A description of EPA's Highway Long Haul drive cycle is provided in the next section.

1.1.3 Interest in Long-Haul Duty Cycle Information

In addition to DOE's interests in developing a real-world-based long-haul operational database that can be used to: 1) support technology investment decisions, and 2) to calibrate and validate PSAT, other federal agencies and representatives have expressed an interest in long-haul duty cycles.

1.1.3.1 EPA's SmartWay Transport Partnership

The EPA initiated its SmartWay Transport Partnership (see: <http://www.epa.gov/smartway/index.htm>) to accelerate the deployment of fuel-efficient, clean technologies for heavy duty vehicles. The Partnership involves collaboration between EPA and the transportation industry to improve energy efficiency, reduce greenhouse gas and air pollutant emissions, and improve energy security. Furthermore, it seeks to define and provide incentives for adopting cleaner, more fuel efficient transportation.

Important goals of the SmartWay Transport Partnership are: 1) to conduct testing, modeling and analyses to determine the environmental benefits of new heavy truck technologies, and 2) to provide the results of these efforts to SmartWay partners and to the general public in order to stimulate early adoption of such technologies. EPA is developing a fuel efficiency test protocol for heavy duty trucks in order to better quantify these potential benefits. Efforts to date have focused on individual components (e.g., tires, wheels, aerodynamic equipment, auxiliary power units, and engines) that have been demonstrated to improve fuel efficiency and reduce emissions. Most recently, EPA and its SmartWay partners have expressed interest in expanding the SmartWay designation for heavy duty vehicles by moving toward a performance-based specification that would be technology-neutral, and would be able to quantify a broad range of heavy vehicle configurations and applications, and to measure technical innovations as they emerge. Such performance-based testing would require the measurement of vehicle-based fuel efficiencies rather than the fuel efficiencies estimated from component testing. A complicating issue is that there exists a wide variety of truck configurations for each base model which makes the testing of every configuration impractical if not impossible. EPA is considering a number of approaches including reference truck configurations and modeling to overcome this complication, and has developed a draft test procedure for medium and heavy duty vehicles (SmartWay Fuel Efficiency Test Protocol for Medium and Heavy Duty Vehicles: Working Draft, EPA420-P-07-003, November, 2007). This procedure applies to: 1) motor vehicles rated at more than 8,500 lbs GVWR, or that have a vehicle curb weight of more than 6,000 lbs, or that have a basic vehicle frontal area in excess of 45 square feet; and 2) tractor-trailer combination trucks, single unit commercial trucks, heavy duty vocational trucks, and buses used in inter-city transit applications. This procedure does not apply to: 1) vehicles with hybrid drive technologies (e.g., regenerative braking, or reductions in engine transient operation), or 2) fuel efficient vehicle components (e.g., single wide base tires or aerodynamic equipment.). The procedure is intended to be used on a voluntary basis to determine whether vehicle configurations meet or exceed SmartWay performance specifications. It may also be useful for calibrating and verifying vehicle software models. The procedure involves testing via the operation of a particular vehicle configuration on either a test track or a chassis dynamometer, over a specified drive cycle and measuring the fuel consumption. Because of the wide variation in truck configurations and vocations/applications, the test protocol requires separate duty cycles for each vehicle application. EPA has acknowledged that standardized drive cycles for the selected base vehicles do not exist, but the draft procedure describes the drive cycles for: 1) a tractor-trailer combination line haul and regional haul truck; 2) a local pick up and delivery

vehicle; 3) a transit bus; 4) a neighborhood refuse truck; 5) a utility truck; and 6) an intermodal (port) drayage truck. The description of the Highway Line Haul is presented here to illustrate the types of duty cycles being considered, and is taken from EPA's Draft Test Protocol.

1.1.3.2 Highway line haul

The highway line haul cycle simulates a combination tractor-trailer commercial freight delivery truck, engaged in interstate (predominantly highway) operation. This type of vehicle operation is characterized by long trip lengths, higher average speeds, more steady-state type engine operation, and overnight rest stops, which in some instances involve long-duration idling. The vehicles are powered by heavy duty engines typically used in Class-8 trucks (33,001 pounds GVWR or greater). Typically, the tractor has a sleeper cab with three axles; it is attached to a tandem axle trailer. Depending upon the type of freight carried, the trailer can be a dry van box, reefer, tanker, car carrier, livestock van, flat bed, or other. A dry van box semi-trailer is recommended for this test by EPA, except when testing for applications that require a specific trailer type.

EPA's SmartWay test protocol describes two options for a highway line haul drive cycle. Both are modifications of the Cruise mode of the California Air Resources Board (ARB) HHDDT emissions test, a four-mode test to represent heavy truck operation. They were developed using data from 171 instrumented heavy duty trucks. Although the ARB test includes an idle, creep, transient, and cruise mode, only the latter is used as the basis of the highway line haul drive cycle. This is because data to develop the ARB test was collected from a random selection of all heavy duty trucks. However, line haul trucks are a unique subset of heavy duty trucks that spend the majority of their miles at highway speed (see Table 24 in Chapter 6 of this report).

The first drive cycle option was developed by EPA for fuel efficiency and emissions track testing of combination tractor-trailers. In this cycle, the most significant modifications made to the Cruise module were to add in some transient and idling operation, and to reduce deceleration and acceleration rates. EPA notes that the deceleration and acceleration rates in the Cruise module are too severe for a Class-8 combination tractor-trailer, especially when loaded to typical weights of 33,000 to 66,000 lbs. Additionally, if tested on a chassis dynamometer, risks associated with damaging the dynamometer and the vehicle's brakes would exist. A graphic of this version of the highway line haul drive cycle is provided in Fig. 4.

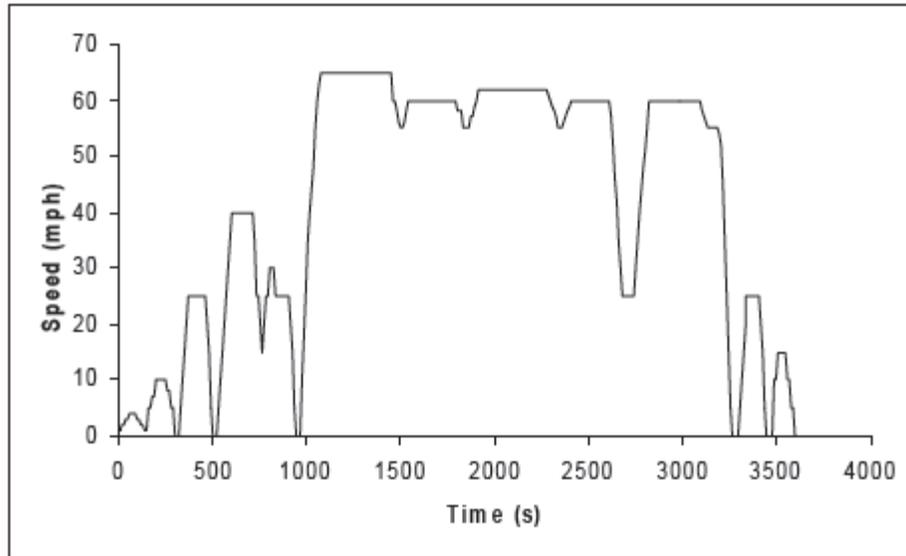


Fig. 4. Modified HHDDT Cruise Module for Highway Line Haul Operations

Another version of a highway line haul cycle that EPA indicates is suitable for use only on a chassis dynamometer, was created by Southwest Research Institute (SRI), using input from a group of stakeholders, including EPA, Northeastern States for Coordinated Air Use Management (NESCAUM), several truck and engine manufacturers, state organizations, and others, for a NESCAUM heavy truck fuel efficiency modeling and simulation project. It is similar to the option in Fig. 4, although the top and average speeds are increased, there are grade impacts, there is less transient operation, and idling is handled in a separate cycle. A graphic of this version of the highway line haul drive cycle is provided in Fig. 5.

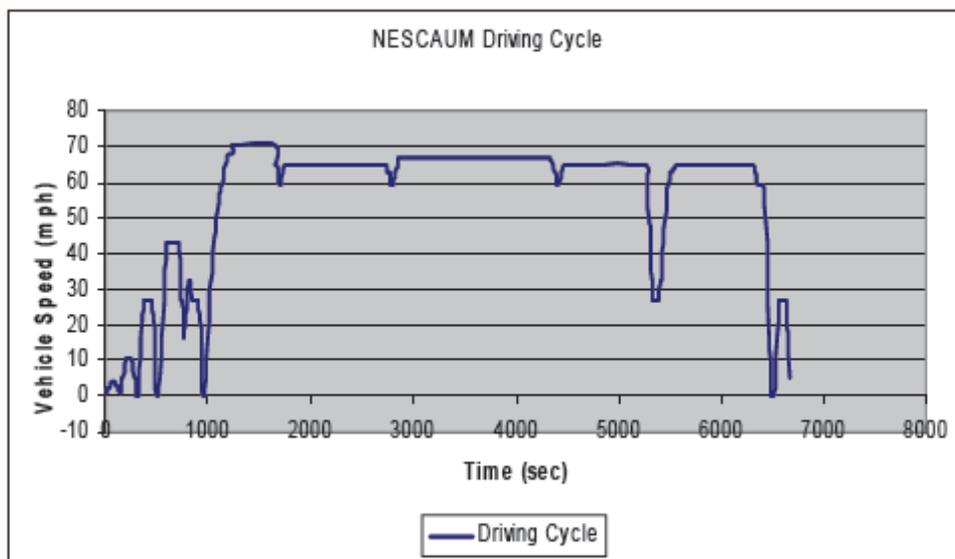


Fig. 5. Southwest Research Institute Modified HHDDT Cruise Module for Highway Line Haul Operations

EPA indicated that each of these cycles may be considered, with the potential to combine features of each into a final Highway Line Haul cycle. Furthermore, EPA indicated that data and input on

payload and accessory load would also be considered to develop these aspects of the drive cycle. Similar discussions are provided for the other five base vehicle drive cycles.

EPA held a public workshop in Washington, DC, on March 19-20, 2008, to discuss the protocol. The purpose of the workshop was to present the current working draft, provide highlights of comments received to date, and to invite further collaboration with interested parties to share data and conduct tests and analyses to further develop and validate the test procedure. ORNL staff met with EPA staff at this workshop and discussed the following topics: 1) the possibility of utilizing HTDC data to partially support SmartWay duty cycle data needs, 2) the idea of utilizing field operational data in conjunction with dynamometer and test track testing for estimating fuel efficiency, and 3) the idea of utilizing a library of standardized duty cycle segments that could be utilized to build duty cycles that were particular to a fleet's unique duty cycle. Discussions on these topics are continuing.

1.1.3.3 21st Century Truck Partnership

The 21st Century Truck Partnership (21CTP) was announced on April 21, 2000 by then-Vice-President Gore in Romulus, Michigan. Shortly thereafter an initial 21CTP Technology Roadmap was developed (see: http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/21ctp_roadmap_2007.pdf). The Partnership consists of four government agencies (USDOE, USDOT, UDDOD, and USEPA), and fifteen industry partners:

- Allison Transmission
- BAE Systems
- Caterpillar
- Cummins
- Daimler Chrysler
- Detroit Diesel
- Eaton Corp.
- Freightliner
- Honeywell
- Navistar
- Mack
- Novabus
- Oshkosh
- Paccar
- Volvo

The primary emphasis of the Partnership is to accelerate the introduction of advanced truck and bus technologies that use less fuel, have greater fuel diversity, operate more safely, are more reliable, meet future emissions standards and are cost-effective. Their ultimate goal is safe, secure, and environmentally friendly trucks and buses, using sustainable and self-sufficient energy sources that enhance America's global competitiveness. 21CTP emphasis area includes:

- Engine Systems
- Heavy-Duty Hybrids
- Parasitic Losses
- Idle Reduction
- Safety

Significant research has been accomplished by this partnership and recent discussions have focused on the development of an integrated demonstrator (tentatively called SuperTruck) that reflects the results of the 21CTP research, and that can be utilized for testing and evaluation via simulation modeling, test track testing, and field operational testing. ORNL has engaged in discussions with DOE on utilizing the HTDC data and duty cycles as a baseline for comparison with the SuperTruck testing and evaluation results.

1.1.3.4 Industry/academia interests

ORNL has received a number of inquiries from industry requesting data and information that was generated by the HTDC project. These requests included the following:

- Duty cycle and situational data for input into an industry developed engine model, and fuel consumption data for comparison to modeling results.
- Long-duration duty cycle data for input into a model of heavy hybrid performance. Subsequently, the HTDC fuel efficiency data would be a benchmark against which the results of the heavy hybrid model could be compared.
- Grade and position data as a basis for understanding driver steering behavior
- Duty cycle and situational data for input into heavy hybrid control module that incorporates terrain features for optimal control.
- Use of HTDC data to assess characteristics of long-haul driver behavior.
- Use of HTDC data to characterize long-haul performance (e.g., percent of time spent in congestion, time spent in various speed categories, idling time, etc.).

1.2 DATA COLLECTED DURING PHASE 1 (PILOT TEST)

Early in Phase 1, a meeting was held between ORNL’s engine specialists and the duty cycle research team. It was determined that an attempt would be made to collect emissions data from a real-world operating truck using laboratory-quality sensors. It was determined that mass air flow data would be taken from the vehicle’s data bus, exhaust temperature would be taken using a type-K thermocouple installed in the exhaust manifold, and NO_x would be measured in the combined exhaust stream. This data would be part of the data suite to be collected by the Pilot Test vehicle.

A finalized set of 106 channels of data was formulated and reviewed by DOE, the research team, and engine and modeling experts at ORNL and ANL. The list was finalized in July, 2005, and a list of these channels and their descriptions are presented in Table 1. Additional information regarding these channels is given in a more comprehensive table in Appendix A (p. A-29ff).

Table 1. Pilot Test List of Signals

Data #	Performance Measure	Benefit of the Performance Measure	Units	Scan Rate (Hz)
1	Date and Time	Time Reference	EST	100
2	Latitude	Route Identification; Mapping	deg	10
3	Longitude	Route Identification; Mapping	deg	10
4	Altitude	Route Mapping; Road Grade	deg	10
5	North Velocity	Vehicle Speed Vector	km/h	10
6	East Velocity	Vehicle Speed Vector	km/h	10
7	Down Velocity	Vehicle Speed Vector	km/h	10
8	Forward Velocity	Vehicle Speed Vector	km/h	10

Data #	Performance Measure	Benefit of the Performance Measure	Units	Scan Rate (Hz)
9	Lateral Velocity	Vehicle Speed Vector	km/h	10
10	Truck Body X Acceleration	Drive Cycle Characterization	m/s ²	256
11	Truck Body Y Acceleration	Drive Cycle Characterization	m/s ²	256
12	Truck Body Z Acceleration	Drive Cycle Characterization	m/s ²	256
13	Truck Longitudinal Acceleration	Drive Cycle Characterization	m/s ²	256
14	Truck Lateral Acceleration	Drive Cycle Characterization	m/s ²	256
15	Truck Vertical Acceleration	Drive Cycle Characterization	m/s ²	256
16	Heading Angle	Drive Cycle Characterization	deg	100
17	Pitch Angle	Describes Vehicle Body Motion, Road Grade	deg	100
18	Roll Angle	Describes Vehicle Body Motion	deg	100
19	Truck Body X Angular Rate	Describes Vehicle Body Motion	deg/s	100
20	Truck Body Y Angular Rate	Describes Vehicle Body Motion	deg/s	100
21	Truck Body Z Angular Rate	Describes Vehicle Body Motion	deg/s	100
22	Roll Rate	Describes Vehicle Body Motion	deg/s	100
23	Pitch Rate	Describes Vehicle Body Motion	deg/s	100
24	Yaw Rate	Describes Vehicle Body Motion	deg/s	100
25	Slip Angle	Difference Between Heading & COG	deg	10
26	Track Angle	Course over ground	deg	10
27	Distance Traveled	Drive Cycle Characterization	m	1
28	Outside Temperature	Drive Cycle Characterization; Aero Modeling; Wear	°F	1
29	Road Surface Temp	Wear Evaluations	°F	1
30	Wind Speed	Drive Cycle Characterization; Aero Modeling	m/s	1
31	Wind Direction	Drive Cycle Characterization; Aero Modeling	deg	1
32	Rain Accumulation	Drive Cycle Characterization	mm	1
33	Rain Duration	Drive Cycle Characterization	s	1
34	Rain Intensity	Drive Cycle Characterization	Hits/cm ² /h	1
35	Barometric Pressure	Drive Cycle Characterization; Aero Modeling	hPa	1
36	Air Temperature	Repeat Channel #28	°F	1
37	Relative Humidity	Drive Cycle Characterization; Aero Modeling	%	1
38	Longitudinal Wheel Load	Ride Input at the Wheel	lb	256
39	Lateral Wheel Load	Ride Input at the Wheel	lb	256
40	Vertical Wheel Load	Ride Input at the Wheel	lb	256
41	Overturning Moment (Mx)	ADAMS Modeling	lbf-in	256
42	Driving/braking Moment (My)	ADAMS Modeling	lbf-in	256
43	Steering Moment (Mz)	ADAMS Modeling	lbf-in	256
44	Longitudinal Wheel Force	Ride Input at the Wheel	lb	256
45	Lateral Wheel Force	Ride Input at the Wheel	lb	256
46	Vertical Wheel Force	Ride Input at the Wheel	lb	256
47	Overturning Moment (Mx)	ADAMS Modeling	lbf-in	256
48	Driving/braking Moment (My)	ADAMS Modeling	lbf-in	256
49	Steering Moment (Mz)	ADAMS Modeling	lbf-in	256
50	Longitudinal Wheel Load	Ride Input at the Wheel	lb	256

Data #	Performance Measure	Benefit of the Performance Measure	Units	Scan Rate (Hz)
51	Lateral Wheel Load	Ride Input at the Wheel	lb	256
52	Vertical Wheel Load	Ride Input at the Wheel	lb	256
53	Overturning Moment (Mx)	ADAMS (Automatic Dynamic Analysis of Mechanical Systems) Modeling	lbf-in	256
54	Driving/braking Moment (My)	ADAMS Modeling		256
55	Steering Moment (Mz)	ADAMS Modeling		256
56	Driveline Speed	VehSim Input	rpm	100
57	Driveline Torque	VehSim Input	N-m	100
58	Longitudinal Acceleration	Concept/Prototype Development		100
59	Lateral Acceleration	Concept/Prototype Development		100
60	Vertical Acceleration	Concept/Prototype Development		100
61	Wheel End Temperature	Bearing Life; Prototype Development	°F	1
62	Wheel End Temperature	Bearing Life; Prototype Development	°F	1
63	Wheel End Temperature	Bearing Life; Prototype Development	°F	1
64	Wheel End Temperature	Bearing Life; Prototype Development	°F	1
65-67	Trailer Axle Strain	Durability	uE	256
68-69	Trailer Axle Strain	Durability	uE	256
70-71	Trailer Axle Strain	Durability	uE	256
72	Steering Angle	Steering Input	Deg	10
73	Brake Treadle Pressure	Brake Application Strength	psi	10
74	Axle Oil Temperature	Axle Oil Operating Temperature Range	°F	1
75	Axle Oil Temperature	Axle Oil Operating Temperatures	°F	1
76	PDU Oil Temperature	PDU Operating Temperatures	°F	1
76	PDU Oil Temperature	PDU Operating Temperatures	°F	1
77	Transmission Temperature	Transmission Oil Operating Temperatures	°F	1
78	Engine Exhaust Temperature	System Efficiency Evaluation	°F	1
79	Engine Nox Sensor	Fuel Usage	PPM	10
80	Engine O2 Sensor	Fuel Usage	PPM	10
81	Test Equipment Power Usage	Energy Efficiency	w	1
82	Battery Current	System Efficiency Evaluation	ma	1
83	Satellites	Trailer vs. Tractor Vehicle Dynamics		1
84	Time	Trailer vs. Tractor Vehicle Dynamics		100
85	Latitude	Trailer vs. Tractor Vehicle Dynamics		10
86	Longitude	Trailer vs. Tractor Vehicle Dynamics		10
87	Velocity	Trailer vs. Tractor Vehicle Dynamics		10
88	Heading	Trailer vs. Tractor Vehicle Dynamics		10
89	Height	Trailer vs. Tractor Vehicle Dynamics		10
90	Vertical Velocity	Trailer vs. Tractor Vehicle Dynamics		10
91	Longitudinal Acceleration	Trailer vs. Tractor Vehicle Dynamics		256
92	Lateral Acceleration	Trailer vs. Tractor Vehicle Dynamics		256
93	Trigger status	Trailer vs. Tractor Vehicle Dynamics		1
94	Distance Travelled	Trailer vs. Tractor Vehicle Dynamics		1
95	Accelerator Pedal Position	Of Interest for Engine Map and Model Verification	%	10
96	Fuel Rate	Fuel Consumption Modeling Verification	L/hr	10
97	Average Fuel Economy	Fuel Consumption Modeling Verification	km/L	10
98	Gear Position	Fuel Consumption Modeling; Driver Behavior	Position	10
99	Engine Torque	Fuel Consumption Modeling	%	10
100	Actual Gear Ratio			10

Data #	Performance Measure	Benefit of the Performance Measure	Units	Scan Rate (Hz)
101	Driver's Demand Engine Torque	Fuel Consumption Modeling	%	10
102	Load at Current Speed	Fuel Usage	%	10
103	Engine Speed	Fuel Consumption Modeling	rpm	10
104	Engine Oil Temperature		°C	10
105	Fuel Temperature		°C	10
106	Vehicle Speed		km/hr	10

1.3 PILOT TEST SENSOR SUITE AND DAS

1.3.1 Procurement of Necessary Sensors and Development of Sensor Architecture

The identification of appropriate sensors to collect pilot data for identified performance measures involved collaboration between all of the project partners. The equipment used in the pilot test included the following:

Vehicle weight was obtained from the Air-Weigh 5800 (Fig. 6).



Fig. 6. Air-Weigh 5800

Weather information was collected through the Vaisala WXT510 Weather Transmitter (see Fig. 7).



Fig. 7. Vaisala WXT510

Road surface temperature was measured by the RoadWatch (see Fig. 8 and Fig. 9)



Fig. 8. RoadWatch Equipment



Fig. 9. Temperature Sensor Mounted on Side Mirror

The following figures show the NGK NO_x/O₂ sensors (Fig. 10); and the Omega exhaust gas temperature probe (Fig. 11).



Fig. 10. NGK NO_x/O₂ Sensors



Fig. 11. Omega Temperature Probe

In addition, a RaceLogic VBOX II was used to provide GPS-based information including coordinates, velocity, and acceleration.

1.3.2 Development of a Prototype Data Acquisition System (DAS).

Four different DASs were identified as potentially suitable for the Pilot Test, and the SOMAT eDAQ was specified and selected as the Pilot Test DAS (shown in Fig. 12). This system was used to benchmark the potential Field Test DASs that were tested during the Pilot Test. Several features influenced its selection for the pilot test, including its modular format, its ability to interface with a variety of sensors, the number of channels available, its ability to synchronize multiple units, and its rugged housing.



Fig. 12. SOMAT eDAQ DAS

1.3.3 Installation of the DAS Prototype and Sensors in One Long-Haul Truck

Phase 1 sensor integration onto the test vehicle took place at Dana's Tech Center in Kalamazoo, Michigan, and was completed in mid-October 2005. Further details regarding the instrumentation schedule and sensors are given in the Pilot Test Letter Report (Appendix A). Concrete ballast was also acquired to bring the test vehicle to 80,000 lbs Gross Vehicle Weight Rating (GVWR). During

this period of time, the sensors were also integrated onto the test vehicle (see Fig. 13 and Fig. 14), and shakedown testing of the test vehicle, sensors, and DAS was completed.



Fig. 13. Pilot Test Tractor (Dana's Peterbilt 379 with Caterpillar 3406e Engine)

A picture of the tractor and trailer during sensor integration is shown in Fig. 14. Additional figures showing details of the sensor integration and placement efforts appear in the Pilot Test Letter Report (Appendix A, Section 3.3.7.1).



Fig. 14. Pilot Test Tractor during Integration

1.3.4 De-instrumentation:

Following the completion of pilot testing in mid-January 2006, the test vehicle was de-instrumented at the Dana Tech. Center and all of the equipment owned or leased by ORNL was returned.

1.4 TIRES USED IN THE PILOT TEST

The Pilot Test efforts also involved the evaluation of the effect of tire type on vehicle fuel economy. Michelin provided the tires shown in Table 2 for the pilot testing efforts.

Table 2. Tire Sizes and Types

No. of Tires	Tire	Size
2	XZA3	275/80R22.5
8	XDA-HT	275/80R22.5
8	XT1	275/80R22.5
4	X-One XDA-HT PLUS	445/50R22.5
4	X-One XTE	445/50R22.5

For each of the Pilot Test routes (see Section 1.4.2 for greater detail), the vehicle was configured with standard dual tires (275/80R22.5) for the first run. On the second run, the vehicle was configured with NGSWBTs (Michelin X-One; 445/50R22.5). The routes with their associated tires are listed in Table 3.

Table 3. Tires per Route

	Steer	Drive	Trailer
Chicago-Portland #1	XZA3	XDA-HT	XT1
Chicago-Portland #2	XZA3	X-One XDA-HT Plus	X-One XTE
Maine-Miami #1	XZA3	XDA-HT	XT1
Maine-Miami #2	XZA3	X-One XDA-HT Plus	X-One XTE

Specific tire pressures were monitored and maintained throughout the Pilot Test to limit uncontrolled variables which would introduce uncertainty into the Pilot Test data collected.

1.5 DESCRIPTION OF THE PILOT TEST

1.5.1 Tractor, Trailer, and Payload

The trailer was loaded with concrete ballast and sandbags to achieve a GVWR as close to 80,000 lbs as possible without exceeding the Gross Axle Weight Rating (GAWR) for any axle. The ballast was secured with load frames and binders to prevent movement and to provide load control during testing. A steer axle weight limit of 12,000 lbs is standard on conventional 6x4 tractors, while the drive and trailer axles were loaded to the limit of 17,000 lbs per axle.

1.5.2 Description of the Routes Traveled

The Pilot Test consisted of operating the test vehicle over predetermined routes on Interstate and state highways. The routes and schedule are outlined in Table 4.

The on-road portion of the Pilot Testing took place from October 23, 2005 through January 19, 2006. This period of time included the holidays and involved considerable bad weather that caused some additional delays. The map in Fig. 15 shows the east-west route. The route traveling south is shown in Fig. 16, and the route traveling north is shown in Fig. 17. Each route was traveled twice (once with standard dual tires and once with NGSWBTs). It should be noted that the routes taken were not strictly identical, but were very similar.

Table 4. HTDC Pilot Test Routes

Route Name	Interstate	Estimated Days To Complete
Kalamazoo MI-to-Portland OR	I-80/I-84	5
Portland OR-to-Kalamazoo MI	I-84/I-80	5
Kalamazoo MI-to-Bangor ME	I-94, I-80	2
Bangor ME-to-Miami FL	I-95	6
Naples FL-to-Detroit MI	I-75	3

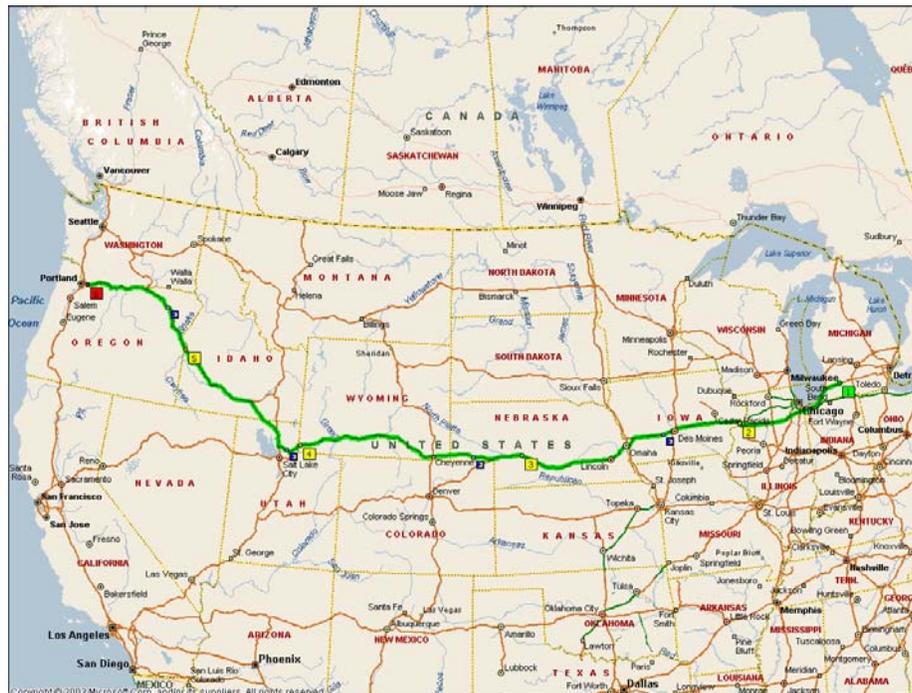


Fig. 15. Pilot Test East-West Route



Fig. 16. Pilot Test North-South Route



Fig. 17. Pilot Test South-North Route

1.5.3 Data Collected

Two Chicago-to-Portland roundtrip runs were made between October 23, 2005, and November 19, 2005. For the first dataset (collected during the period of October 23 - November 2, 2005), the truck was mounted with standard dual tires; for the second dataset (November 7 – November 18, 2005) the truck was outfitted with NGSWBTs. During the two round trips 8,500 miles were covered and 220 hours of driving were logged. More than 24 gigabytes of data were collected and saved to DVD. It should be pointed out that both runs involved the same tractor, trailer, payload, and driver. The timeframe and routes taken were not strictly identical, but were very close.

The first Maine-to-Tampa-to-Detroit run ended December 14, 2005. Due to weather delays and truck maintenance, this run took 14 days to complete. This run utilized the NGSWBTs and logged 4,581 miles, 114.5 hours of driving, and generated approximately 12 gigabytes of data.

The final route (Maine-to-Orlando-to-Detroit) of the Pilot Test was completed on Thursday, January 19, 2006. This run utilized standard dual tires on the tractor and trailer and logged 4,616 miles of driving, 90 hours of operation, and generated approximately 11 gigabytes of data taken over a ten-day period.

1.5.4 Analyses and Results of the Pilot Test

1.5.4.1 Pre-analysis efforts

As the pilot testing efforts were being initiated in October 2005, the ORNL staff readied itself for the data analysis efforts. One of the main challenges was the extraction of data from the eDAQ software and its subsequent translation into a spreadsheet or database that would be directly usable by the ORNL staff. After contacting eDAQ staff, the eDAQ Application Programming Interface (API) was obtained which provided ORNL the capability to program the necessary procedures to extract the relevant data from the project data files without the need for significant human intervention. Without this capability, the process would have been very time-consuming especially in light of the extremely large datasets that were generated. Once the ORNL staff became familiar with the API, a signal extraction strategy for the data sets was developed.

ORNL felt that it was important that ANL be kept in the loop regarding the Pilot Test data collection effort, and that current versions of PSAT and associated software be available at ORNL. In November 2005, ORNL installed and tested new versions of Matlab, Simulink, and PSAT. The ORNL staff also met with Dr. Aymeric Rousseau (ANL) at the NTRC to discuss avenues for collaboration including the sharing of the pilot and field test data. In December 2005, ORNL provided a copy of one DVD Pilot Test data disk to Dr. Rousseau for coding and input into PSAT.

1.5.4.2 Pilot Test data

In December 2005, ORNL received two sets of data (consisting of ten DVDs per set) collected on the Chicago-to-Portland-to-Chicago runs. Each set of data consisted of more than 100 channels of information which amounted to more than 15 GB per set. ORNL read the information using the InField software provided by the manufacturer of the data collection equipment (eDAQ) and was able to export selected data to other formats for more extensive analyses. This was done manually, since the databases generated by eDAQ use a proprietary compression algorithm which, while minimizing disk space, does not lend itself easily to data processing. These sample subsets were mapped using Microsoft MapPoint and a number of errors in the database were discovered (e.g., problems with the

GPS information collected with the VBOX equipment, and a few problems with the data stream [especially at the beginning of each data collection period]).

1.5.4.3 Mapping utility

As the Pilot Test data was received, ORNL began the development of a mapping utility that would allow users to access, in a geo-spatial manner, the information collected during the runs. This tool allowed the user to select a certain portion of the data on the map, to view the data for that selected area in a graphical form, and to export the information to other formats (e.g., Excel) for further analyses. This tool was essential for the data analysis task and provided the basis for the DCGenT.

1.5.4.4 Data analyses

The data analyses efforts for the Pilot Test were focused on the demonstration of the capability of generating usable duty cycles for input into PSAT, based on the data collected in the Pilot Test. In addition, the ORNL staff also looked for interesting long-haul characterization statistics including fuel usage vs. tire configuration, emission profiles, etc. The results of the data analyses efforts were presented in the Pilot Test Letter Report (Appendix A, Section 3.3.7). A number of lessons learned came from the Pilot Test efforts. These included the following:

- A DAS should be selected on the basis of its ability to store data in an easily extractable format.
- Accurate and reliable time stamping is of critical importance for data analyses and comparison purposes.
- An indicator should be provided for those periods in which data is inadvertently not collected for various technical reasons. This indicator should explicitly tell when data is missing so that the analysis will not have to infer such information. Without such an indicator, data synchronization would be a problem.
- The collection of data can be done at a rate that is much less than 100 Hz. A rate of two-to-ten Hz is felt to be sufficient.
- The data collection rate should be the same for all performance measures.
- Data handling and processing, especially with extremely large data sets, were found to be extremely resource-intensive and therefore need to be appropriately accounted for in the project planning.

2. FIELD OPERATIONAL TEST

The primary objective of the HTDC Project was to collect real-world performance and situational data for long-haul operations of Class-8 trucks from a fleet engaged in normal freight operations. It was desirable for the selected fleet to cover a wide variety of geography and to engage in the FOT for at least one year to ensure that seasonal data is collected. The collected data will support the development and evaluation of the Class-8 module of PSAT, and as such needs to incorporate a rich source of information beyond velocity and time (basic duty cycle data). In particular, other types of information of interest pertain to the engine/vehicle performance, fuel consumption, road conditions, weather, and congestion. Data not collected included aerodynamics, emissions, rolling resistance, and driver performance. Much of the data was accessible through the vehicle's databus, but some additional sensors were added as well. The FOT was done in partnership with Michelin and Schrader, and involved attention to the impact of tires on fuel efficiency. The analysis of the fuel efficiencies in the FOT is presented in Section 6.

The FOT resulted in data (60 channels) from six instrumented tractors and ten instrumented trailers, taken at 5 Hz for at least 12 months. Data was collected for nearly 700,000 vehicle-miles traveled and involved more than 200 gigabytes of data. Dynamometer (dyno) testing was conducted on one of the instrumented vehicles at West Virginia University (WVU) in Morgantown, West Virginia in order to obtain drive torque data, which was not collected during the field test. For the dyno testing, three duty cycles were addressed including one that was generated by the vehicle engaged in the dyno testing while it was engaged in the field testing. In addition, fuel consumption and emissions data were collected during dyno testing, and the fuel consumption data from the field test for the selected duty cycle will, in the future, be compared to the fuel consumption from the dyno test for the same duty cycle.

Two major software tools were developed by ORNL to be used in conjunction with the data collected during the FOT. The DCGenT was developed to generate duty cycles based on the collected data, and based on characteristics selected by the user (e.g., road grade, time-of-day, type of highway, road condition, weather, etc.). This tool also allows the user to specify the desired length of the duty cycle, and generates them in a format that is directly usable by PSAT. The DCGenT is available to users through arrangements made with the project staff at ORNL. The second tool, called simply the HTDC data access tool, allows analysts to specify duty cycle characteristics within a Boolean "OR" structure to generate a set of files for future analyses. DOE will determine how non-DOE or non-ORNL staff can have access to the HTDC data access tool.

Data analyses associated with the use of standard dual tires vs. NGSWBTs were conducted by the ORNL staff. Overall, at least 6% fuel savings was experienced when NGSWBTs were utilized on either the tractor or the trailer. More than 9% fuel savings was experienced when the tractor and trailer had NGSWBTs compared to the tractor and trailer with standard dual tires. When tractors and trailers that both had NGSWBTs were compared to tractors and trailers both having standard duals, and the comparison was made across low-, medium- and high-payloads, the NGSWBTs provided more than a 10 % fuel savings for the high-payload cases.

The HTDC database is unique in the depth and breadth of data collected on Class-8 long-haul operations, and in the capability to generate real-world-based, Class-8, long-haul duty cycle and performance data. The following sections provide greater details of the FOT efforts.

2.1 REVIEW OF PERFORMANCE MEASURE REDUCTION BASED ON PILOT TEST EXPERIENCE

As a result of the lessons learned in the execution of the Pilot Test and its associated data analyses, several changes were made to the data collection methodology for the FOT. First, it was determined that all signals would be read at a single sampling rate to facilitate the processing of the data; a rate of 5 Hz was considered to be sufficient for all of the chosen signals without needlessly increasing the size of data files. Second, ORNL contracted with SoMat to create software which would include a time-stamping feature in the data file. ORNL also contracted with SoMat to develop software to automatically convert the data from the proprietary SIF file format (i.e., the format in which it is saved) to a standard ASCII file format, (i.e., the format read by most data processing software) after the file was uploaded from the eDAQ. In order to facilitate early diagnosis of problems associated with sensors (e.g., loose connections, faulty cabling, and normal wear of parts), the data was downloaded frequently, at intervals of approximately two weeks. In order to troubleshoot/debug minor problems during the sensor suite development stage, the equipment was initially put on a single truck and the data downloaded frequently before the actual start of the FOT.

The list of channels collected was paired down from 106 (the number of channels addressed in the Pilot Test) to 60 channels. An informal literature review and discussions with subject matter experts were conducted to identify the channels of importance for duty cycle applications, fuel efficiency analyses, and engine modeling. The finalized list addressed in the FOT appears in Table 5 (Section 2.3.2).

2.2 COORDINATION WITH ANL AND LLNL

2.2.1 Aerodynamics Data

In August 2006, about two months before the formal initiation of the FOT, Lawrence Livermore National Laboratory (LLNL) contacted the ORNL project staff to discuss the possibility of collecting aerodynamics data during the FOT. After a number of conference calls, it was concluded that it was not feasible to collect the aerodynamics data of interest; however, collection of the wind velocity and direction from the on-board weather station would be of interest. The reasons for not collecting aerodynamics data included the following:

- The addition of pressure ports to the tractor-trailer was considered to be too invasive for the volunteer fleet (Schrader),
- Acquisition of the aerodynamics equipment needed and adding it to the tractor-trailers could not be achieved without impacting the scheduling of the initiation of the FOT, and
- DAS channels were not available to facilitate adding aerodynamics data to the channel suite. An additional data layer at approximately \$2,000 per layer would have had to have been added to each of the six DASs. ORNL project funding was not available to add these layers.

2.2.2 ANL/PSAT Coordination and Dynamometer Testing

One of the primary purposes of the FOT was to collect real-world performance and situational data that could support the development and evaluation of the Class-8 PSAT module being developed by ANL. During the Pilot Test, the list of 106 channels of data was reviewed by ANL to ensure that PSAT modeling needs were being met. For the FOT, the list of channels was again reviewed by ANL PSAT experts to ensure that as the list was reduced from 106 to 60, that data that was important for PSAT was not eliminated from the list.

Near the end of the FOT, ANL indicated that a major parameter that was needed for PSAT was not being collected during the FOT. This parameter was the tractor's drive torque. Although engine torque was collected, drive torque was necessary because it reflected the losses between the engine and the turning of the drive axles. It was concluded that drive torque could be collected on one of the trucks running selected duty cycles (including one or more duty cycles from the FOT) on a heavy truck dyno. One of the test trucks was taken to WVU for dynamometer testing. This testing provided torque and emissions data to be used to verify ANL's PSAT Model. This testing is outlined in Section 5. While ANL was primarily interested in the raw data from the testing, some analyses were also performed. WVU's report for this testing, which includes detailed information about the test set-up as well as a complete description of the duty cycles tested, is presented in Appendix E.

2.3 CONSTRUCTION AND SHAKEDOWN TESTING OF THE FOT DAS SUITES

Phases 2 and 3 of the project involved the instrumentation of six Class-8 long-haul tractors and ten trailers with a suite of sensors/DAS for use within the FOT. The purpose of this instrumentation was to collect, store, and transfer signals related to the vehicle's duty cycle, performance, and situation.

2.3.1 Field Test DAS

For the FOT, the following DAS were initially considered:

Racelogic VBOX III	http://www.racelogic.co.uk/vbox/
Iotech Logbook	http://www.iotech.com/catalog/daq/logbook.html

In November 2005, the initial FOT DAS and instrumentation suite was identified and verified as the Somat eDAQ-lite DAS, the Vaisala WXT510 weather station, the vehicle's own J1939 data bus, and the Racelogic VBOX II-Lite GPS. During the FOT, the vehicle data bus and the VBOX II-Lite were connected to the DAS via a Controller Area Network CAN data module, and the WXT510 was connected via serial port. The Air-Weigh system was connected to the eDAQ-lite via a J1708 vehicle bus module (see Fig. 18).

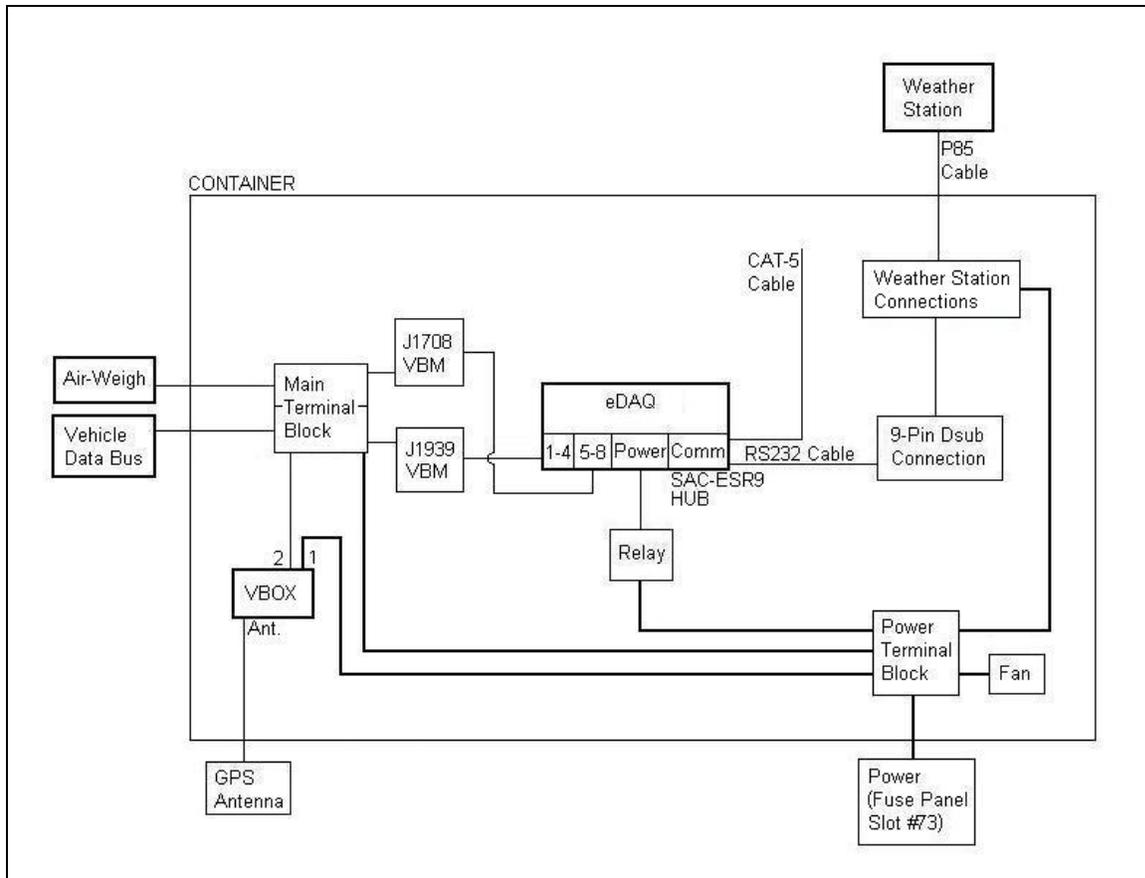


Fig. 18. Wiring Overview for FOT DAS

2.3.2 Performance Measures

A variety of metrics were identified as being necessary to support drive cycle and modeling needs pertaining to the test vehicles. The importance of the signal in supporting project objectives, cost, sensor survivability, and practicality of implementation were all considered in deriving the list of signals for the FOT, shown in Table 5.

Table 5. FOT Measures of Performance and Associated Sensors

	Signal	Sensor
1	Instantaneous Fuel Economy	J1939 Vehicle Data Bus
2	Average Fuel Economy	J1939 Vehicle Data Bus
3	Fuel Rate	J1939 Vehicle Data Bus
4	Total Fuel Used	J1939 Vehicle Data Bus
5	Total Idle Fuel Used	J1939 Vehicle Data Bus
6	Current Gear	J1939 Vehicle Data Bus
7	Selected Gear	J1939 Vehicle Data Bus
8	Output Shaft Speed	J1939 Vehicle Data Bus
9	Actual Engine - Percent Torque	J1939 Vehicle Data Bus
10	Actual Gear Ratio	J1939 Vehicle Data Bus

	Signal	Sensor
11	Driver's Demand Engine - Percent Torque	J1939 Vehicle Data Bus
12	Percent Load at Current Speed	J1939 Vehicle Data Bus
13	Engine Speed	J1939 Vehicle Data Bus
14	Engine Oil Temperature	J1939 Vehicle Data Bus
15	Fuel Temperature	J1939 Vehicle Data Bus
16	Front Axle Speed	J1939 Vehicle Data Bus
17	High Resolution Total Vehicle Distance	J1939 Vehicle Data Bus
18	Accelerator Pedal Position	J1939 Vehicle Data Bus
19	Total Idle Hours	J1939 Vehicle Data Bus
20	Maximum Vehicle Speed Limit	J1939 Vehicle Data Bus
21	Total Power Takeoff Hours	J1939 Vehicle Data Bus
22	Clutch Switch	J1939 Vehicle Data Bus
23	Brake Switch	J1939 Vehicle Data Bus
24	Cruise Control Enable Switch	J1939 Vehicle Data Bus
25	Cruise Control Active	J1939 Vehicle Data Bus
26	Cruise Control Accelerate Switch	J1939 Vehicle Data Bus
27	Cruise Control Resume Switch	J1939 Vehicle Data Bus
28	Cruise Control Coast Switch	J1939 Vehicle Data Bus
29	Cruise Control Set Switch	J1939 Vehicle Data Bus
30	Battery Electrical Potential (Voltage)	J1939 Vehicle Data Bus
31	Tractor Drive Axles Weight	Air-Weigh
32	Tractor Steer Axle Weight	Air-Weigh
33	Trailer Weight	Air-Weigh
34	Tractor Serial Number	Air-Weigh
35	Trailer Serial Number	Air-Weigh
36	Latitude	VBOX
37	Longitude	VBOX
38	Altitude	VBOX
39	Vertical velocity	VBOX
40	Velocity over ground	VBOX
41	Longitudinal acceleration	VBOX
42	Lateral acceleration	VBOX
43	Heading	VBOX
44	Satellites	VBOX
45	Time UTC	VBOX
46	Wind Speed	Weather Station
47	Wind Direction	Weather Station
48	Rain Intensity	Weather Station
49	Barometric Pressure	Weather Station
50	Air Temperature	Weather Station
51	Relative Humidity	Weather Station
52	Tire Flag	Calculated from Air-Weigh data

	Signal	Sensor
53	Road Grade	Calculated from VBOX data
54	Placeholder B	none
55	Placeholder C	none
56	Placeholder D	none
57	Placeholder E	none
58	Stationary Latitude	Calculated from VBOX data
59	Stationary Longitude	Calculated from VBOX data
60	Tractor-Trailer Marriage	Calculated from Air-Weigh data

The purpose of the placeholders (signals 54-57 from 6) was to accommodate necessary changes to the signals during the debugging stage without requiring major changes to data analysis software that was also under development during that stage.

2.3.3 Sensors

The signals listed in Table 5 were obtained from a variety of autonomous sensor systems. Table 5 also lists the sensor system which provided each signal, shown in Fig. 19 through Fig. 22. The weather station (Fig. 21) was not tested in a wind tunnel to determine accuracy when used in non-static applications.

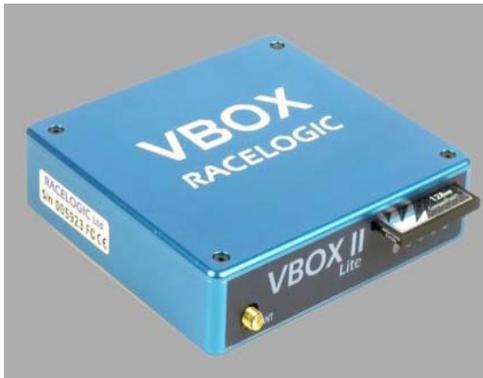


Fig. 19. VBOX II Lite



Fig. 20. Air-Weigh Scale



Fig. 21. Vaisala Weather Station



Fig. 22. J1939 Vehicle Data Bus Connector

2.3.4 Data Acquisition System

The SoMat eDAQ-lite data acquisition system shown in Fig. 23 was used to capture data from the sensors called out in Section 2.3.2.



Fig. 23. SoMat EDAQ-lite DAS

2.3.5 Test Vehicles

Schrader provided access to six 2005 Volvo VNL tractors, along with ten trailers for use in the FOT. These vehicles were instrumented with the DAS and sensor suite, and then continued in their normal vocational operations. A typical Schrader truck used in the FOT is shown in Fig. 24.



Fig. 24. Schrader Truck

2.3.6 Tractor and Trailer Details

Table 6 and Table 7 contain information regarding the test vehicles. To minimize the complications arising from the use of different data buses, all trucks chosen to participate were of the same make and model (Volvo VNL 2005). To maximize the usefulness of the data collected in the FOT, the vehicles chosen represent two transmission types (manual and auto-shift) and three different tire types.

Table 6. Test Truck Information

DAS	Transmission	Tire Type (Drive Axles)	Tire Model
1	Manual	NGSWBTs	445/50R22.5 XOne XDA
2	Manual	Duals*	275/80R22.5 XDN2
3	Auto	NGSWBTs	445/50R22.5 XOne XDA
4	Manual	Duals**	275/80R22.5 XDA5
5	Auto	NGSWBTs	445/50R22.5 XOne XDA
6	Auto	Duals**	275/80R22.5 XDA5
Steer tires for all test trucks			275/80R22.5 XZA3

* Newly-mounted tires provided by Schrader Trucking for the FOT.

** New Michelin dual tires provided for the FOT.

Table 7. Test Trailer Information

Trailer	Test Tire Type*	Suspension	Tire Model
1	Duals	VANTRAAX.4742 HKA180-16	275/80R22.5 XT-1
2	Duals	VANTRAAX.4742 HKA180-16	275/80R22.5 XT-1
3	Generic Duals	VANTRAAX.4742 HKA180-16	Dual Retreads
4	Generic Duals	VANTRAAX.4883 HKA180-16	Dual Retreads
5	Generic Duals	VANTRAAX.5431 HKA180-16	Dual Retreads
6	NGSWBTs	slider suspension # HKANT 40 K	445/50R22.5 XOne XTA
7	NGSWBTs	slider suspension # HKANT 40 K	445/50R22.5 XOne XTA
8	NGSWBTs	slider suspension # HKANT 40 K	445/50R22.5 XOne XTA
9	NGSWBTs	slider suspension # HKANT 40 K	445/50R22.5 XOne XTA
10	NGSWBTs	slider suspension # HKANT 40 K	445/50R22.5 XOne XTA
* “Duals” denotes new Michelin dual tires provided for the FOT; “Generic Duals” identifies the tires on the tractor before the FOT, that were to remain on the tractor during the FOT.			

2.3.7 Instrumentation Details

The equipment included in the first DAS (i.e., DAS 1) of six, is called out in Table 8. A more exhaustive list that details each DAS individually is presented in the FOT Test Plan (Appendix D, Section 4.6).

Table 8. Equipment for DAS 1

TTG HTDC FTS Unit 1, Manual Transmission, X-One Tires		
Instrument	Serial Number	Currently Installed Firmware/Software Rev # and Date
VBOX	006868	VBOXTools 1.2.1 (Build 090), Firmware 2.0.1 (Build 90)
eDAQ	0315	TCE V3.8.6d (17Jul 2006), MPB - V3_8_6d(V4.3d); Power - V2.2; DIO_1 - V1_2; Vaisala WXT
Weather Station	B2140054	Vaisala Configuration Tool Version 2.00 r.2
CAN Module	EMCAN.03-0469	V2.0, Checked 7/10/2006
J1708 Module	EMLIN.01-0185	V2.0, Checked 7/10/2006
Air-Weigh Truck Comlink	10004649	Identifier: 43177 (16 Least Significant Bits of SN)
Air-Weigh Display	4399	Calibration: Steer: Ratio 3.1267, Offset 7341. Drive: Ratio 17.862, Offset 25.

2.4. ISSUES RESOLVED DURING SENSOR SUITE DEVELOPMENT

2.4.1 Tilt Sensor and Grade Data

Analysis of results from the Pilot Test indicated that the height channel given by the VBOX was inaccurate. Rather than smooth transitions to different heights as would be representative of actual topography of a road surface, time plots of the data showed discontinuities. For the FOT, the use of a separate tilt sensor was pursued to provide accurate grade data.

A single Posital CAN-based tilt sensor was secured for testing with the idea that the CAN-based interface would allow the sensor to connect directly into the test truck’s CAN (J1939) databus along with the VBOX, eliminating the need for expensive additions to the DAS. However, after numerous attempts to connect with the eDAQ unit (including attempts by an engineer from SoMat), it was

determined that the particular CANopen protocol used by the Posital device was incompatible with the standard CAN protocol used by the eDAQ.

After additional efforts, it was determined that no suitable CAN-based tilt sensor was available on the market. As a result, an analog tilt sensor was ordered in addition to an analog layer for the eDAQ. The AccuStar IP-66 tilt sensor was connected to the eDAQ and communication was successfully established. The unit functioned as expected during benchtop testing, and further testing in a passenger vehicle was conducted. During this testing, it was noted that in periods of acceleration and deceleration, the vehicle's tilt did not give a consistent indication of road grade. This occurred because during those events, the vehicle did not remain parallel to the ground. It was assumed that this phenomenon may be less noticeable on a Class-8 trailer. The research team subsequently focused on examining vibration issues. Since the vehicle vibrated at a frequency of approximately 2-3 Hz, and the sample rate for all signals for the FOT was to be 5 Hz, the effect of this vibration was such that at this sampling rate, it could not be filtered out in post-processing. As a result, it was determined that the vibration of the vehicle could be an insurmountable problem with the use of a tilt sensor, and as a result, a discrete tilt sensor was not selected for use in the FOT.

Once it was realized that the use of a tilt sensor would not provide the needed tilt data, height data (Z-data) from the VBOX was reconsidered to determine if this data could be used to provide the needed grade data. It was discovered that although the VBOX height data was inaccurate, reasonable grade data could be obtained from the information collected over short intervals of time. Given the repeatability of routes over the course of the year-long data collection, it was surmised that sufficient data could be obtained from the VBOX for each point along the route to build a complete set of grade information from these "short intervals" for well-traveled roads.

2.4.2 Obtaining Identifier from Instrumented Trailers

The majority of long-haul fleets in the U.S. use a "drop-and-hook" operation, in which freight is delivered to a terminal, drop lot, or customer; and the tractor returns to its point of origin with a totally different trailer. Thus, a given trailer is rarely connected to the same tractor again, or at best, very infrequently. Because a 100% mating rate was impossible to achieve, vehicle identifiers were needed in order to link the identity of the tractor and trailer(s) that were providing data, to the actual tire type utilized by the trailer. One initial setback was the inability to get vehicle identification information from the tractor or the trailer. This problem was solved by getting a portion of the Air-Weigh serial number from the J1708 bus for the situations in which the test truck was connected to one of the instrumented trailers. Each Air-Weigh unit (one on the tractor and another on the trailer) has a unique serial number which can be requested through the appropriate request code on the J1708 databus used by the Air-Weigh for communication. The value read from the databus in response to this request is then looked-up in a file created on the eDAQ, and this data is saved with the appropriate code to indicate the specific trailer, and hence, the types of tires used on the trailer. For all of the other trailers (i.e., un-instrumented trailers), Schrader provided ORNL with a weekly schedule of which trailers were connected to the test tractors. A separate lookup table was also provided in which the tire type of each Schrader trailer was listed. Although the weight information for these un-instrumented trailers was not available, this did allow the addition of trailer tire type information to the collected data through post-processing.

2.5 PARTNERSHIP BUILDING

Field tests tend to be relatively expensive when compared to laboratory-based research. Because of this, significant effort was directed toward leveraging the needs of this project with industry

partnerships and with cooperative efforts with other federal agencies. The industry participation in this Program is valued in the multiple-hundreds-of-thousands of dollars.

2.5.1 Dana

With regard to industry participation, ORNL partnered with Dana which generously provided engineering support for instrumentation integration, instrumentation to generate vehicle dynamics data, and provided access to the Dana Truck Fleet (DTF) which was used in the Pilot Test portion of the Project. This partnership significantly reduced the Phase 1 costs to DOE.

2.5.2 Michelin

Michelin also provided resources for the Pilot Test and continued as a partner during the FOT. Michelin provided new standard dual tires for half of the Pilot Test runs, and NGSWBTs for the other half of the runs. For the FOT, they provided new NGSWBTs and dual tires used for five of the six instrumented tractors and two of the instrumented trailers. Michelin's interest in the testing activities involved the energy efficiency effects of NGSWBTs vs. standard dual tires. Such information is useful in contributing to the modeling and understanding of heavy truck rolling resistance.

2.5.3 Schrader

Initially, the test team experienced difficulty in locating a suitable fleet partner with all of the following characteristics:

- Long-haul operations that spanned the continental US (rather than just regionally), in order to obtain duty cycle data for a variety of terrains and road types
- Mated tractors and trailers (mostly drop-and-hook) – so that weight sensors can be installed on the trailer as well as the tractor in order to obtain weight data for all of the miles traveled
- Usage of NGSWBTs acceptable – for comparison of singles and duals

Ultimately, a partnership was formed with Schrader Trucking. While Schrader did not appear to meet every one of the desired criteria, their interest in new technology and strong desire to assist the testing team allowed for novel solutions for accommodating the needs of the FOT. Schrader trucks travel throughout the eastern U.S. and occasionally even as far west as California. Details of the routes taken by the instrumented Schrader trucks are provided in Section 6 of this report. Several Schrader tractors were already using NGSWBTs, along with over a quarter of their trailers. While Schrader runs primarily a drop-and-hook operation, they own their own trailers which means that although the tractor-trailers are not married, the tractors are pulling a quantifiable pool of trailers. Schrader made all tractor and trailer mating records available to ORNL on a weekly basis, along with a database indicating the tire type of each trailer. As a result, although there were a limited number of trailers that were instrumented, the data obtained from each DAS could be linked to a particular trailer type based on the data provided by Schrader.

2.6 INSTRUMENTATION OF THE FLEET

2.6.1 Sensor and DAS Integration into the Test Vehicles

The test vehicles called out in Section 2.3.6 were fitted with the sensors listed in Section 2.3.7 (the J1939 Vehicle Data Bus already existed on the vehicle). The sensor-to-test-vehicle integration took place at the Schrader truck yard in Jefferson City, Tennessee.

Cable runs to and from sensors were routed in a manner to allow for sustained testing and occupant safety. Consideration was given to shielding these cables from engine/exhaust heat as well as damage from objects thrown from the roadway. The step-by-step integration process is described in the System Installation section of the System Design and Operations Document (SDOD – see Appendix D, Section 6).

2.6.2 Sensor/DAS Verification and Calibration

All sensors, cabling, and the DAS were verified for operation after the initial integration. This verification took place at the Schrader truck yard. Verification information is included in the Operational Procedures section of the SDOD (Appendix D, Section 8).

2.7 LAUNCH OF THE FOT (OCTOBER 23, 2006)

A MOU signing and media event was held on Monday, October 23, 2006 at the National Transportation Research Center (NTRC). Signing of the MOU was accomplished between DOE (signing by Mr. Lee Slezak, DOE OVT Technical Manager for the HTDC Project), ORNL (signing by Dr. Dana Christensen, ORNL Associate Laboratory Director for Energy and Engineering Sciences Directorate), and Schrader Trucking (signing by Mr. Phil Schrader and Tom Hodge, Owners). Representatives from Michelin (Ms. Sue Nelson) and Argonne National Laboratory (Mr. Glenn Keller) were also present. Good coverage of the event was provided by local media, with front page articles appearing in the *Oak Ridger* and the *Knoxville News Sentinel* and feature stories on two local TV stations. Images from this event are shown in Fig. 25 through Fig. 27.



Fig. 25. (L – R) Dr. Dana Christensen (ORNL) , Mr. Phil Schrader (Schrader Trucking), Mr. Bill Knee (ORNL), Mr. Tom Hodge (Schrader Trucking), and Mr. Lee Slezak (DOE)



Fig. 26. Mr. Ronnie Osborn (Driver for Schrader) and Mr. Tom Hodge (Co-Owner, Schrader) at the HTDC Media Event (October 23, 2006)



Fig. 27. Ms. Sue Nelson (Michelin) Shows the X-One New Generation Single Wide-Based Tire (NGSWBT)

2.8 CONDUCTION OF FOT

The FOT lasted 12 months and required ongoing involvement of the test team in regular data collection, equipment maintenance, and preliminary data analysis to diagnose sensor problems.

2.8.1 Upload Procedure

Data collected during the FOT was uploaded periodically from each test vehicle onto an ORNL project computer. An ORNL staff member would travel from Knoxville, Tennessee, to Jefferson City, Tennessee, a distance of about 50 miles (one-way), and would upload the collected data from the DAS of each of the instrumented tractors in the Schrader truck yard. Typically, all of the tractors would return to Jefferson City for the weekend which provided a good opportunity to upload the collected data. Initially, data was uploaded weekly in order to quickly diagnose and correct instrumentation and configuration problems early in the FOT. After several weeks of regular uploads without encountering any major problems with the instrumentation suite, data was uploaded approximately every two weeks. This procedure included verifying that the sensors were working, uploading the data, and archiving the data to prevent data loss. This procedure is detailed in the SDOD (Appendix D, Section 8.2.1). On several occasions, a tractor would not be available at the Schrader truck yard over the weekend. There was sufficient capacity in the DAS memory to allow about a month's worth of data to be collected between data uploads.

2.8.2 Issues Encountered during the FOT

During the FOT, the majority of the equipment functioned as expected. Preliminary testing of each DAS allowed most of the problems to be discovered and resolved before the actual FOT. The problems which were not foreseen during the early stages of the testing involved the long-term nature of the project which could not be simulated prior to the start of the FOT.

On several occasions, the weather stations ceased to generate data, and were found to have been water-damaged in use. After the weather stations were repaired, they were mounted at a different location in order to avoid the damage that had been experienced. The weather stations were mounted on the driver's side mirror rather than the front mirror. After re-deploying, water damage to the weather station was experienced again. Upon further investigation, it was discovered that all of the Schrader trucks were being power-washed regularly, and that this power-washing damaged the weather stations. It was requested that Schrader personnel cover the weather stations during washing, and by doing so, no further water-related weather station problems were encountered for the remainder of the FOT.

Technical difficulties were also encountered with the VBOX. For several data collection periods, no data was being reported by the VBOX. Upon investigation, the problem was found to be the result of failing antennas, again from water infiltration. This problem was corrected by replacing the antennas on the failing units and restarting the VBOX. Because the channels were checked each time the data was uploaded, this problem was identified and corrected soon after deployment, resulting in a minimum loss of data. It is not clear if the water infiltration was due to the pressure washing of the Schrader trucks or from normal exposure to rain at highway speeds.

2.8.3 Test Routes

Because the FOT resulted in the collection of an entire year's worth of data for six test trucks, the data included a variety of weather conditions and terrain. A description of the routes traveled, along with interesting duty cycles obtained in the FOT, appear in Section 6, Data Analysis.

2.8.4 De-instrumentation

Upon the completion of the FOT, the six test vehicles were de-instrumented from October 27, 2007, to February 16, 2008. This involved the removal of all DAS components and wiring with the exception of the Air-Weigh, which remained on each test vehicle. In accordance with the MOU, the tires supplied for the FOT remained with the test vehicles as well. Mounting brackets for the weather stations were removed, and the holes that had been drilled to accommodate wires were filled.

3. INTERNET DATA ACCESS TOOL

The HTDC Internet Data Access Tool provides access to a web-based catalog of archived data files of heavy-truck operations in real-world driving environments. This tool allows the user to retrieve data collected during the FOT. The application has the capabilities to locate and summarize data files for downloading purposes based on user-selected parameters.

3.1 PURPOSE

This application (Fig. 28) was developed to provide data mining capabilities of the extensive data set collected during the FOT. This tool enables the user to search the database for parameters to extract data meeting certain criteria (e.g., road conditions, tire type, road grade, weather conditions, etc.), and download the zip files for analysis.

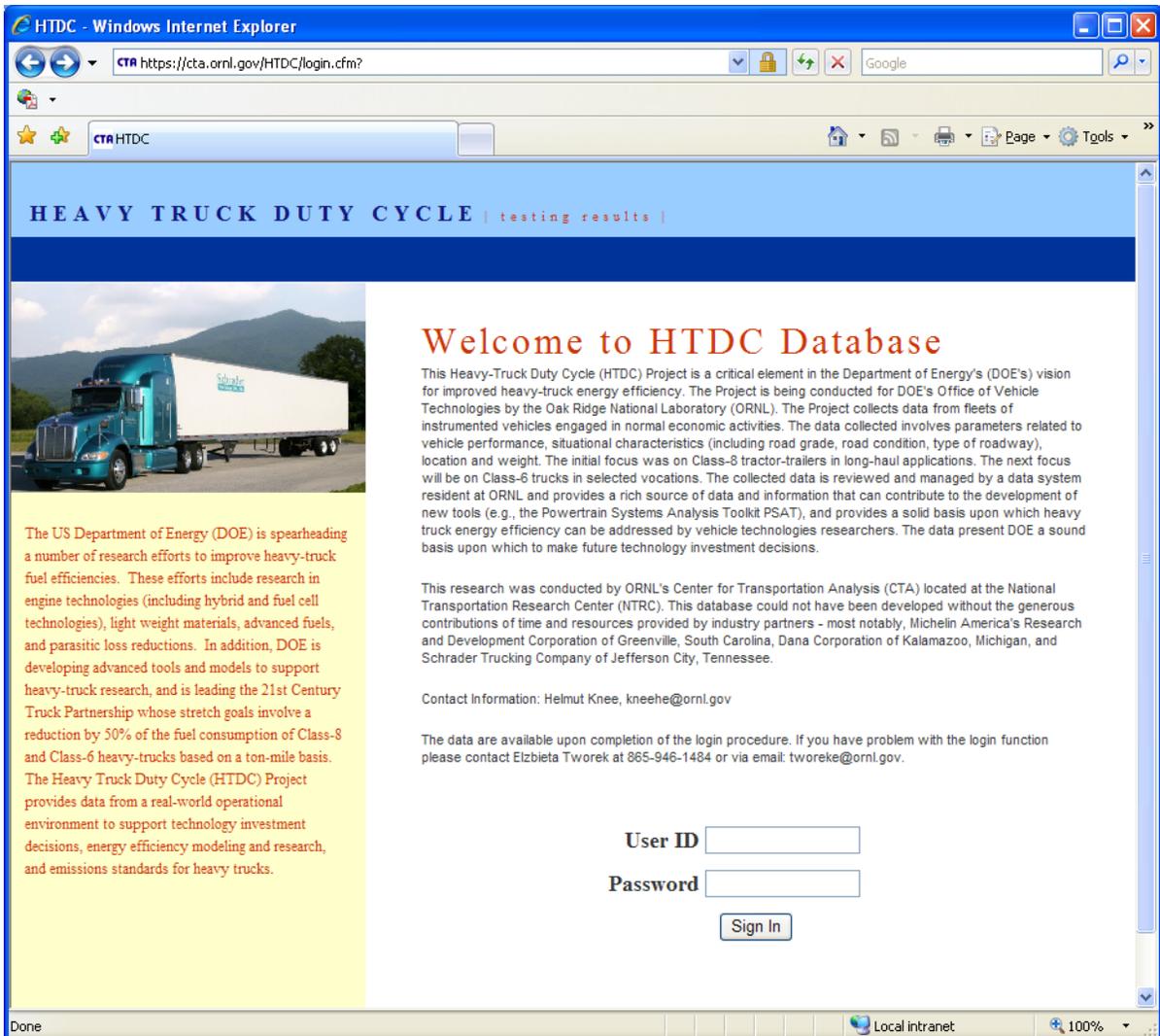


Fig. 28 HTDC Internet Data Access Tool Home Page

3.2 HOW TO ACCESS THE TOOL

The HTDC data can be accessed by logging in at <https://cta.ornl.gov/HTDC/login.cfm>.¹ Several lists of search criteria will appear (Fig. 29), allowing the user to select any of several data characteristics. Some of these options are related to the vehicle, such as tire type and vehicle weight. There are also geographic criteria including state and topography. Road conditions can also be selected, including time-of-day (recurring road congestion), weather conditions, and road class. For the user interested in data which contains a certain type of travel, movement type and/or operation, speed could also be selected. Multiple selections can be made under each section by pressing “Ctrl” while clicking on more selections or pressing “Shift” while clicking to select an entire block of values.

HEAVY TRUCK DUTY CYCLE | testing results |

WELCOME TO THE FILE SEARCH APPLICATION **SIGN OUT**

MAIN SEARCH CRITERIA SECTION

Hours of operation <input type="checkbox"/> Any <input type="checkbox"/> Early morning (12AM - 6:30AM) <input type="checkbox"/> Morning (6:30AM - 9:30AM) <input type="checkbox"/> Late morning (9:30AM - 12PM) <input type="checkbox"/> Middle day (12PM - 2PM) <input type="checkbox"/> Afternoon (2PM - 3:30PM) <input type="checkbox"/> Late afternoon (3:30PM - 7PM) <input type="checkbox"/> Evening (7PM - 12AM)	Topography <input type="checkbox"/> Any <input type="checkbox"/> Sev Dn Slope< -4% <input type="checkbox"/> Mild Dn Slope -4% to -1% <input type="checkbox"/> Flat Terr -1% to -1% <input type="checkbox"/> Mild Up Slope 1% to 4% <input type="checkbox"/> Sev Up Slope> 4% Instrumented vehicle <input type="checkbox"/> Any <input type="checkbox"/> Both Tractor & Trailer	Operation speed <input type="checkbox"/> 0 - 10 mph <input type="checkbox"/> 10 - 20 mph <input type="checkbox"/> 20 - 30 mph <input type="checkbox"/> 30 - 40 mph <input type="checkbox"/> 40 - 65 mph <input type="checkbox"/> 65+ mph	Truck's movement type <input type="checkbox"/> Any <input type="checkbox"/> Stationary <input type="checkbox"/> Constant speed <input type="checkbox"/> Accelerating <input type="checkbox"/> Decelerating	Truck weight <input type="checkbox"/> Any <input type="checkbox"/> Weight less 24,000lbs <input type="checkbox"/> Weight between 24,000-44,000lbs <input type="checkbox"/> Weight between 44,000-62,000lbs <input type="checkbox"/> Weight between 62,000-80,000lbs	States <input type="checkbox"/> Any <input type="checkbox"/> Alabama <input type="checkbox"/> Alaska <input type="checkbox"/> Arizona <input type="checkbox"/> Arkansas <input type="checkbox"/> California <input type="checkbox"/> Colorado <input type="checkbox"/> Connecticut <input type="checkbox"/> District of Columbia <input type="checkbox"/> Delaware <input type="checkbox"/> Florida <input type="checkbox"/> Georgia <input type="checkbox"/> Hawaii <input type="checkbox"/> Idaho <input type="checkbox"/> Illinois <input type="checkbox"/> Indiana <input type="checkbox"/> Iowa <input type="checkbox"/> Kansas <input type="checkbox"/> Kentucky <input type="checkbox"/> Louisiana
Type of roads <input type="checkbox"/> Any <input type="checkbox"/> Interstates only <input type="checkbox"/> Any pavement road excl. interstates	Weather / temperature conditions <input type="checkbox"/> Any <input type="checkbox"/> Cold (below 7C/45F) <input type="checkbox"/> Normal (7C/45F - 25C/77F) <input type="checkbox"/> Warm (above 25C/77F)	Road conditions <input type="checkbox"/> Any <input type="checkbox"/> Wet pavement <input type="checkbox"/> Dry pavement	Type of tires <input type="checkbox"/> Any <input type="checkbox"/> Tractor Single tires <input type="checkbox"/> Tractor Dual tires <input type="checkbox"/> Trailer Single tires <input type="checkbox"/> Trailer Dual tires	Class of roads <input type="checkbox"/> Any <input type="checkbox"/> Urban <input type="checkbox"/> Rural	

GO ->

The application is a web-based catalog of archived data files that contain records collected during heavy-truck operation in real-world driving environments.

The application has the capabilities to locate and download files containing desired records.

Fig. 29. Selecting Search Criteria

All selected criteria will be used to locate files which each contain one day of data for one truck. After “Go” is clicked, the tool will find and display all files which match at least one of the criteria, searching with a Boolean “OR” logic. The search results (Fig. 30) will be displayed below the search criteria. A histogram showing the total miles represented by each of the files is displayed above the list of files found. General file statistics are also shown for each zip file found, including file size, total miles, average speed (including idling time), percent idling time, and average fuel economy (including fuel used during idling). The desired files can be downloaded individually by right-clicking the appropriate link and choosing “Save Target As...”

¹ Login accounts can be requested by contacting Bill Knee at kneehe@ornl.gov; requests must be approved by DOE.

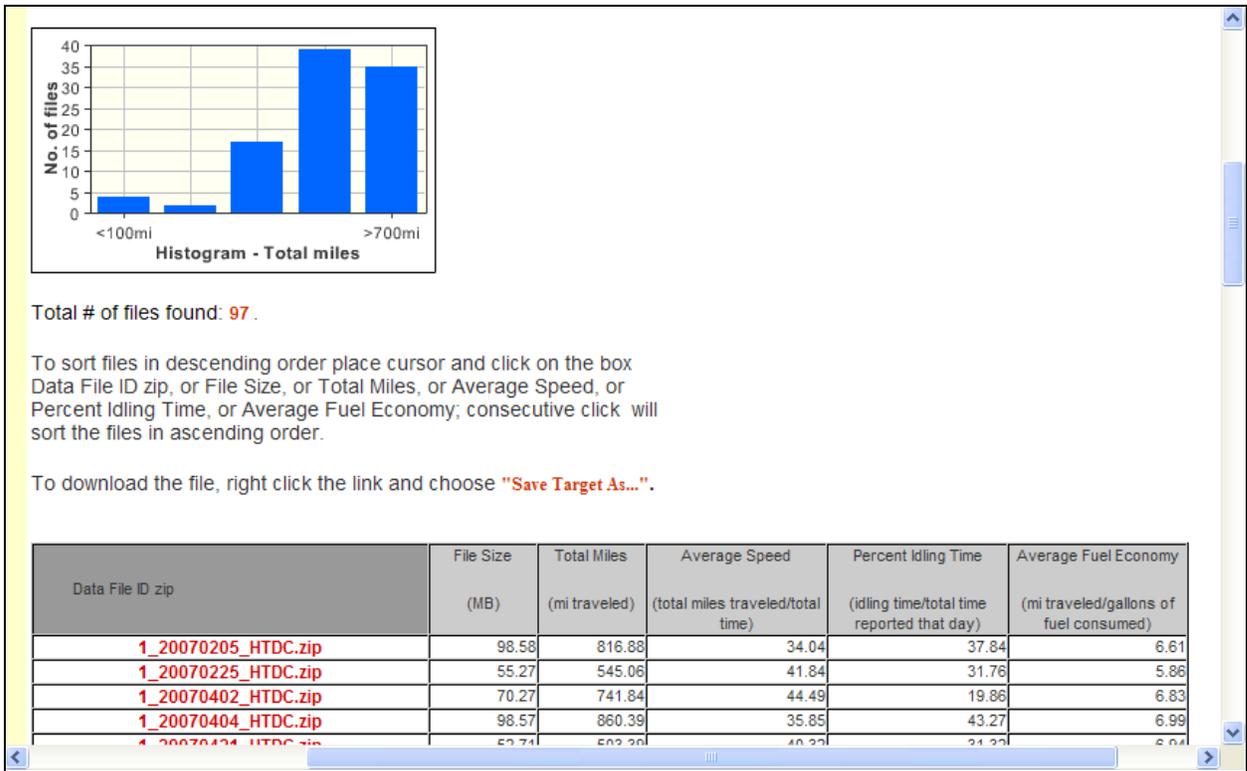


Fig. 30. Search Results

The file search can be repeated for different parameters by modifying the search criteria at the top of the page and clicking “Go.” When finished, the user can log out of the data access tool by clicking “SIGN OUT” at the top of the page.

4. DUTY CYCLE GENERATION TOOL

The DCGenT is a software tool for generating a driving duty cycle that meets specific user-specified criteria. The criteria, in addition to cycle duration, include the number of stops, and the statistical distribution of speeds and accelerations obtained from measured driving data. Presently the tool is focused on features of interest recorded in the HTDC database, such as traffic conditions, weather, road slope, etc. The tool uses a menu-driven interface to allow the selection of pertinent features, and finds the multiplicity of time-location data segments that meet the selected criteria. Subsequently, for statistical processing purposes, it links the segments into a single continuous driving record. The linked record includes not only speed versus time, but also the remaining available parameters of interest, such as road conditions, engine data, etc. Finally, the tool creates a speed versus time record that fits the time length desired, while attempting to preserve the statistical distributions of speed and acceleration in the linked record. In future versions, the speed versus time duty cycle obtained will be interfaced to a vehicle model that will facilitate a search of the HTDC database for real-world truck performance data that can be added to the synthetic duty cycle that was generated. This will allow users to generate benchmarking duty cycles based on real-world driving experience data that meet user-specified characteristics.

4.1 PURPOSE/FUNCTION

Unlike the internet data access tool discussed in Section 3, which allows the mining of relevant data from the large set of data collected in the FOT and produces a data set of segments that meet the user's search criteria within a Boolean "OR" logic, the DCGenT allows for the selection of data set segments based on Boolean "AND" logic and facilitates the construction of a synthetic duty cycle from this data. This tool allows the user to select parameters of interest from signals collected in the FOT (e.g., temperature, time-of-day, tire type, weather conditions, and road grade) and to generate a single duty cycle of any duration based on multiple segments of real-world data containing parameters of interest. Statistical processing of the data facilitates the creation of a duty cycle which is reflective of the speed and acceleration distributions of the original data.

4.2 HOW IT WORKS

The first step for all DCGenT functions is the selection of the duty cycle criteria of interest. As shown in Fig. 31, selectable parameters include the following: 1) external factors such as time-of-day, weather conditions, and topography; 2) vehicle parameters such as transmission and tire type; and 3) traffic congestion data such as vehicle speed. In Fig. 31, the circles highlight the selected criteria. All data is for segments lasting longer than ten minutes, for Truck Number 1, fitted with single tires and having a manual transmission. The search is initiated by clicking on the box highlighted with the orange colored number "1" in the Figure. The dotted box surrounds the list of names and durations of the segments found. Other factors such as vehicle weight will be added in the future. In addition, a User's Guide for DCGenT will be developed in FY2009.

The user has the option of specifying each parameter individually or only some of them, leaving the remaining fields with default values of "any" or "either." Additionally, the database search can also be limited to identifying segments that exceed a user-selected time duration. When the "Search Database" button is clicked-on, the database is searched for segments fulfilling all desired parameters. The resulting segments are temporarily stored in data files in a comma-separated format. As shown in Fig. 31, the search results for the selected criteria appear in the right column with the white background, and in addition to the file name assigned, include the time length of each segment.

When the button “Extract Data” is clicked-on, an option is presented to further limit data extraction to segments between minimum and maximum durations. Once the data are extracted, the geographic routes for each segment are displayed in a map. In addition, pertinent data can be displayed and analyzed for each segment.

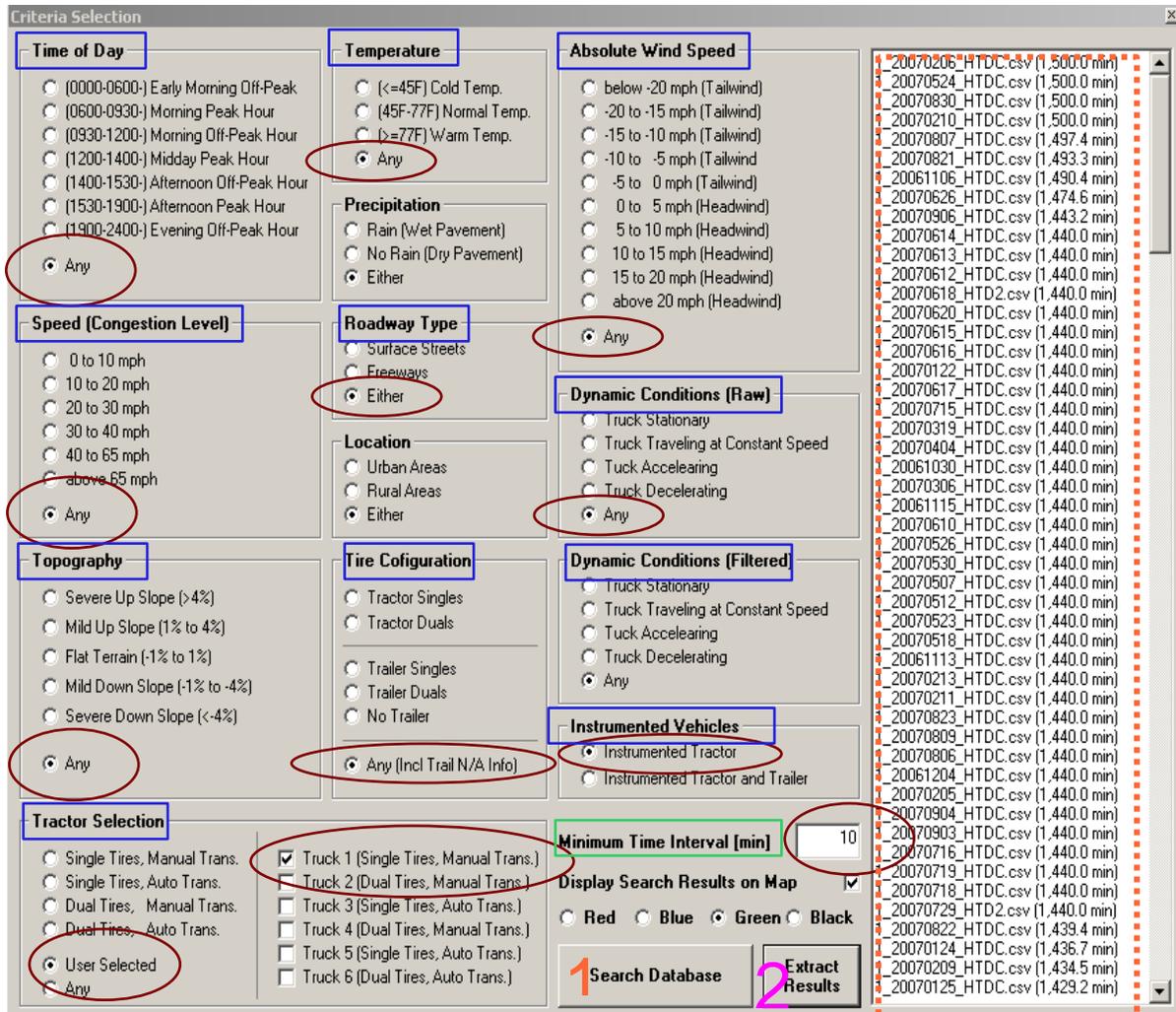


Fig. 31. Screen with Selection Criteria for DCGenT

The data extracted can be graphed in two- or three-dimensional bar or line graphs. Parameters available for graphing include time, engine speed, wind speed, road grade, and fuel consumption. As shown in Fig. 32, a summary of the statistical indices appear at the bottom of the interface screen. Alternatively, a single parameter could be graphed and its data stored in a separate file. The oval-highlighted region in Fig. 32 shows negligible fuel consumption in a five-mile downhill segment at slightly higher speed.

- Duty Cycle Generation
- Duty Cycle Synthesis
- Make PSAT DC File
- Graph Data**
- ✓ Metric Units

Data Display Tool: MultiPlot

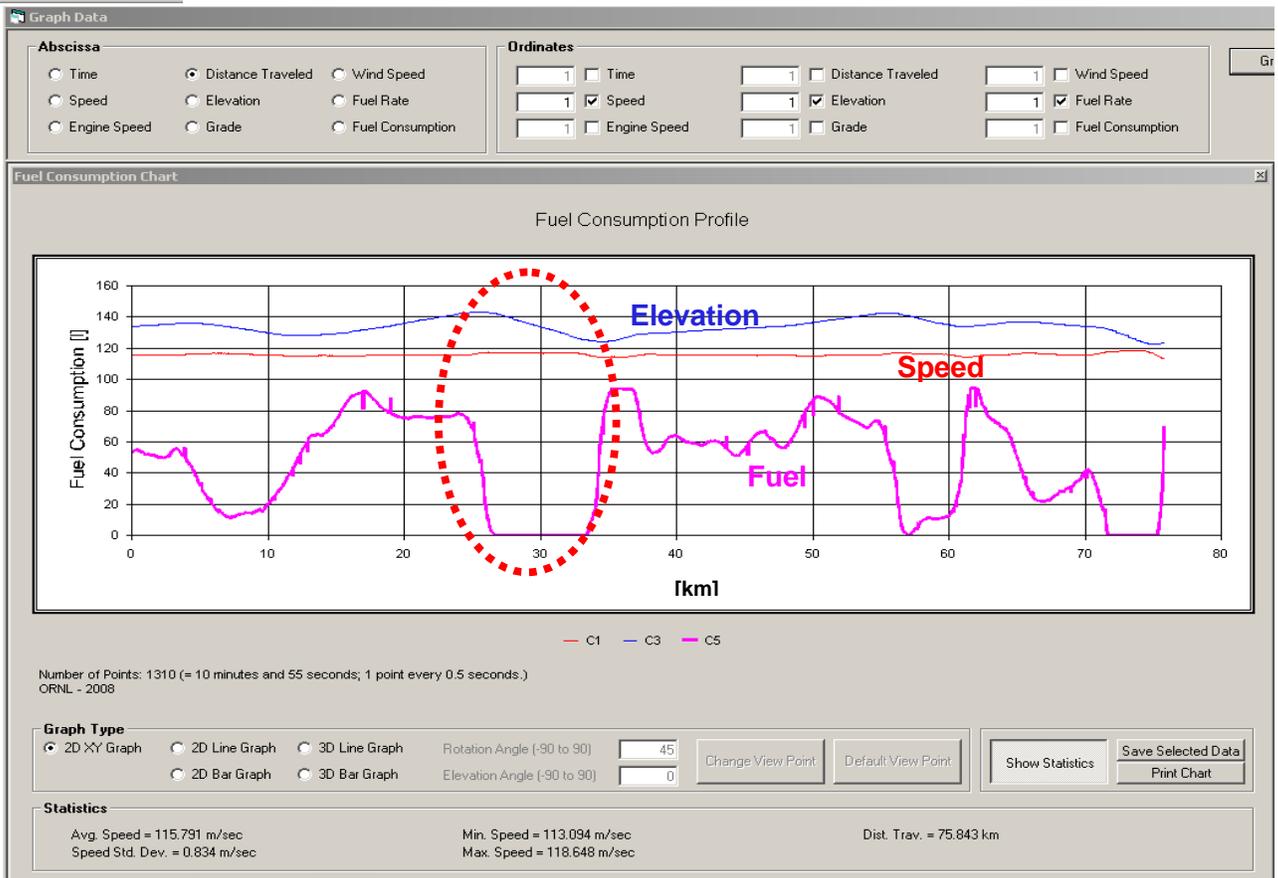


Fig. 32. Data Graphing Function

The set of extracted data can also be linked sequentially to form a single driving record. The DCGenT connects segments of data together by merging a section at the end of one segment with a section of equal length belonging to the beginning of the next segment. Different weighting functions are used to merge the overlapping regions in a smooth and sensible manner, depending on the kind of data merged. For data such as elevation, longitude and latitude, the absolute value at the end of the segment becomes the base value for the segment being merged. Thus, all segments but the first contribute only the change in value with respect the first datum in their segment. For data such as vehicle speed, engine speed and fuel consumption rate, the overlapping segments are multiplied by complementary ramp factors and then added. For instance, if the length of the overlap region is 10 (seconds or elements), then the first elements are weighted by 1.0 and 0.0 respectively, while the second element weights are 0.9 and 0.1, the third 0.8 and 0.2; and so on until the tenth element is weighted by 0.0, 1.1. For other data that can vary rapidly like wind speed and rain, the values are simply appended together. Fig. 33 shows the merging of two segments. The dotted ovals highlight the vehicle speeds in the regions to be overlapped. The solid oval shows the resulting transition speed and front-axle speed (superimposed blue and pink), fuel rate (green), engine speed (red).



Fig. 33. Segment Merging

In addition, options are provided to modify the head and/or tail of the composite cycle so that it may start and end at zero speed. This is accomplished by adding short start-stop segments that are found within the data segments themselves. This permits the generation of a typical duty cycle which begins and ends with the vehicle at zero speed but is synthesized from data available in the data set. Fig. 34 illustrates the merging of data corresponding to a previously observed stop, with the tail of the final record. The dotted pink ovals highlight the vehicle speeds in the regions to be overlapped. The dotted red oval on the left shows the part of the distribution that will become the tail of the record on the right; where the other dotted red oval is located. The solid ovals at the bottom show the results.

The last component of the DCGenT is synthetic cycle-maker tool. This tool first computes histograms of speed and acceleration of a driving cycle of arbitrary time-length, and subsequently attempts to synthesize a driving cycle of a user-specified time-length with similar histograms of speed and/or acceleration. Some of the different options available are illustrated using a standard driving cycle, FUDS, as input to DCGenT. The associated outputs are shown in Fig. 35 to Fig. 39.

Fig. 35 shows the input driving cycle (FUDS) and its speed and acceleration statistics in the form of histograms. The Federal Urban Driving Schedule (FUDS) is shown in the upper part of the figure. FUDS lasts 1,372 seconds, has 17 stops, and reaches a maximum speed of 56.7 miles/hour. The two histograms show the distributions of speed and acceleration in the cycle.

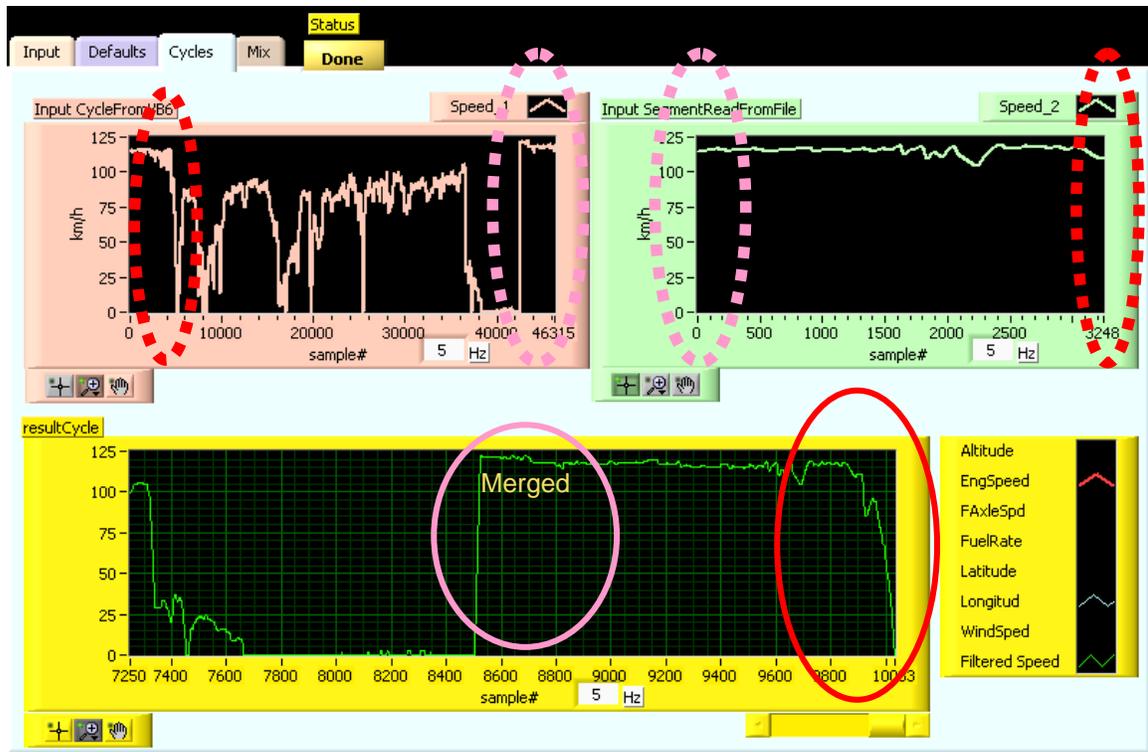


Fig. 34. Segment Tailing and Merging of Two Data Sets

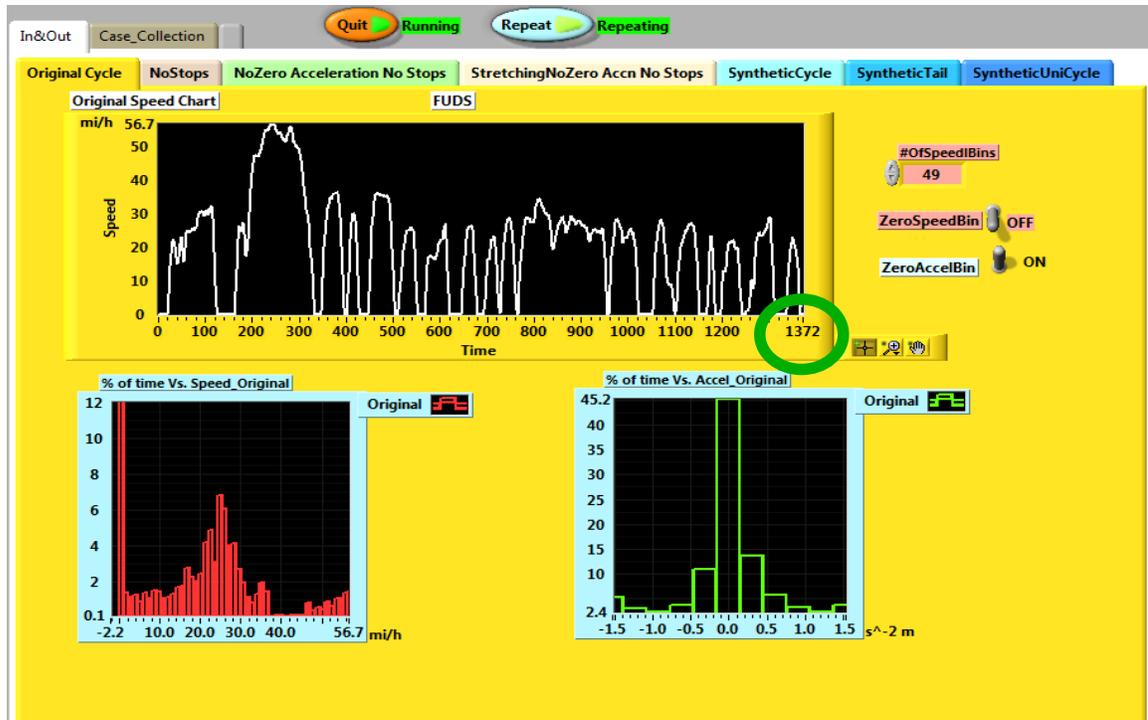


Fig. 35. The FUDES Driving Cycle and Its Speed and Acceleration Statistics in the Form of Histograms

Fig. 36 shows the synthetic cycle generated with a time length of 2,230 seconds, which is longer than the original 1,372 second duration of FUDS, and has the same distributions of non-zero accelerations, and the same set of unique velocities. The “stretched FUDS” cycle conserves the accelerations and speed levels of the original FUDS. The Xi-square goodness-of-fit for the accelerations (excluding the zero acceleration bin) confirms that the two cycles have the same statistical distributions.

The stretching takes place by the insertion of periods of zero acceleration (constant velocity) at random into a compressed version of FUDS obtained by eliminating all periods of zero acceleration. This synthetic cycle will place identical acceleration demands to those produced by the original FUDS cycle. The primary difference is that the periods of constant speed are longer in the new longer cycle.

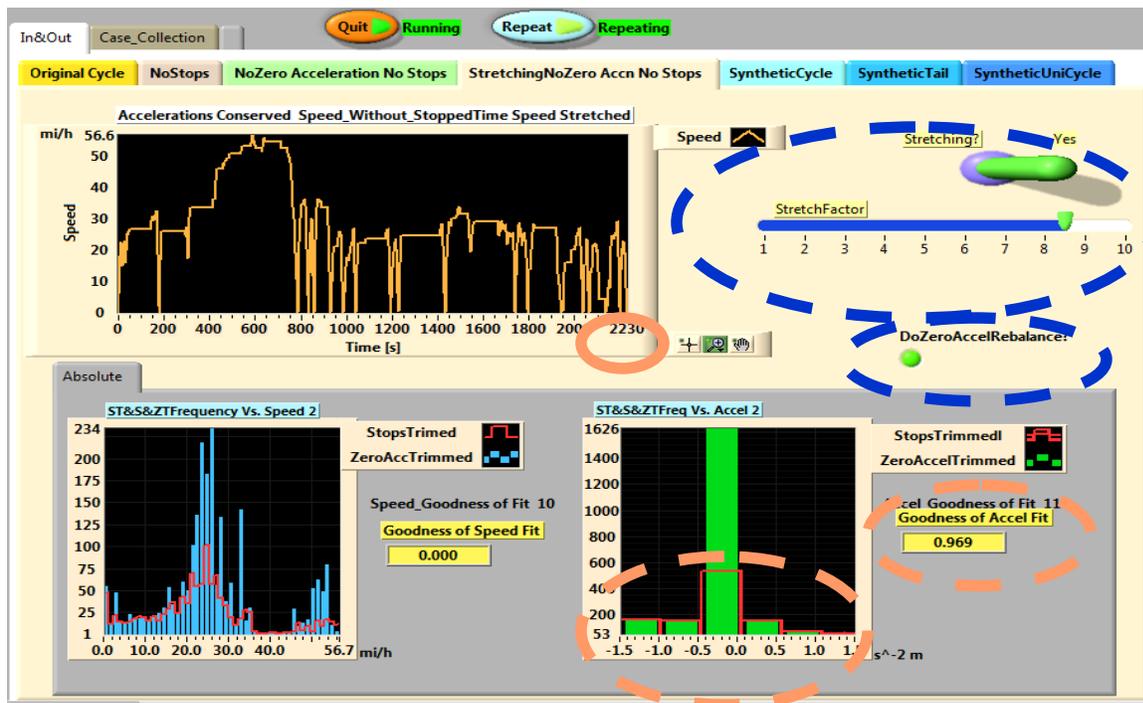


Fig. 36. Elongated Duty Cycle with FUDS Characteristics

A more challenging situation is when the length of the cycle desired is shorter than the original cycle.

Fig. 37 shows a fully synthetic cycle that is 3.42 times shorter (i.e., 406 seconds) than the original FUDS, and generated directly from the speed and acceleration histograms while attempting to keep the same number of stops. The Xi-square goodness-of-fit in Fig. 37 confirms that the two cycles have the same statistical distribution of speeds but not of accelerations. This is due to the extreme reduction in length and the short travel duration between some intermediate stops.

To illustrate the goodness of the algorithm, Fig. 38 shows a fully synthetic cycle of the same length of time as the original FUDS generated directly from the speed and acceleration histograms, and maintaining the same number of intermediate stops. The histograms and Xi-square goodness-of-fit in Fig. 38 confirms that the two cycles have the same statistical distribution for both speeds and accelerations.

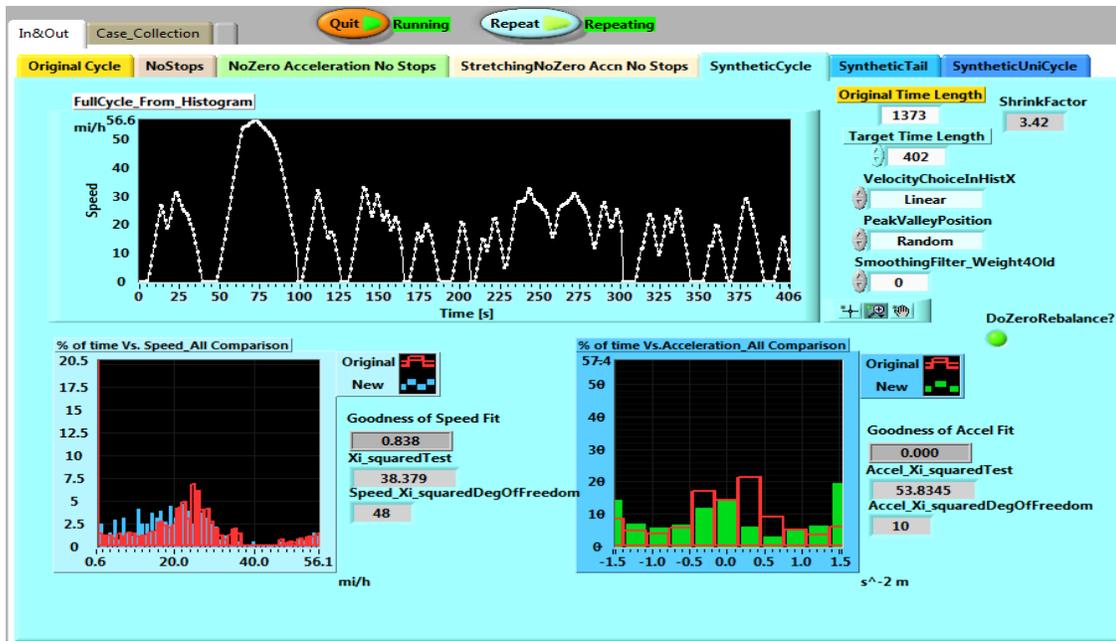


Fig. 37. Compressed Duty Cycle with FUDS Characteristics

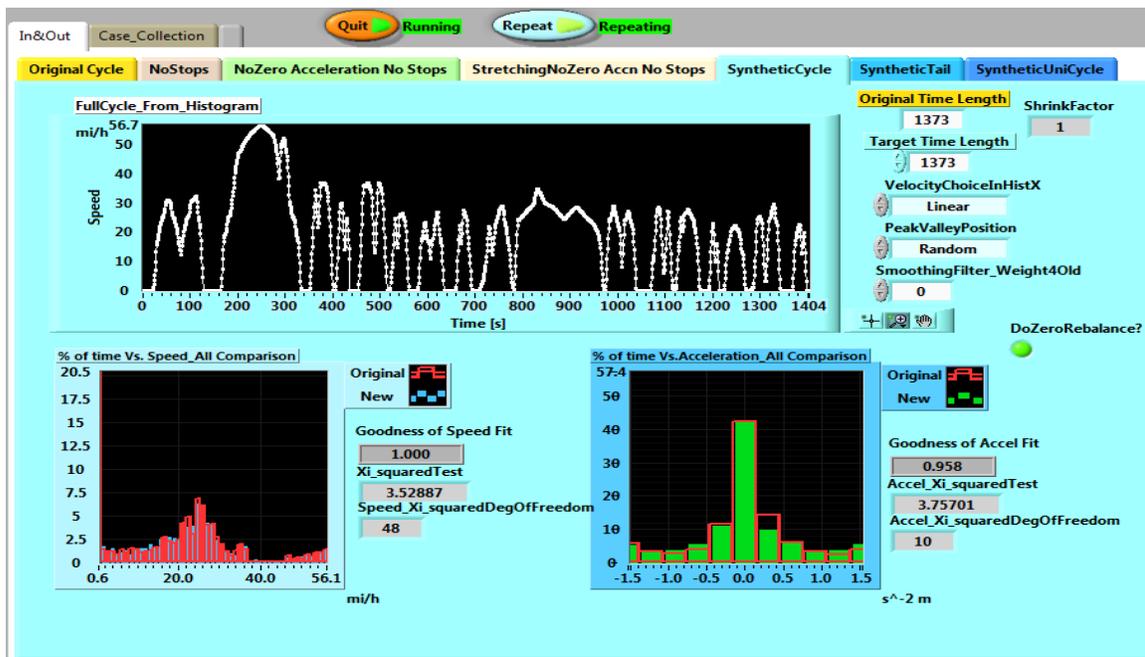


Fig. 38. Synthetic Duty Cycle Generated from FUDS Characteristics

Finally, Fig. 39 shows a synthetic cycle with the same length as the original FUDS, with no intermediate stops, and the same statistical distribution of speeds; with two peaks and one valley and with minimal accelerations. The histogram and Xi-square test confirm that the speed statistics are the same and that the accelerations in the synthetic cycle lay in the zero bin zone (i.e., minimum accelerations).

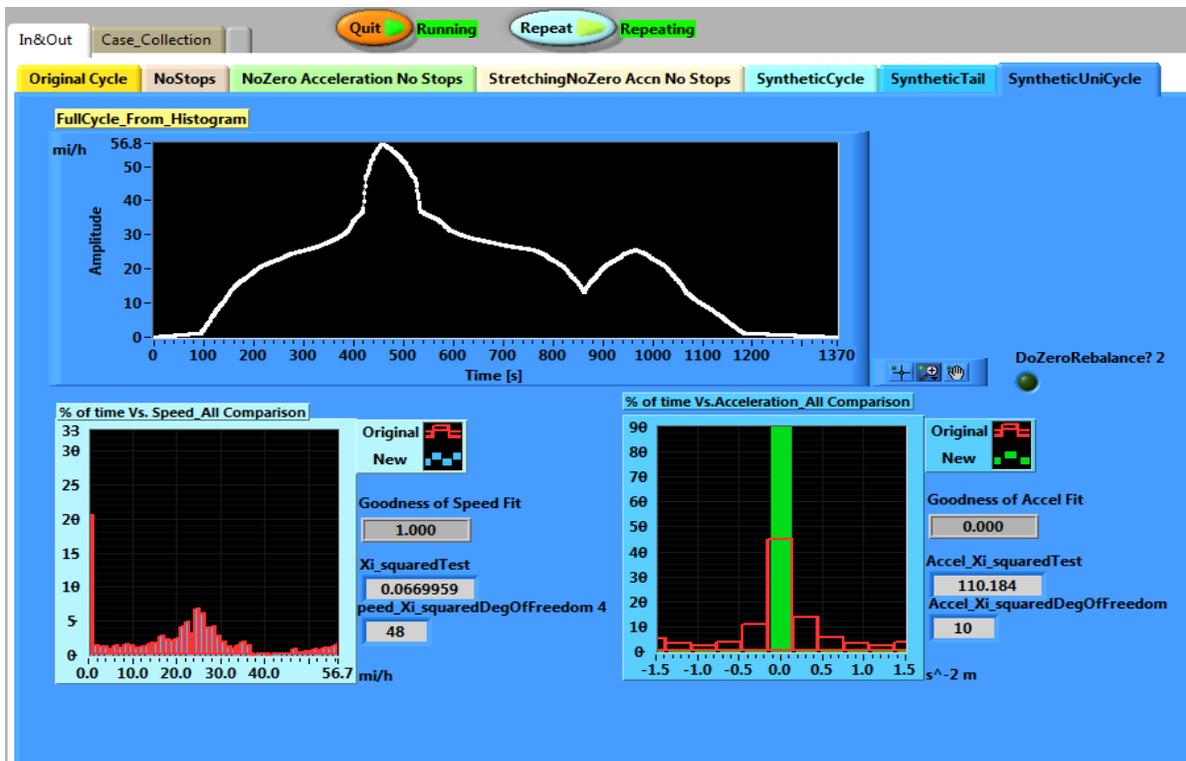


Fig. 39. A Synthetic Duty Cycle with the Same Length as the Original FUDS but with No Intermediate Stops, and the Same Statistical Distribution of Speeds

5. DYNAMOMETER TESTING

In order to obtain drive torque data on at least one of the tractors involved in the FOT, it was decided that dynamometer testing would be conducted, and that testing would involve a small set of duty cycles selected to adequately describe the tractor/engine performance. A decision was made to conduct these tests on the Class-8 capable chassis dynamometer at WVU (Fig. 40²).

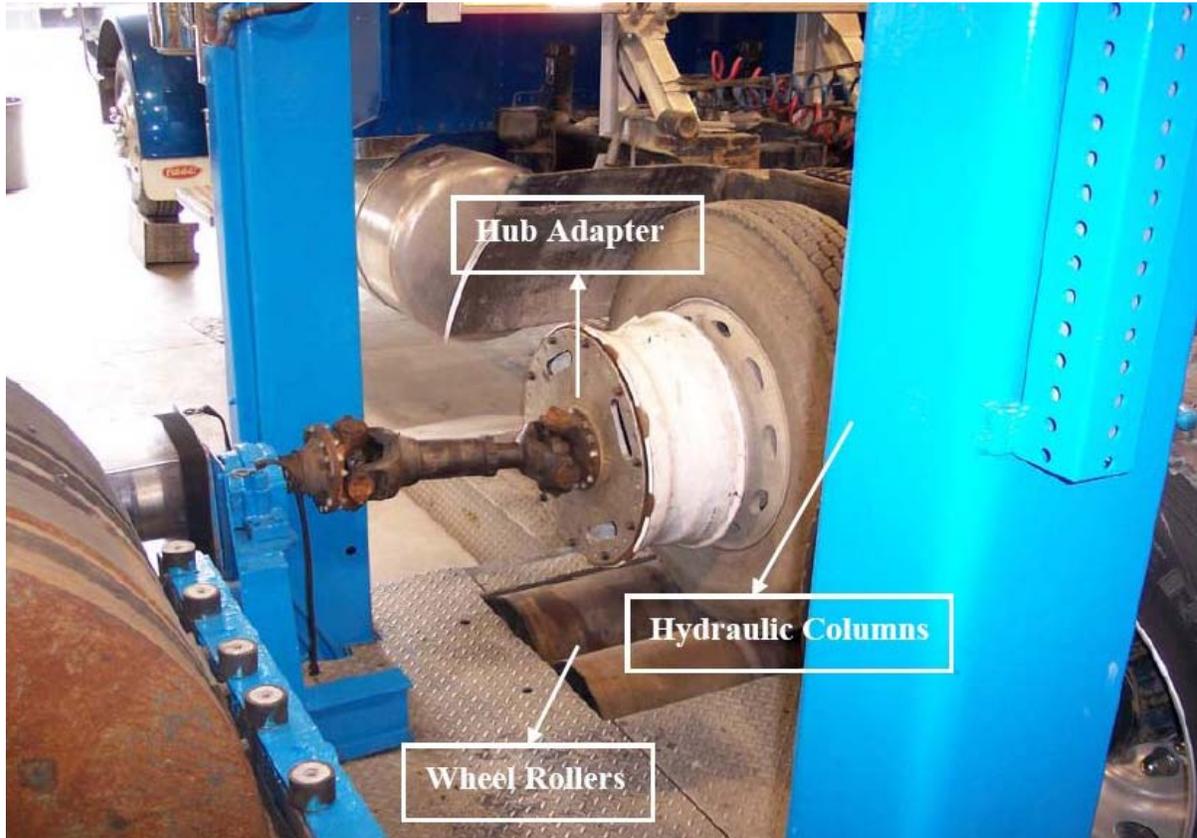


Fig. 40. Connection and Support Structure of WVU's Chassis Dynamometer

In order to conduct the dynamometer tests at WVU, ORNL developed a series of duty cycles to be implemented in those tests. The first cycle generated was synthetic, aimed at mapping the basic vehicle engine/torque characteristics. The second duty cycle, which was obtained from actual information collected in this project, had the objective of getting vehicle performance information from real-world situations. A third set of duty cycles was also tested at WVU; those corresponding to EPA's UDDS (Urban Dynamometer Driving Schedule), and that the agency developed for chassis dynamometer testing of heavy-duty vehicles.

5.1 SYNTHETIC DUTY CYCLES

Information was collected regarding tire and wheel attributes as well as the characteristics of the transmission used by the six tractors participating in the project. Table 9 presents the gear ratio as a function of the gear number for the FRO-16210C transmission (the model used by the participating

² Picture provided by WVU in dynamometer testing report (Appendix E).

tractors) as well as the maximum torque. Fig. 41 shows a performance chart based on 1,800 RPM with an engine operating at 1,550 RPM/62 mph.

Table 9. Gear Ratio and Maximum Torque for Transmission Model FRO-16210C*

	Gear #										Max TQ lb-ft [Nm]
	1	2	3	4	5	6	7	8	9	10	
Gear Ratio	12.69	9.29	6.75	4.90	3.62	2.59	1.90	1.38	1.00	0.74	1650 [2237]

* This transmission can be rated at 100 additional lb-ft torque above the stated limit in the top two gears only.

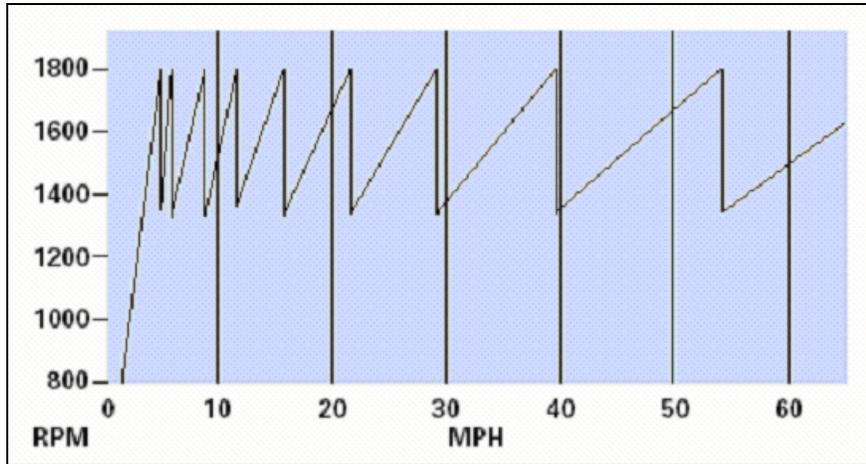


Fig. 41. Performance Chart (Based on 1,800 RPM Engine Operating at 1,550 RPM/62 mph)

In addition to this information, data related to the optimal operation of the transmission was obtained from the manufacturer. Fig. 42 shows the engine torque and vehicle speed as a function of engine revolutions. The highlighted rectangle that goes from 1,450 to 1,550 RPM shows the “sweet-spot” or ideal area of operation, with the engine speed highlighted values (i.e., 1,300 and 1,800 rpm) showing the optimum shifting points. For example, a vehicle traveling at 85 mph (upper right corner of the graph) would be in 10th gear, with the engine operating at about 2,000 rpm and producing a torque of 1,650 Nm. When the speed is reduced to 59 mph (1,332 rpm) then the driver should down shift to 9th gear (top horizontal arrow pointing to the right); the engine will then operate at 1,800 rpm with a torque of about 2,000Nm. In 9th gear the speed can be reduced up to 42.8 mph (1,304 rpm) at which point (to operate under optimal conditions) it would be required to be downshifted to 8th gear, and so on. The same procedure, but in reverse, would apply to increasing the speed of the vehicle.

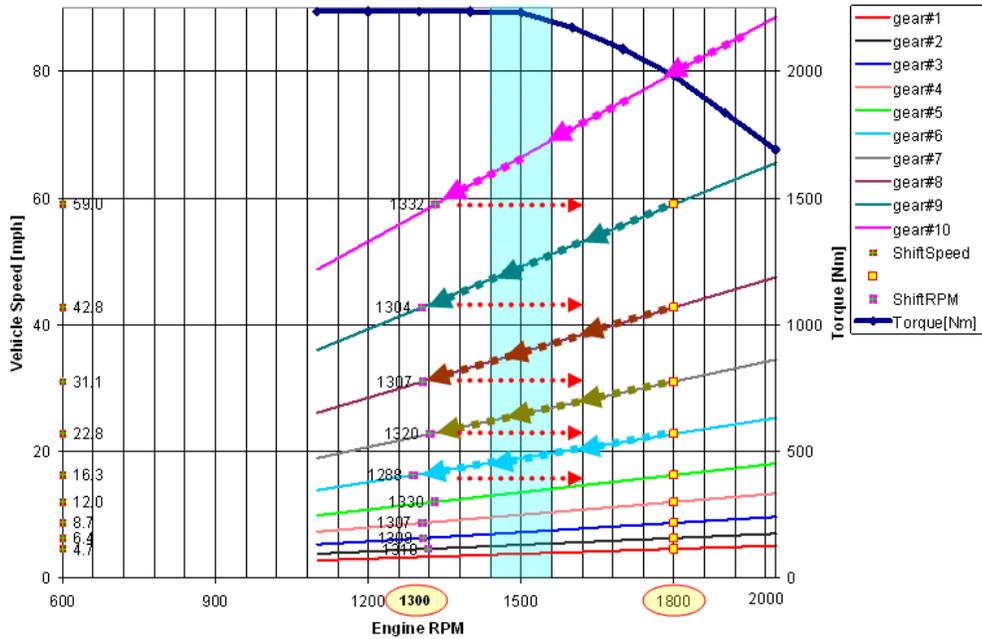


Fig. 42. Engine Torque and Vehicle Speed vs. Engine RPM

Fig. 43 shows the same information as Fig. 42, except that in this case, engine power instead of torque is represented in the graph. Notice that the maximum power is obtained at 1,800 rpm; this is not within the so-called “sweet-spot” (an area of maximum efficiency).

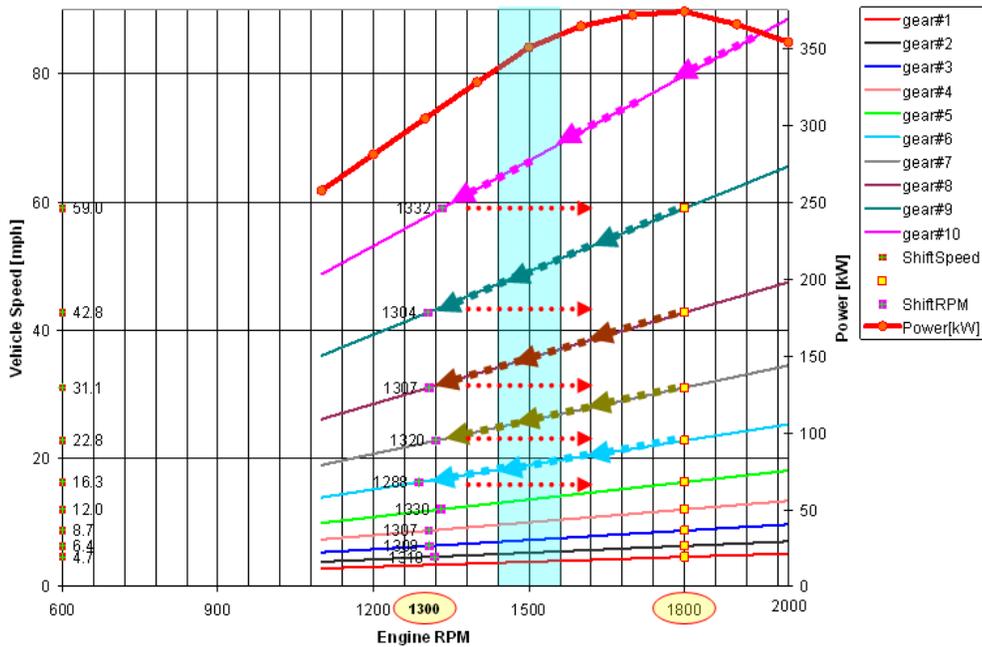


Fig. 43. Engine Power and Vehicle Speed vs. Engine RPM

The described way of operating the vehicle is, of course, theoretical. With the information collected in the project, ORNL mapped the shifting points for a particular truck (Truck 4) for a trip in which the

vehicle was carrying a heavy load on one leg of the trip, and was empty on the return leg. The information is shown in Fig. 44 in which it is possible to see that the operation boundaries are not between 1,300 and 1800 rpm, but rather between 900-1,100 rpm and 2,000 rpm.

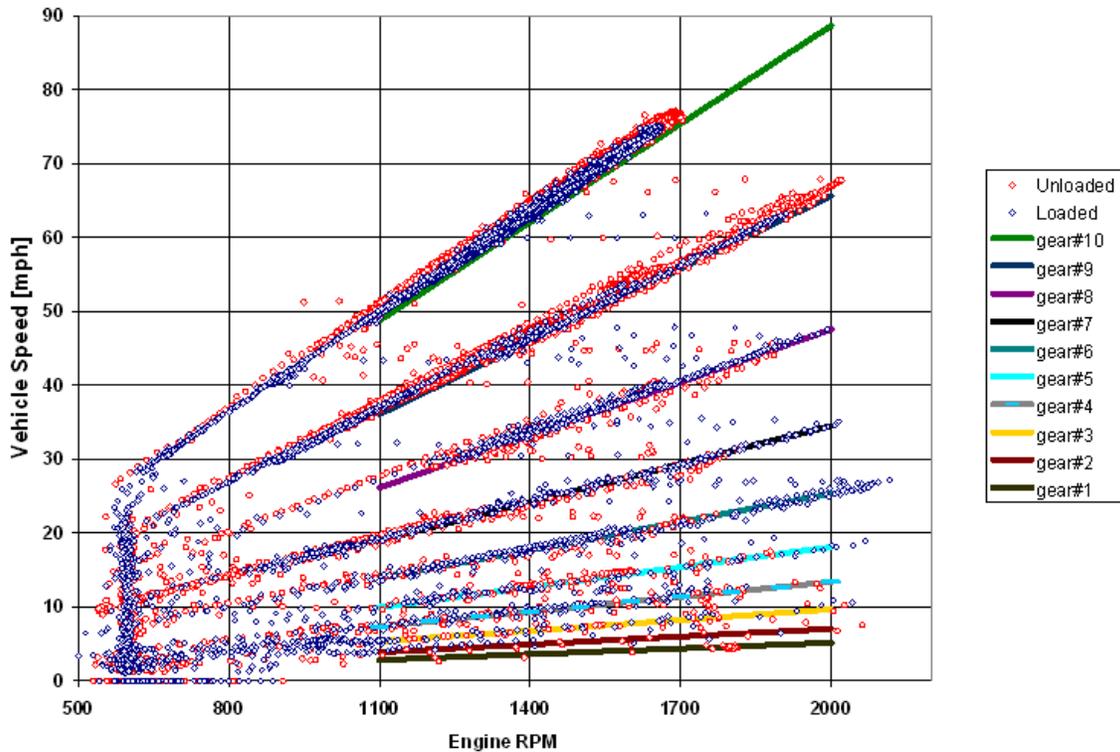


Fig. 44. Observed Operation Points (Truck 4, Loaded and Unloaded)

These limits were used to generate a series of test points which served as the basis to create several synthetic duty cycles. These test points are shown in Fig. 45 and summarized in Table 10. In that table, the time dimension has been added to create a synthetic duty cycle that assesses the characteristics of the vehicle at these points. Each entry in the table corresponds to a given speed (in mph) and it is defined by the gear (header), the engine speed level (first column of the table), and the length of time during which that vehicle and engine speed should be maintained (last column on the table). Allocating 140 seconds per measurement point – consisting of 120 seconds for the target speed plus 20 seconds for the transition from one target speed to the next– the test can be run in about 100 minutes (6,160 seconds as shown in Table 10).

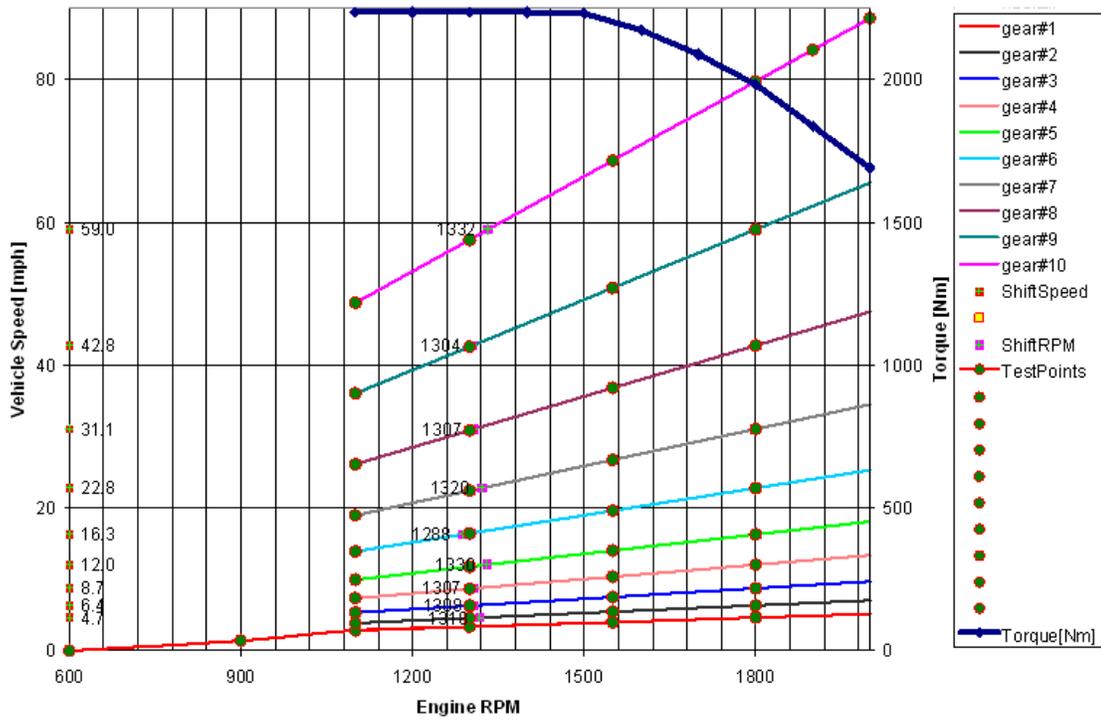


Fig. 45. Test Points for Proposed Vehicle Mapping

Table 10. Operating Speeds by Gear for Proposed Vehicle Mapping Duty Cycle

		Gear #										Time at each RPM		
		0	1	2	3	4	5	6	7	8	9		10	
Engine Speed [RPM]	600	0.0												140
	900		1.4											140
	1100		2.8	3.9	5.3	7.4	10.0	13.9	19.0	26.1	36.1	48.8		1,400
	1300		3.4	4.6	6.3	8.7	11.8	16.5	22.4	30.9	42.6	57.6		1,400
	1550		4.0	5.5	7.5	10.4	14.0	19.6	26.8	36.8	50.8	68.7		1,400
	1800		4.7	6.4	8.7	12.0	16.3	22.8	31.1	42.8	59.0	79.8		1,400
	1900												84.2	140
	2000												88.6	140
Time at Gear#		140	700	560	560	560	560	560	560	560	560	840	6,160	

The information presented in Table 10 is shown in graphical form in Fig. 46. Based on this information, a number of synthetic duty cycles can be created. Two of them (pseudo-driving cycles A and B) are shown in Fig. 47 and Fig. 48, respectively, in which speed and gear are shown as functions of time.

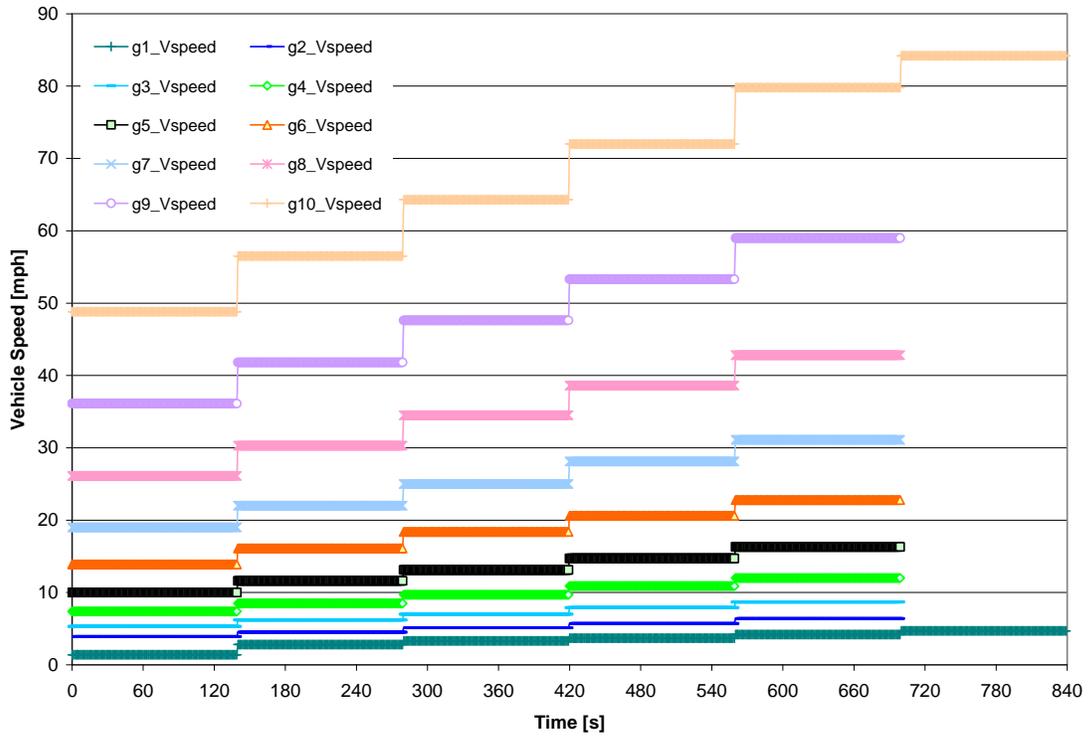


Fig. 46. Vehicle Speed Map for Each Gear

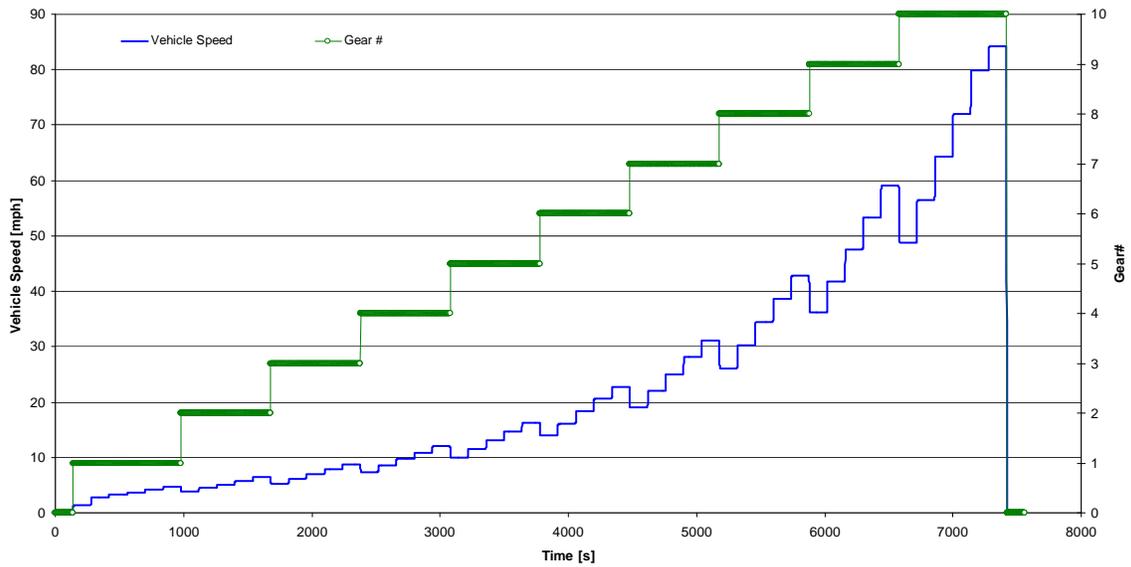


Fig. 47. Proposed Mapping for Duty Cycle Type A

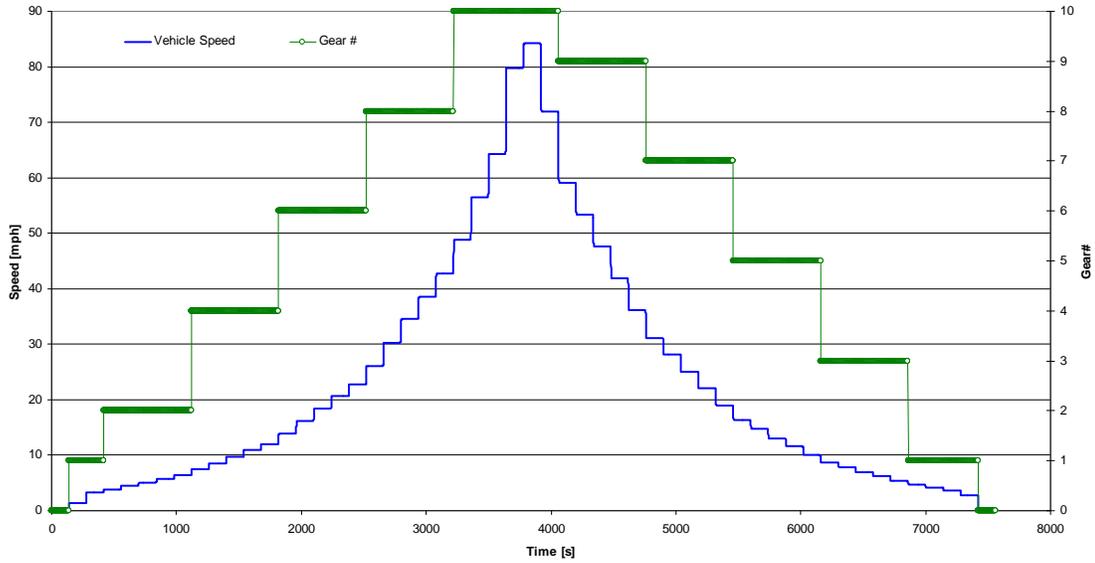


Fig. 48. Proposed Mapping for Duty Cycle Type B

During the WVU Dyno Tests, synthetic duty cycle Type A was implemented, and information was generated and collected for that cycle. One of the runs (i.e., run 5259-2; see the Dyno Test Report in Appendix E) is shown graphically in Fig. 49. The information to produce this duty cycle (i.e., vehicle speed as a function of time) was obtained from sensors installed by WVU during the tests. Notice that, although for this particular run the speeds are different from those suggested in Fig. 47, the shape of the duty cycle is similar to the one shown in that figure or in the left half of Fig. 48.

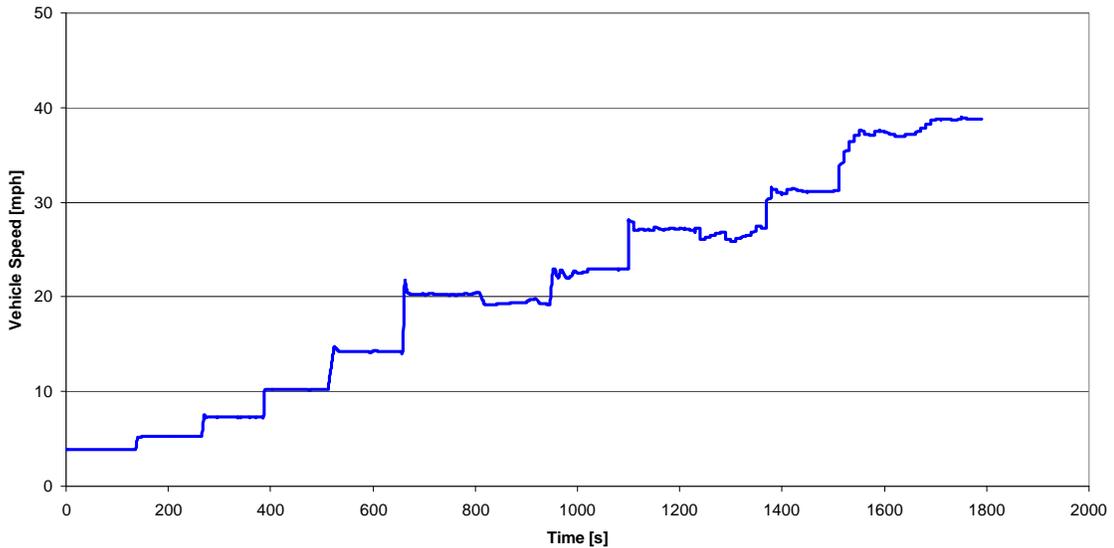


Fig. 49. WVU Implemented Mapping of the Selected Duty Cycle (Duty Cycle Type A, Run 5259-2)

5.2 REAL-WORLD DUTY CYCLES

Information collected during the project was also used to generate a real-world duty cycle that was sent to WVU for the dyno tests. Specifically, a trip performed by Truck 4 was selected, and information relevant to a dyno test was compiled and submitted to WVU. Fig. 50 below shows the duty cycle for this particular trip (the truck was carrying a payload), the corresponding engine speed, and also the topography (altitude) and the wind encountered by the vehicle during the trip.

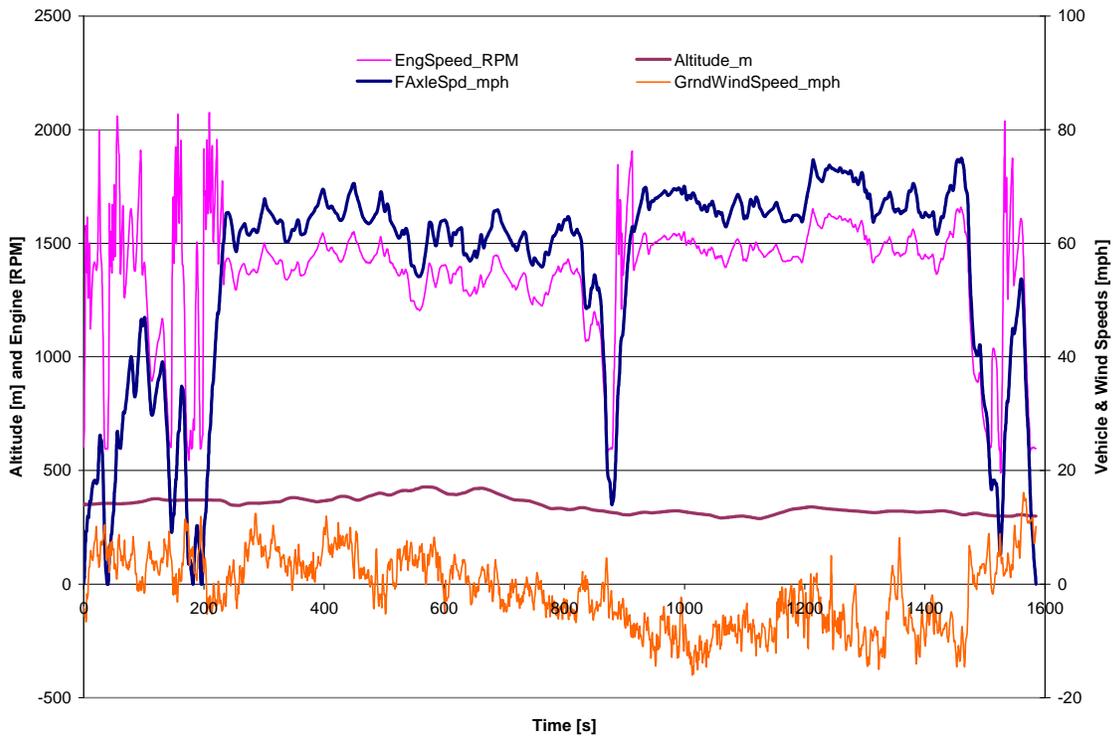


Fig. 50. Truck 4 Duty Cycle (Loaded Truck)

The duty cycle shown in Fig. 50 was implemented at WVU during the dyno tests and one of the runs of that test, run 5271-4, is presented in Fig. 51 (additional information about this particular run can be found in Appendix E). Notice that the duty cycle was followed very closely during the dyno tests, except that the speed was always lower by an offset which varied from 3 to 7 mph.

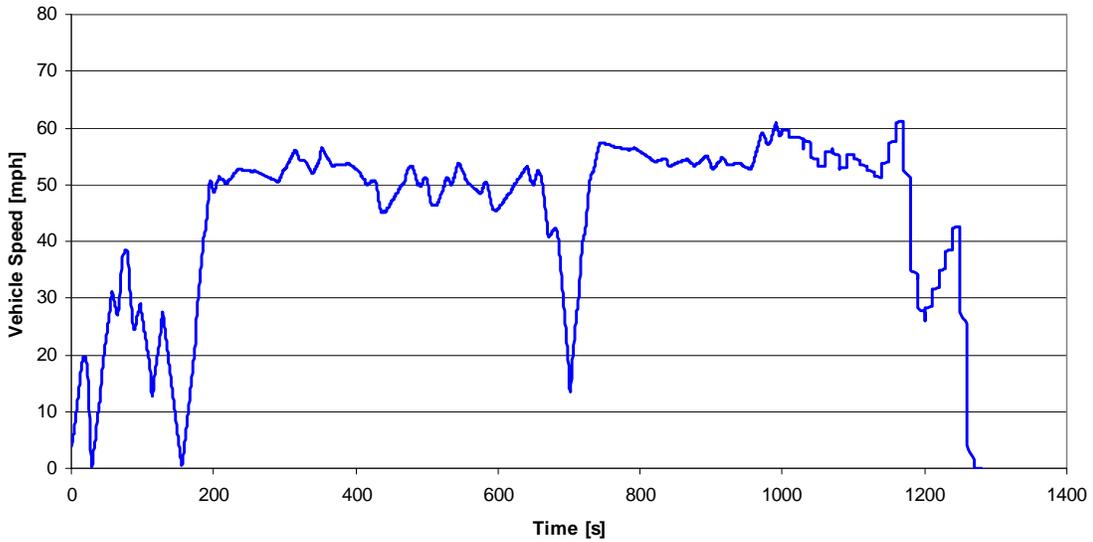


Fig. 51. Implemented Truck 4 Duty Cycle (Run 5271-4)

5.3 STANDARD DUTY CYCLES

The third set of duty cycles tested at WVU was a standard EPA duty cycle. Specifically the Heavy Duty UDDS duty cycle, which is a transient chassis dynamometer test cycle for heavy duty vehicles, was used at WVU. Fig. 52 shows this specific duty. Notice that although cycles such as this may not really reflect real-world driving, they were included in the dyno tests for completeness.

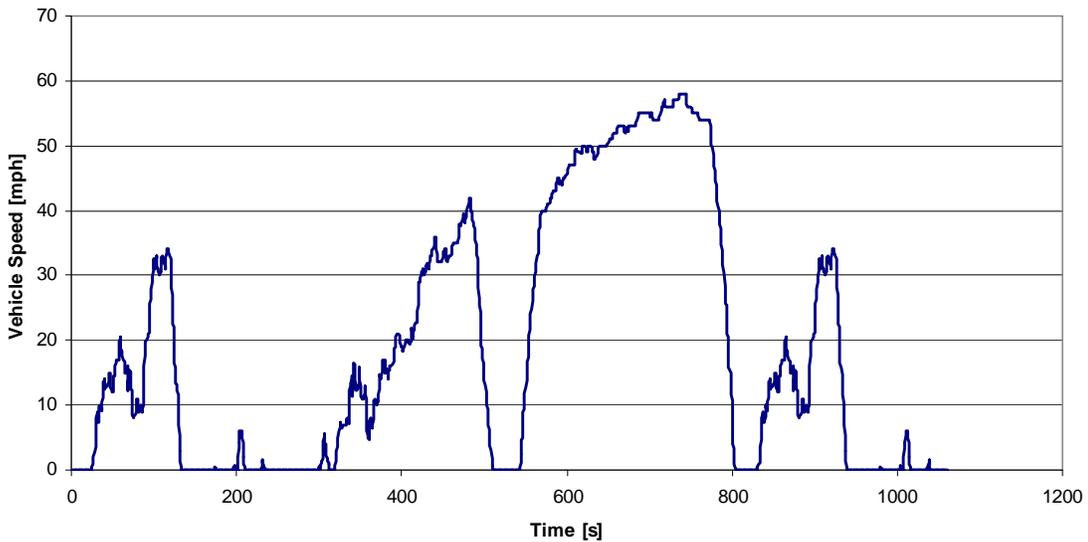


Fig. 52. Heavy Duty Urban Dynamometer Driving Schedule (EPA's UDDS Cycle D)

Fig. 53 presents the actual implementation of the EPA Heavy Duty UDDS (run 5270-2 is shown). The implemented duty cycle was very close to the theoretical duty cycle shown in Fig. 52, in both shape and scale (i.e., the speeds and times were almost a perfect match).

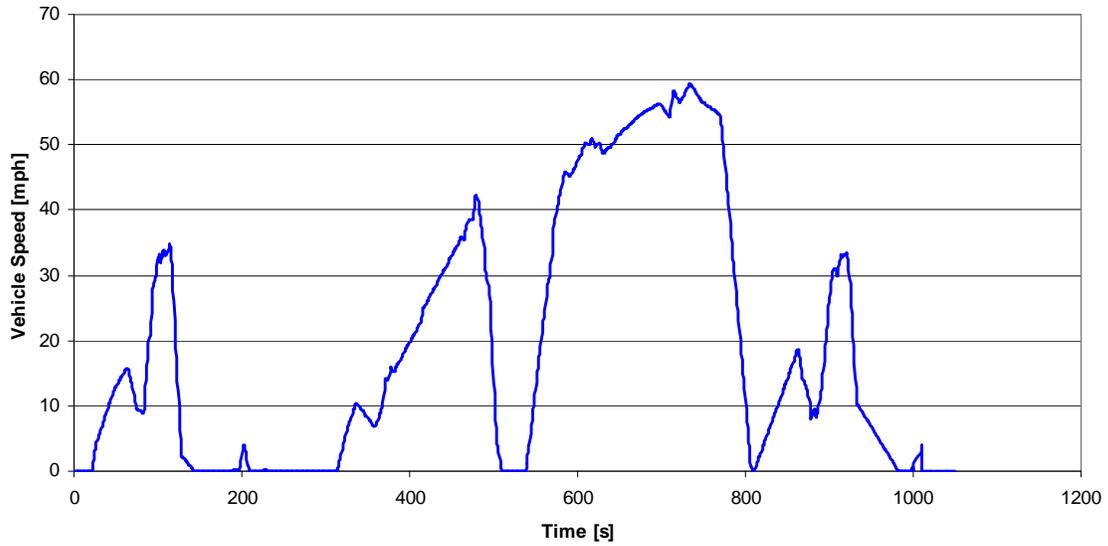


Fig. 53. Implemented Heavy Duty Urban Dynamometer Driving Schedule (UDDS) (Run 5270-2)

5.4 DYNO TEST RESULTS

The results of the dyno tests are presented in detail Appendix E. The raw and processed data collected during these tests (approximately 35 MB of comma-separated value files) was sent to ORNL and archived. The information included information such as CO Mass Rate; CO₂ Mass Rate; HC Mass Rate; High CO Mass Rate; Hub1 and Hub2 Power, Speed, and Torque; NO_x Mass Rate; NO_x Mass Rate; Teom Flow; Teom MR, Low CO Mass Rate, among others. All this information, together with the information collected by the ORNL DAS will be further analyzed to compare, among other things, the fuel efficiencies obtained from the tests with that indicated by the truck databus.

The information submitted by WVU to ORNL, together with the report, was forwarded to ANL.

6. FOT DATA ANALYSIS

The primary objective of the project was to collect real-world performance and spatial data for long-haul operations of Class-8 trucks from a fleet engaged in normal freight operations, and to provide a means for managing and using the collected data to generate real-world-based, long-haul heavy truck duty cycle data and information. Six Class-8 tractors from the Schrader fleet were instrumented and 60 channels of data were collected for over a one-year period of time at a rate of 5 Hz (or 5 readings per second). The Schrader fleet, which is headquartered in Jefferson City, Tennessee, operates within a large area of the country extending from the east coast to the Mountain Time Zone, and from Canada to the U.S.-Mexican border,

The collected data included information such as instantaneous fuel rate, engine speed, gear ratio, vehicle speed, and other information read from the vehicle's databus; weather information (wind speed, precipitation, air temperature, etc.) gathered from an on-board weather station; spatial information (latitude, longitude, altitude) acquired from a GPS (Global Positioning System) device; and instantaneous tractor and trailer weight obtained from devices mounted on the six participating tractors and ten trailers. Three of the six instrumented tractors and five of the ten instrumented trailers were mounted with New Generation Single Wide-Based Tires (hereupon referred as Singles or NGSWBTs) and the other tractors and trailers were mounted with regular dual tires (hereupon referred as Duals or D). Over the duration of this phase of the project (just over a year) the six tractors traveled nearly 700,000 miles.

This report presents the first results of a data analysis of the information collected in this project. The main focus of the data analysis is on the assessment of the effect that different types of tires have on the fuel efficiency of Class-8 trucks. Before the results are presented, the next section describes in some detail the data cleansing process and the organization of the extensive information collected in this project. Following that, there is a discussion of additional models (such as a vehicle weight model) that were developed to complement the information collected. Those models were developed using the data gathered in the project and were used to "fill-in-the-gaps" for those cases in which a particular channel of information was not collected for some reason.

The results of the analysis are subsequently presented, starting with some general statistics and followed by statistical comparisons of the average fuel efficiencies observed from vehicles mounted with different combinations of dual and NGSWBTs. These statistical analyses are conducted for a general case and for a case in which the data is controlled for vehicle weight. The effect of vehicle speed on fuel efficiency is also investigated. A summary of the results and conclusions follow.

6.1 DATA CLEANSING AND ORGANIZATION

The quality of any data analysis depends not only on the accuracy of the data itself, but also on its organization and accessibility. The latter are particularly important when the size of the information database is significantly large. The field tests conducted as part of this project (60 channels of data collected at 5Hz for six vehicles that traveled around the country for more than a year) generated a database with a size surpassing 295GB of uncompressed information. To put this in perspective, if 13.5 Megabytes of information were to be printed, double-sided on standard 8.5-by-11 inch paper, it would produce a report that was 0.6 inches thick (i.e., a normal-size report). The database of collected data in this project would be equivalent to 20,000 of such reports, and if stacked, they would tower to a height equivalent to a 110-story building, or two stacked Washington Monuments.

Given the size and complexity of the data collected, a significant effort was devoted to the task of preparing the raw data for the analysis. As explained elsewhere in this report, the information was collected using a data acquisition system that saved the information in its proprietary format (i.e., SIF files or SoMat Information Files; SoMat was the manufacturer of the equipment used in the data collection task). These binary files are saved using a data structure format that optimizes the size and accessibility of the information. Unfortunately, however, it is a format that cannot be read unless the associated data structure is known. Because the data structure is SoMat proprietary information, the company provided ORNL with a dynamic-link library, or dll (i.e., software in the form of a shared library of functions) that could be incorporated into the special software developed by ORNL to cleanse and organize the information. This dll was used to translate the data from the proprietary format (SIF) to a flat text (i.e., ASCII, or American Standard Code for Information Interchange) format that is readable by any user. The software was tested and debugged during the pre-FOT timeframe with data collected by one of the test trucks (Truck 4) during preliminary testing as an instrumented truck. The preliminary testing data was also used to: 1) check that all the equipment was working as expected, 2) that the data gathered was in the right format, and 3) map Truck 4 during this preliminary effort to better understand the geographical area that would be covered by the project (see Fig. 54).



Fig. 54. Truck 4 Trips, by Week for a Month of Preliminary Testing

Once the FOT was initiated, the protocol that was used to save the information collected by the instrumented truck was as follows. Every one-to-two weeks (usually during a weekend when the instrumented trucks returned to the Schrader garage/parking lot), the information collected and stored on-board was retrieved and saved to a laptop computer. This created a SIF file with a size of about 0.5 GB per truck per week of data gathering³. The week-long SIF file was then translated into an easily readable format as explained above, and the information was parsed into the 60 channels that were collected and saved to files that stored one-day’s worth of data collection data. These files were named with the calendar date in which the data was collected (e.g., 20061113, for information

³ The size of the file was directly correlated to the time that the truck was powered (i.e., the ignition key was in the “on” position), whether it was moving or stationary.

collected on November 13th, 2006), plus a one-digit identifier that identified the truck (1 to 6) that gathered the information.

The apparently easy-sounding task of parsing the information into calendar date files required substantial manipulation of the raw data. Each record (i.e., each reading of the 60 channels, which occurred once every 0.2 seconds) was time stamped by the DAS using Universal Time Coordinates (UTC or Greenwich Time). This time information had to be adjusted based on the geographical location of the truck (e.g., a truck traveling within the Eastern Time Zone would have a time stamp of UTC - 4 hrs or UTC - 5 hrs, depending on the time of the year and the year itself since the daylight saving time start and end dates are year dependent⁴). This, in turn, required determining when a given truck crossed the border between one time zone and the next one. When that line was crossed, the local timestamp has to be immediately reduced by one hour for westbound trucks and increased by one hour for eastbound trucks. As a result, instead of being 24 hours long, some of the calendar date files could be up to 25 hrs long (i.e., they could have up to two “eleven pm-to-midnight” hours) for westbound trips and some could be 23 hrs long (even if the trips started at midnight) for eastbound trucks that crossed time zones. Obtaining the correct local time stamps was important for later analyses involving peak and off-peak hour periods.

Simultaneous with the time stamp corrections, the software developed by ORNL also checked the validity of the data provided by the 60 channels. There were instances in which the on-board sensors did not provide information due to, for example, a malfunction of the sensor (sensor invalid data), and other cases where the DAS had problems storing the data (eDAQ invalid data). Each channel had a numeric code that identified these types of problems, and those codes were stored in the file for that particular channel and record. The data cleansing software read this information and generated statistics that allowed the ORNL researchers to determine when a certain sensor was systematically failing or when the failures were just “glitches” that occurred sporadically. In the first case, troubleshooting, repair/replacement of the particular sensor was accomplished the next time the team was in contact with the particular truck with the problem.

Other errors such as out-of-range errors and errors attributed to the GPS system were also identified and indications of their occurrence were added to the summary reports. Any record that had any kind of error for any channel was marked with a code that allowed for the identification of those errors, and this information was added to the corresponding calendar date file as a new field.

Table 11 below shows a sample of the general statistics generated for the first nine channels for Truck 1 during the week of October 21 to 28 (only October 21st and 23rd are shown). It should be noted that statistics were generated for all channels but because of space constraints only the first nine channels are shown in Table 11. For each data collection date, the table shows the statistics (count, minimum observed value, maximum observed value, etc.) for each channel (column header), followed by a detailed accounting of the different errors observed, going from errors reported by the data acquisition system, sensor errors, out of range errors, and other errors (e.g., errors attributed to the GPS system).

Consider, for example, the statistics for October 23, 2006. The first channel, AcPdIPos (Acceleration Pedal Position), generated 73,132 readings without errors which ranged from 0-to- 100, with a mean of 19.28 and a standard deviation of 25.78 (no integration⁵ was computed for this channel). There were also 14,136 instances in which the sensor provided invalid data, but there were no eDAQ invalid

⁴ See http://nationalatlas.gov/articles/boundaries/a_savingtime.html for daylight saving time start and end dates.

⁵ For some channels such as speed or instantaneous fuel rate, the software integrated the information across time to generate, for example, the distance traveled and total fuel consumed.

data or out-of-range data. Therefore, 16.2% of the time (i.e., $14,136 / (73,132 + 14,136)$) on October 23, 2006, channel AcPdIPos generated apparently erroneous data. However, a closer look at this particular case showed that those 14,136 records were collected while the truck key was in the “on” position but the engine was not running (e.g., the truck was inside the garage having maintenance) and therefore the sensor did not generate any information during that period.

For the same truck and period, Table 12 shows a summary of the errors (i.e., the total percent of observations that showed some type of error) for selected channels. Consider once more October 23rd, 2006. For 22.6% of the 87,268 records collected that day by Truck 1, the GPS system produced errors (see Table 12, columns 4 to 6); again, those errors were due to the fact that the truck was inside a maintenance garage and the GPS could not “see” the satellites to acquire its position. Those errors, therefore, were deemed “glitches” and did not raise any flags. However, for the same day (actually for the entire week) the data channels collecting weather information showed errors 100% of the time. This prompted a requirement for further investigation of the on-board weather data collection system for this truck. In this particular case, it was discovered that a cable connecting the weather station to the data acquisition system became loose due to vibration; the problem was fixed for Truck 1 and the connections of this particular cable was reinforced for all of the participating trucks to avoid potential future problems.

Table 11. General Statistics and Error Type by Channel

Statistics	TruckID	Date	AcPdIPos [%]	ActEngTq [%]	ActGrRto	AirTempr [deg F]	Altitude [m]	AvFuEcon [km/l]	BarPress [hPa]	BattVolt [V]	BrakingS
Count	1	10/21/2006	3799	4009	0	0	3961	4009	0	0	3059
Minimum	1	10/21/2006	0	0	N/A	N/A	323.86	2.970711	N/A	N/A	0
Maximum	1	10/21/2006	0	18	N/A	N/A	335.57	2.970711	N/A	N/A	0
Mean	1	10/21/2006	0	0.109753	N/A	N/A	329.7462	2.970711	N/A	N/A	0
Std Deviation	1	10/21/2006	0	1.247523	N/A	N/A	2.927347	1.48E-06	N/A	N/A	0
Integration	1	10/21/2006	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
eDAQ Invalid Data	1	10/21/2006	0	0	4009	4009	0	0	4009	4009	0
Sensor Invalid Data	1	10/21/2006	210	0	0	0	0	0	0	0	950
Out of Range	1	10/21/2006	0	0	0	0	0	0	0	0	0
Other Errors	1	10/21/2006	0	0	0	0	48	0	0	0	0
Runs in this File 001002003											
Count	1	10/23/2006	73132	87268	0	0	67536	81032	0	0	34893
Minimum	1	10/23/2006	0	0	N/A	N/A	221.89	0.046875	N/A	N/A	0
Maximum	1	10/23/2006	100	97	N/A	N/A	408.12	2.974617	N/A	N/A	1
Mean	1	10/23/2006	19.27551	17.45952	N/A	N/A	303.5636	2.965488	N/A	N/A	0.106984
Std Deviation	1	10/23/2006	25.7801	20.88591	N/A	N/A	41.05352	0.134998	N/A	N/A	0.309098
Integration	1	10/23/2006	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
eDAQ Invalid Data	1	10/23/2006	0	0	87268	87268	0	0	87268	87268	0
Sensor Invalid Data	1	10/23/2006	14136	0	0	0	0	0	0	0	52375
Out of Range	1	10/23/2006	0	0	0	0	0	6236	0	0	0
Other Errors	1	10/23/2006	0	0	0	0	19732	0	0	0	0
Runs in this File 003004005006007008009010011											

Table 12. Percentage of Data Points with Errors per Channel (Selected Channels)

Truck ID	Date	# Data Pts	Lat [deg]	Long [deg]	Altitude [m]	Ground Speed [m/s]	Front Axle Veloc. [km/h]	Fuel Rate [l/h]	Drive Ax W [lbs]	Steer Ax Wt [lbs]	Trailer Wt [lbs]	Rain Int. [mm/h]	Wind Speed [m/s]
1	10/21/2006	4009	1.20%	1.20%	1.20%	1.20%	0.00%	0.00%	0.00%	0.00%	100.00%	100.00%	100.00%
1	10/23/2006	87268	22.61%	22.61%	22.61%	22.61%	0.00%	0.00%	0.12%	0.12%	37.18%	100.00%	100.00%
1	10/24/2006	147	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	100.00%	100.00%
1	10/26/2006	111115	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.00%	0.00%	100.00%	100.00%	100.00%
1	10/27/2006	308261	0.01%	0.01%	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%	100.00%	100.00%	100.00%

6.1.1 Spatial Information

Using the spatial location provided by the on-board GPS (i.e., latitude and longitude collected every 0.2 seconds), the ORNL-developed software determined the road on which the truck was traveling (freeway, arterial, other), if it was traveling inside or outside an urban area, as well as the state in which the truck was located. For the latter (state and urban/rural areas), a database with the perimeter (defined by a series of lat-long points) of each one of the 500+ urban areas in the U.S., and each one of the lower 48 states was created with information obtained from the U.S. Census Bureau. This database was used to determine, at any instance, the names of the urban area and state in which the truck was located, or just the name of the state if it was traveling in a rural area. This spatial information was added to the database containing the 60 channels collected by the on-board equipment.

Much more challenging was the determination of the road on which the truck was traveling, especially since databases with this type of information are not readily available. The first approach was to use the spatial data collected by the trucks, and by using a GIS software package (Microsoft MapPoint), to visually determine the type of road (freeway, surface street) as well as the name of the road (if it were a freeway). The approach used was to divide the area traveled by all of the trucks during the data collection period (about 13 months) into a grid containing one-degree squares. As the trucks traveled any particular grid, a database with road location (i.e., a series of latitude-longitude points gathered by the GPS system) and roadway name (obtained visually from the map used by the GIS system) was created. Once all of the segments of freeway inside that particular grid were covered, the grid was classified as “complete” and could be utilized to automatically determine (i.e., no longer manually, but by using software) if a truck was traveling on freeways or surface streets when it was located inside that grid. Fig. 55 shows the 350+ one-degree grids in which the traveled area was divided.

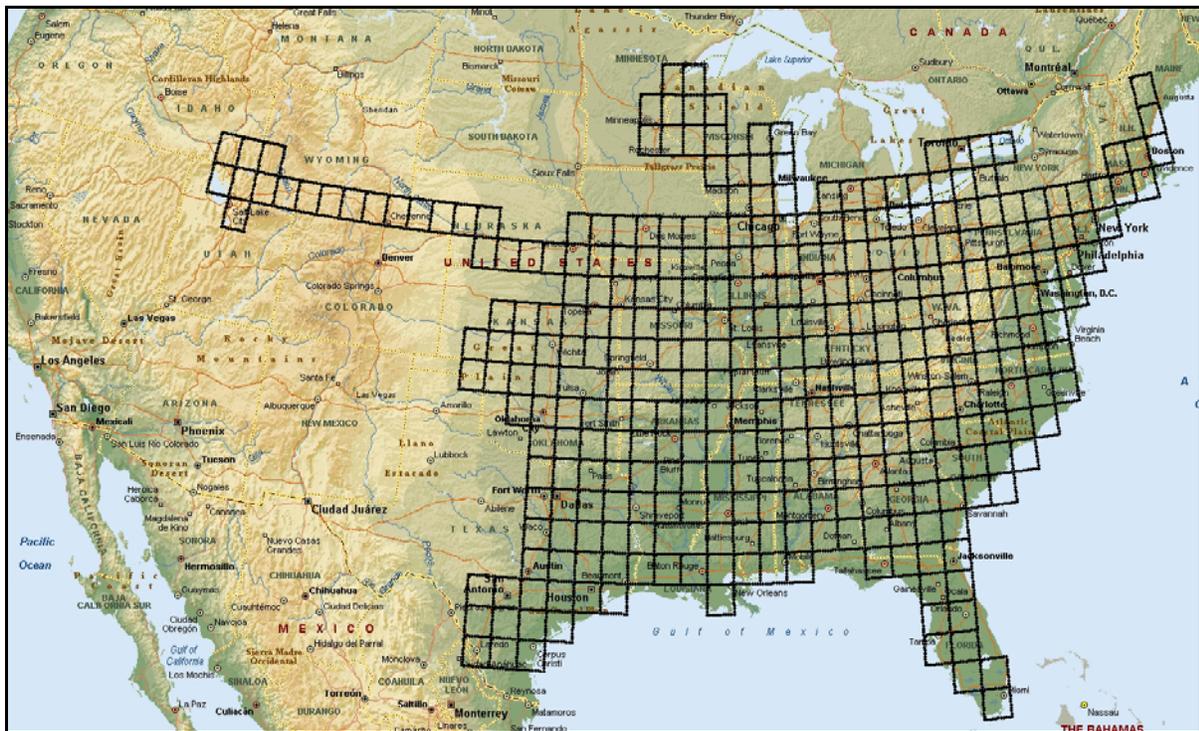


Fig. 55. One-Degree Wide Grids for Roadway Identification

This methodology worked well at the beginning of the data collection when a only few of the grids were traveled; but it became more time consuming as the size of the database increased, and a new approach had to be used. The new approach consisted of the development of a reverse geocoding procedure that used Microsoft MapPoint as the GIS software.

In a normal geocoding procedure, a given spatial feature (e.g., a segment of roadway) is represented by a series of points defined by latitude, longitude, and sometimes altitude; and the attributes of that spatial feature (e.g., the name of the roadway, its classification, number of lanes, etc.) that are associated to these points. This information, kept in proprietary databases, is used by GIS software (MapPoint in this case) to draw these features on a map such that when a coordinate is entered (e.g., the location of a truck as determined by the latitude and longitude provided by the on-board GPS device) it could be displayed by placing a symbol of some sort on its actual location (e.g., the off-ramp from eastbound I-40 at Exit 383 in Knoxville, Tennessee).

A reverse geocoding procedure is the process of finding the attributes of a certain feature given the latitude and longitude information of a given point within that feature. That is, and for this project, it was necessary to find the classification and name of a given roadway once a point on, or very close to, that roadway was known. These points were obtained from the on-board GPS devices as the trucks traveled across the country and therefore were known. Software was written to force MapPoint to return the name and classification of a given spatial feature (roadways in this case) when a latitude-longitude point was provided. The information collected in this way was added to the database of channels, data errors, and spatial information (city and state) described above.

At this point, the collected information database was archived and three copies were made which were stored at three different locations to minimize the risk of data loss.

6.1.2 Tractor and Trailer Tire Information

One important objective of this project was to study the impact of different types of tires on the fuel economy of Class-8 trucks. The type of tires mounted on the six tractors was, of course, known with certainty at any time during the data collection period. On the other hand, the type of tires mounted on the trailer was only directly known when one of the ten instrumented trailers was mated with the participating tractors. For these ten instrumented trailers, the AirWeigh device mounted on each of these trailers (which was used to determine the trailer's weight in real-time) broadcast a unique ID that was gathered by the DAS and saved as one of the 60 channels. Since that ID was associated uniquely with that particular trailer, the type of tires mounted on the trailer was also known.

However, because Schrader had more than 180 trailers, and only ten of those were instrumented, most of the time⁶ the instrumented tractors were mated with non-instrumented trailers. For these cases, just by looking at the collected data it was impossible to know by the on-board instrumentation which trailer was mated with the tractor (i.e., the channel corresponding to the trailer AirWeigh ID would post a missing value in the database), and as a result the type of tires on that trailer could not be readily determined. It should be noted that Schrader had a mix of tractor and trailers with duals and NGSWBTs.

⁶ Most U.S. trucking companies utilize their trailers on an availability basis; that is, available trailers are loaded and then the tractor and driver are assigned to a trip as well as to the corresponding trailer. Within this operational protocol, it is very difficult to try to match a particular trailer to a particular tractor. For the numbers of tractors and trailers of Schrader Trucking Company, if the trailers were assigned randomly to the tractors, then it would be expected that tractors would be mated with non-instrumented trailers 94.44% of the time. The observed overall percentage obtained from the collected data was 94.31%, indicating that the trailers were assigned randomly to the tractors.

For those cases in which an instrumented tractor was mated to a non-instrumented trailer, a procedure was developed to assess the type of tires that was on that trailer. Schrader provided ORNL with a database (called the trailer-tire database) of all of the Schrader trailers. This database included the trailer ID number as well as the type of tires that were mounted on that trailer. The company also provided ORNL with a database (called the trailer-trip database) of all the trips that each one of the six instrumented tractors undertook during the data collection period. This database contained the starting and ending date and time of each trip, its origin and destination (city and state), the trailer ID of the trailer that was assigned to that trip, information about fuel tickets (if any), and information about vehicle weight (if any) obtained at a commercial vehicle scale.

For each record in the data collected for this project, the time stamp of that record (which included date and time) was used to access the trailer-trip database to extract the ID of the trailer that was utilized in that trip. This trailer ID, in turn, was used to enter the trailer-tire database to determine the type of tires that the trailer had. This information was subsequently added to the database of data collected in this project. This procedure was followed until all of the records had been assigned a type of tire for the trailer that was used when the information in that record was collected. The tractor and trailer tire information, which was critical for the determination of the effect of tires in fuel efficiency, was archived, and three copies were made and stored at three different locations to minimize the risk of data loss.

6.1.3 Tractor and Trailer Weight Information

Weight plays a main role in Class-8 truck fuel economy variations. It was therefore paramount that this type of information be collected in this study. To do so, a device (AirWeigh) which is described elsewhere in this report, was mounted on the six participating tractors, and provided instantaneous weight measurements at the steer and drive axels⁷, which were saved as two of the 60 data channels of the DAS. The AirWeigh device was also mounted on the ten instrumented trailers; therefore, when one of these ten trailers was mated with one of the six tractors, the DAS collected weight data for the entire truck. However, as discussed above, the mating of an instrumented tractor with an instrumented trailer was not a very common occurrence (less than 6% of the time), and as a result, most of the time (94%) the six tractors were mated with non-instrumented trailers (i.e., trailers without an AirWeigh device on board). This situation therefore did not provide weight data for about 94% of the trips engaged in by the instrumented tractors, and a remedy for this was developed by the ORNL staff.

Based on the data collected for the cases in which the instrumented tractors and trailers were mated, ORNL developed a model that predicted the trailer weight when only the tractor was equipped with an AirWeigh device. This model, which is described in detail later in this report, was used to assign trailer weight to each one of the records in the database of data collected in this project.

Other Information

Other information relevant to the data analysis task was also generated and added to the database of data collected in this project. This included roadway slope (in %), which was computed using the altitude data gathered with the help of the GPS device, and filtered to smooth out local fluctuations due to GPS errors; relative wind speed (raw and filtered); and filtered vehicle speed which was later used to determine acceleration, deceleration and constant speed intervals⁸. The filter used was a

⁷ As described earlier, the AirWeigh device uses inputs from the vehicle air-suspension system. For the tractor, only the drive axle weight is measured; the steer axle weight is computed by the AirWeigh device.

⁸ Filtering was needed because of the inherent fluctuations in the data, which if not filtered would have introduced errors into the data analyses.

sliding exponential smoothing filter that considered the median of eleven observations before, and eleven observations after the current point.

6.1.4 Information Indexing

As discussed earlier, the size of the final database surpassed 295GB. In order to efficiently find and retrieve specific information from such a large database it was necessary to index the information and to create a database of pointers that would allow for the quick retrieval of data records that comply with possibly multiple search criteria specified by the analyst. Recalling that the final database was analogous to a stack of double-sided paper 110 stories tall, searching for specific criteria would be very labor intensive. However, creating a database of pointers, i.e., an index of the information contained in the main database, would expedite the search process since these pointers would indicate exactly where (e.g., file and records within that file) to find a specific set of data.

For each one of the main attributes of the collected information that might play a relevant role in the data analysis (for example,

- a truck moving in an urban area vs. a truck moving in a rural area;
- a truck moving on a freeway vs. a truck moving on a surface street;
- a truck moving under rainy conditions vs. a truck moving under clear weather;
- a truck moving during the morning peak hour vs. a truck moving during mid-morning off-peak hours;
- a truck moving vs. a truck in a stationary position; and many others).

The ORNL-developed software identified, within the daily data files previously generated, the records in which each attribute is valid, and where it is not valid. This indexing allowed for a very efficient management of the information and was used in the data analysis task to allow for the selection of files that contained only the specific information of interest; for example, a truck traveling in urban areas, during the morning peak-hour, during rainy weather.

A search engine, that uses the index pointers was developed and included with the DCGenT Prototype to help with the identification and retrieval of information that satisfies one or more user-selected criteria simultaneously. Fig. 56 shows a screen capture of the data selection criteria that is part of the DCGenT Prototype. Those criteria include:

- 1) time of day (peak- and off-peak periods),
- 2) air temperature,
- 3) precipitation status,
- 4) roadway type (freeways or surface streets),
- 5) spatial location (urban or rural areas),
- 6) congestion level as a function of traveling speed,
- 7) topography (different type of terrains from upslope to flat to down slope),
- 8) truck tire configuration,
- 9) instrumented (i.e., both tractor and trailer equipped with AirWeigh devices) or non-instrumented (i.e., trailers with no AirWeigh devices) vehicles,
- 10) type of transmission and tires for the tractor,
- 11) specific tractors (one or more of the six instrumented tractors),
- 12) wind speed range,
- 13) vehicle dynamic condition (e.g., truck stationary, truck accelerating, etc), and
- 14) vehicle weight (in four levels: empty; light load, medium load, and heavy load).

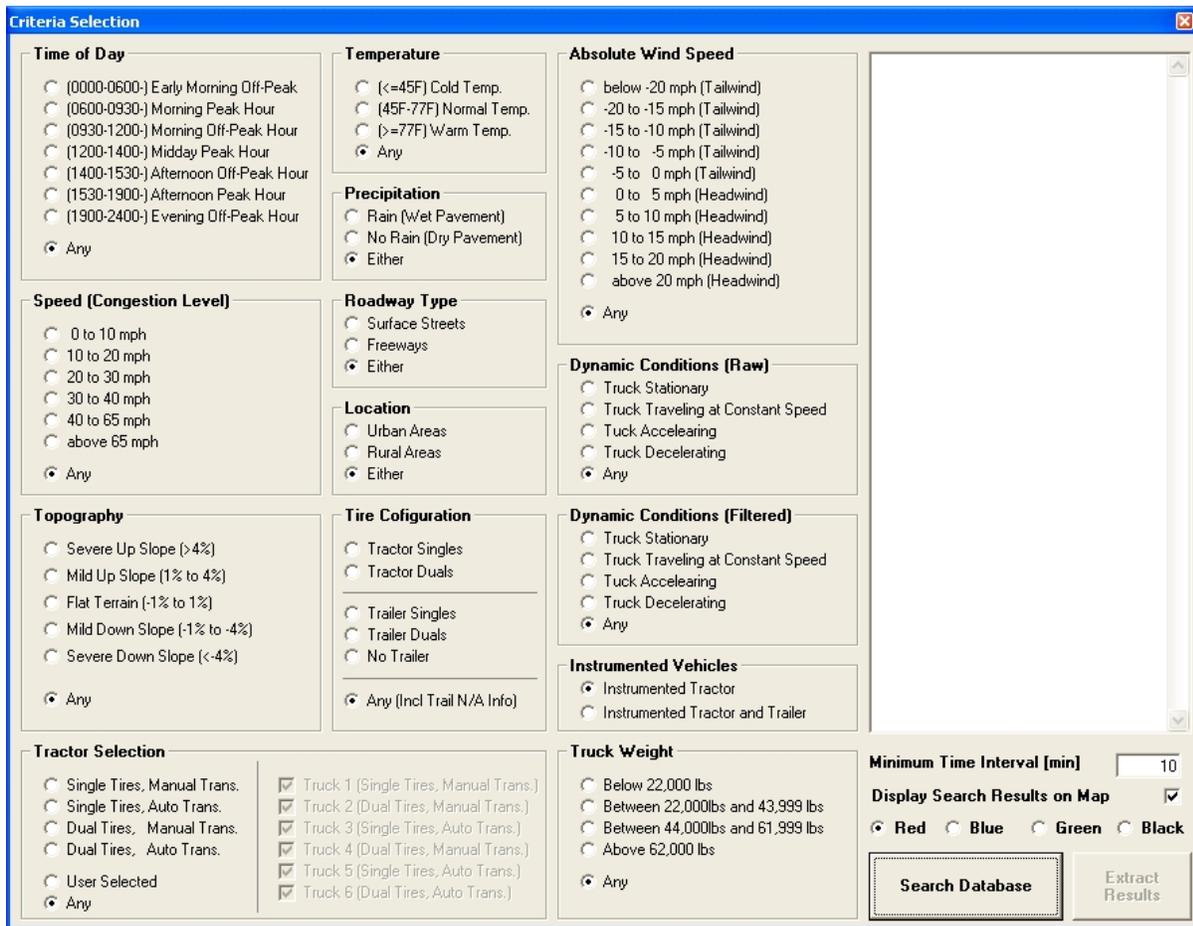


Fig. 56. DCGenT Prototype Search Criteria Dialog Box

Once the user has selected all of the searching criteria of interest, and after pressing the *Search Database* button, the software finds the list of pointers for the chosen criteria and retrieves from the database all of the records that satisfy these criteria simultaneously.

A data archiving and retrieval tool was also developed that allows remote users to access the collected information database through a web portal. Similarly to the search engine included with the DCGenT Prototype, the Web Data Archiving Tool allows users to select different criteria. Once specified, all of the (daily) files in the database that comply with these criteria are then presented in a list to the user who can select and download the files of interest. Notice that, although each one of these files has all the selected criteria, it is not assured that they will be satisfied simultaneously (i.e., they will be satisfied at the file level, but may not be satisfied simultaneously at the record level).

6.2 ADDITIONAL DEVELOPED MODELS AND DATA CALIBRATION

6.2.1 Vehicle Weight Model

As discussed briefly in the last section, it was not always possible to pair the instrumented tractors with instrumented trailers and for those cases, the truck's total weigh information could not be

directly assessed. A truck total weight prediction model was developed that used the tractor weight, which was always available, and the physics related to inertia. That is, as a truck accelerates, the weight of the trailer would resist the change in speed by inducing a force proportional to that weight. This force would impede the movement of the tractor and would appear as a loss of weight as registered by the AirWeigh device on the tractor, which determines axle weight by sampling the pressure of the air suspension system. Therefore, by observing the behavior (i.e., weight readings provided by the AirWeigh devices) of the instrumented tractor and instrumented trailer under different acceleration levels, it would be possible, in theory, to characterize the tractor and trailer's response for a particular payload. A parametric study of payload weights would theoretically provide a truck response map that can be used to estimate the payload weight of tractors mated to un-instrumented trailers.

This theory was tested using the weight information collected for the cases in the database where both the tractor and the trailer were equipped with AirWeigh devices. The tractor weight and the truck total weight were sampled within pre-specified acceleration intervals, and linear regression models⁹ were developed to fit the "loss of weight" observed as a function of the vehicle acceleration. Fig. 57 to Fig. 59 show a representation of the cabin weight (triangle symbols) and total truck weight (circles) as a function of vehicle acceleration for trucks carrying light, medium, and heavy loads respectively. The figures also show the linear regression lines as well as the parameters of these lines, and the R^2 (or "goodness of fit" parameter). In all cases, and as was expected, the observed weight (either that of the tractor or that of the truck) decreases in a way that is very close to a linear function (i.e., all of the R^2 values are very high) as the vehicle acceleration increases. Notice also that the R^2 values were slightly higher for the light- and heavy-load models than for the medium-load models, indicating a better (linear) fit for the first two.

In order to develop a truck weight prediction model, the information collected from trips in which both the tractor and trailers were equipped with the AirWeigh device was used to generate the linear regression parameters of the tractor weight (i.e., its slope m and intercept b) as a function of vehicle acceleration va (call this linear regression model, M1). At the same time the tractor weight tw and total truck weight ttw were noted; these two parameters were sampled from the information collected by the on-board AirWeigh devices when the truck was traveling at constant speed. All of these four parameters (m , b , tw , and ttw) were determined using information from about 75% of the trips that had both the tractor and trailer instrumented. That is, each one of these trips was divided into time segments in which the truck was moving¹⁰ and the four parameters were computed and stored in a database. A second linear regression model (M2) was developed using the observed ms , bs , and tw_s as independent variables, and the ttw_s as the dependent variable. M2 models were developed for each one of the six tractors.

The M2 models were then tested using the remaining 25% of the information collected on trips for which both the tractor and the trailer were equipped with the AirWeigh device. This was done in order to determine the accuracy of the truck total weight prediction model. The testing procedure was as follows. Using the remaining 25% of the data, parameters m , b , tw , and ttw were determined; the first two using the vehicle acceleration as independent variable as explained above, and the last two by observing the AirWeigh reported weight for the tractor and trailer when the vehicle was traveling

⁹ A linear fitting function was used since the force opposing the movement of the tractor is proportional to the acceleration (and trailer weight).

¹⁰ Any time the truck was stopped for a time interval that was less than ten minutes, it was considered to be part of the current time segment. However, if the stopped time was greater than ten minutes, a new time segment was initiated. The purpose of this time-segmentation of the information was to avoid including data where the vehicle weight was not constant. That is, it was assumed that it would take more than ten minutes to load or unload the vehicle to a weight level that was significantly different from the previous registered weight. Starting a new data collection segment would assure that the vehicle weight was constant.

at constant speed. Parameters m , b , and tw were then used as inputs for the corresponding model M2, which in turn predicted the total weight of the truck, $ttwp$. The latter was then compared against the one provided by the AirWeigh device, i.e., ttw .

The results of these comparisons are presented in Table 13 below. The last two rows of the table show respectively the number of generated M1 models that were used to calibrate the M2 models (i.e., the row labeled Model Cal.), and the number of M1 models that were used to test the developed M2 models (i.e., the row labeled Model Pred.). A distribution of the percent difference between the predicted truck weight ($ttwp$) and the measured truck weight (ttw) was constructed for each of the six M2 models; the parameters of these distributions are presented in Table 13. Notice that on average, the prediction model was always within ten percent of the AirWeigh reported total weigh, and in some cases (i.e., T2, T4) it was within a four percent difference.

Table 13. Comparison of Truck Weight Prediction Model vs. Truck Weight Read from On-board Air-Weigh Devices

		T1	T2	T3	T4	T5	T6
Percent Difference between Predicted and Measured Weights	Min	1.32%	0.16%	0.28%	0.24%	0.10%	0.09%
	Max	20.78%	11.00%	14.99%	10.13%	10.86%	7.48%
	Mean	9.30%	3.65%	6.20%	3.14%	5.22%	4.30%
	Std Dev.	6.66%	3.64%	4.71%	3.08%	3.63%	2.91%
Number of Observations	Model Cal.	41	51	66	42	54	18
	Model Pred.	16	17	23	16	17	9

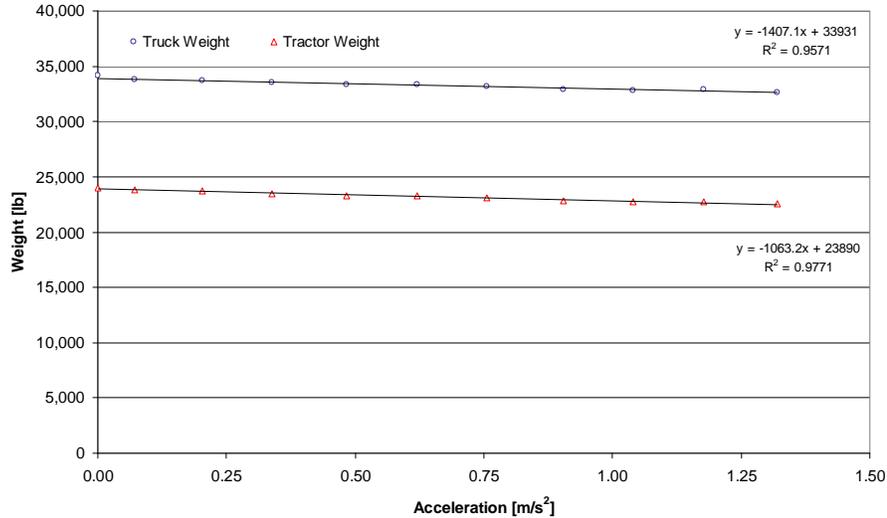


Fig. 57. Tractor and Total Truck Weight vs. Acceleration - Light Load

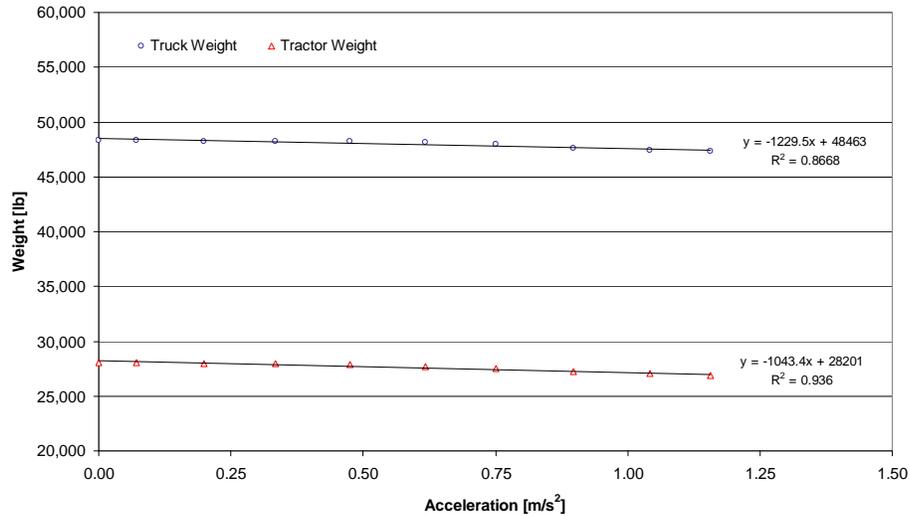


Fig. 58. Tractor and Total Truck Weight vs. Acceleration - Medium Load

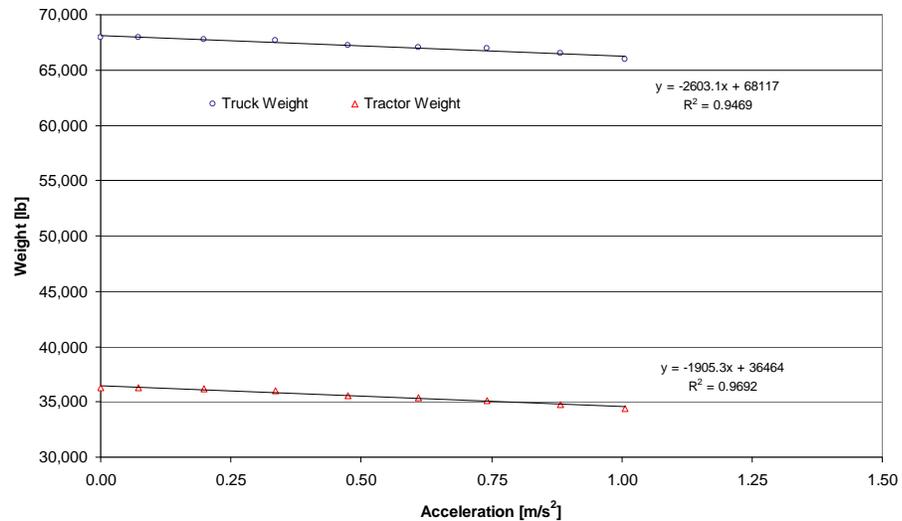


Fig. 59. Tractor and Total Truck Weight vs. Acceleration - Heavy Load

The methodology to determine truck total weight for trips where the trailer was not instrumented (94% of the trips) was the same as the one used to test the weight model. That is, using the tractor AirWeigh readings parameters m , b , and tw (i.e., model M1 parameters) were generated for each time segment in those trips in which the truck was moving, as explained above. Those parameters were then used as inputs in the corresponding tractor M2 model to predict the truck total weight. The latter quantity was then assigned to the corresponding records in the database of collected information.

During the data collection period, the participating trucks were periodically weighted at commercial vehicle scales and the information from those truck weight scale tickets was entered in a database for subsequent use in the calibration of the AirWeigh devices. A distribution of the information collected through these truck weight scale tickets is shown in Fig. 60 below which presents the truck total

weight. Notice that, as expected, most of the truck weight scale tickets correspond to heavily loaded trucks since in those cases the trucking company wanted to be sure that the vehicle would not exceed the legal load limit. This bias towards tickets collected for heavily loaded trucks together with the low percentage of time in which both the tractor and trailer were instrumented simultaneously, resulted in very few matches (only four observations) that could be used to calibrate the information collected from the AirWeigh devices. This low number of observations made it impossible to calibrate those devices against commercial vehicle scale weight measurements.

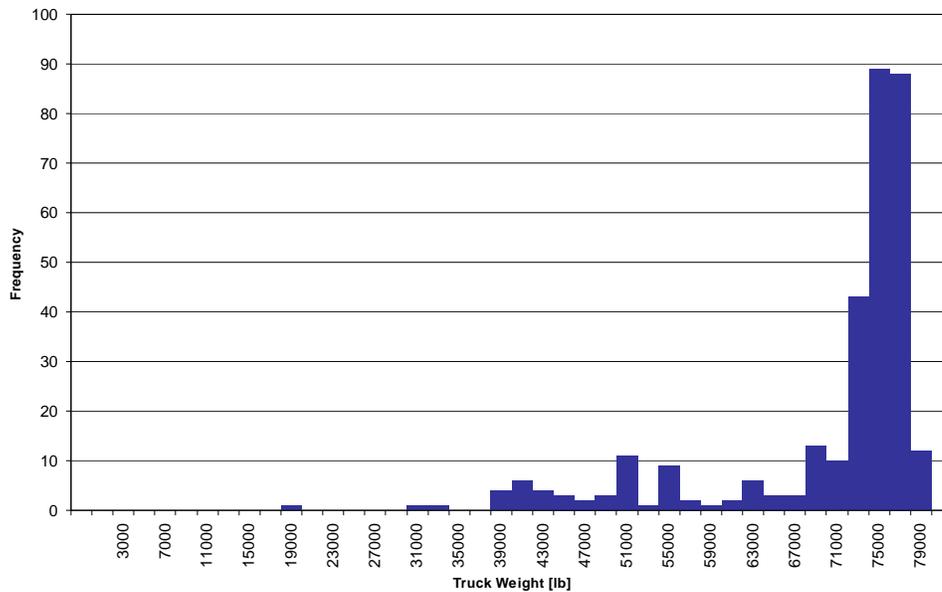


Fig. 60. Truck Total Weight (All Trucks, Weight Tickets)

The information collected from the AirWeigh devices for trips in which both the tractor and trailer were simultaneously instrumented (i.e., less than 6% of the trips) is presented in Fig. 61. Notice that there are three clearly defined gross vehicle weight levels: a light-load level that goes from approximately 32,000 lbs to 44,000 lbs, a medium-load level ranging from 44,000 lbs to 62,000 lbs, and a heavy-load level going from 62,000 lbs to the legal limit of 80,000lbs for Class-8 trucks. These three load levels, plus a fourth load level in which the trailer was either empty¹¹ or when the tractor traveled without a trailer, were used as criteria for weight selection in the database search engine described in the last section (see Fig. 56).

¹¹ The light-load level was later expanded to range from 22,000 lbs to 44,000 lbs to include the case of a tractor carrying an empty trailer.

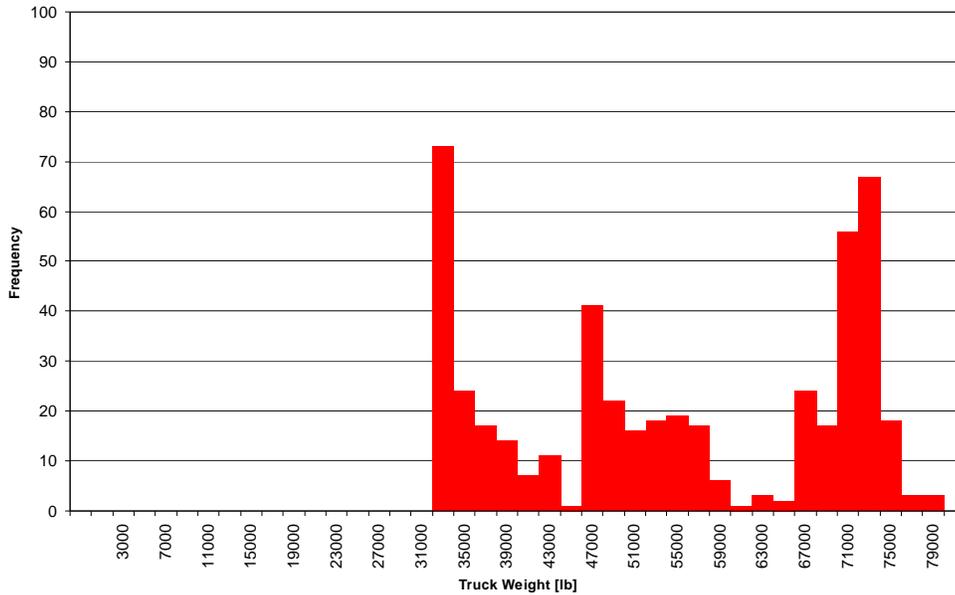


Fig. 61. Truck Total Weight (All Trucks, AirWeight Devices on Both the Tractor and Trailer)

6.2.2 Fuel Information

The main objective of the data analysis for this project was to determine the effect of the different types of tires (i.e., regular duals vs. NGSWBTs) on the fuel efficiency of Class-8 trucks. In order to accomplish this objective, fuel consumption needed to be measured; moreover, to determine fuel efficiency under different conditions (e.g., peak-hour vs. off-peak, urban vs. rural, etc.) it was necessary to determine fuel consumption instantaneously. As described elsewhere in this report, the vehicle databus provided this type of information (i.e., the instantaneous fuel consumption rate, measured in liters/hour) which was captured through one of the data channels (see Table 5) and saved every 0.2 seconds into the collected information database.

It is obvious that to determine the absolute fuel efficiency of any vehicle, the fuel consumption needs to be measured accurately. At the beginning of the project, it was decided to collect fuel tickets every time one of the participating tractors was fueled. The fuel ticket information (i.e., total number of gallons of fuel) was to be used to calibrate the observed fuel consumption as reported by the vehicle databus. The calibration methodology consisted of a comparison of the total fuel consumed obtained by adding the fuel reported in the fuel tickets against the total fuel consumed obtained from the collected information database for the same trip, or series of trips.

Three assumptions were made when this fuel consumption calibration methodology was adopted: 1) there would not be any gaps in the data collected; 2) the date and time at which the vehicle was fueled would be recorded; and 3) every time a vehicle was fueled the tank would be completely filled. None of these assumptions were valid. As described elsewhere in this report, there were instances in which a participating tractor was not at the company's parking lot when the researchers were there to download the data collected and to clear the storage capacity of the on-board data collection equipment. For such instances, if the DAS's memory became full, then no more collected data could be saved, and part of the information was lost, thus creating a gap in the information. On other occasions, a sensor (e.g., GPS device) may have malfunctioned for some period of time, resulting in

the loss of information, and consequently again, gaps in the database. Although for almost any data analysis these gaps are irrelevant (most of the time they were proportionally small), they introduce cumulative errors in the calibration of the fuel consumption, and would have resulted in an underestimation of the fuel consumed as computed by the databus information. This problem could be corrected by simply comparing the fuel reported in the fuel tickets with the databus information for all the trips that were completed between two consecutive “gaps” in the database.

The second and third assumption would have permitted the determination of the fuel consumption and efficiency between two consecutive fuel stops. Fuel time information was necessary for cases in which the vehicle was parked at a truck stop overnight. In these cases, whether the vehicle was fueled in the evening or the next morning would have made a difference (due to the engine idling overnight) in the fuel consumption computed from the databus information and as reported in that particular fuel ticket. That is, if the tank was filled up at the previous gas stop, then the fuel consumed since then would have been the fuel necessary to attain a full tank.

Because the time at which a particular truck was fuelled was not reported, those trips in which the vehicle was fuelled at a truck stop where it was parked overnight had to be discarded. This created a new set of artificial gaps in the database, further reducing the data intervals between two consecutive “gaps” in the database. However, more problematic was the fact that, in an effort to minimize costs, a vehicle may not have filled up its tank every time it stopped at a gas station.

The combination of all these factors resulted in short segments of data for which the amount of fuel in the tank (as provided by the information collected from the fuel tickets) was unknown at the beginning and at the end of the data segment. This uncertainty regarding starting and ending fuel levels would have introduced errors in the “ground-truth” measure of the consumed fuel, with these errors increasing as the data segment decreased¹². On the other hand, the fuel consumption computed using information obtained from the vehicle databus could be calculated precisely for these data segments. However, because of the described “ground-truth” errors, it would have been impossible to calibrate the fuel consumption measurements obtained from the databus¹³.

To illustrate this point, a Monte Carlo simulation model was developed to determine the maximum expected error in fuel consumption when the amount of fuel that is in the tank at the beginning and end of the analysis period is not known. A four thousand mile data segment was considered in which four stops to fuel the truck were made. The same amount of fuel was added at these four stops; however, the amount of fuel in the tank at the beginning and at the end was randomly assigned for each one of the 100 replications of the experiment. For each one of these 100 replications, the difference (in percentage) between the fuel consumption calculated using the fuel tickets and the databus information was generated for three cases: 1) a databus that underestimates fuel consumption by 5%, 2) a databus that measures fuel consumption with total accuracy, and 3) a databus that overestimates fuel consumption by 5%.

These differences or errors, which were sorted in ascending order, are presented in Fig. 62. Notice that because of errors in estimating fuel consumption using the fuel ticket information as described previously, there could be cases in which it would be impossible to even determine if the databus is underestimating, overestimating, or accurately reporting fuel consumption. Consider, for example

¹² As the data segment decreases, there is less fuel consumed and therefore less fuel stops. Suppose there are n fuel stops which resulted in a total of g gallons of fuel added at these stops. Assume further that the tank was at $b\%$ and $e\%$ of its capacity c at the beginning and at the end of the data segment, respectively. The error in the computation of fuel consumption by using the fuel tickets would have been $(e - b) * c / g$, which increases as g decreases.

¹³ Nevertheless, some preliminary calibration was done which indicated that the databus fuel sensors underestimate fuel consumption by about 7% to 9%.

runs 91 to 100. Just by chance, the combination of the amount of fuel in the tank at the beginning and end of the 4,000 mile trip for any of these runs was such that the observed discrepancy in fuel consumption would have been positive. In this case, the conclusion would have been that the databus overestimated fuel consumption even when in reality it could have underestimated it or measured it with total accuracy.

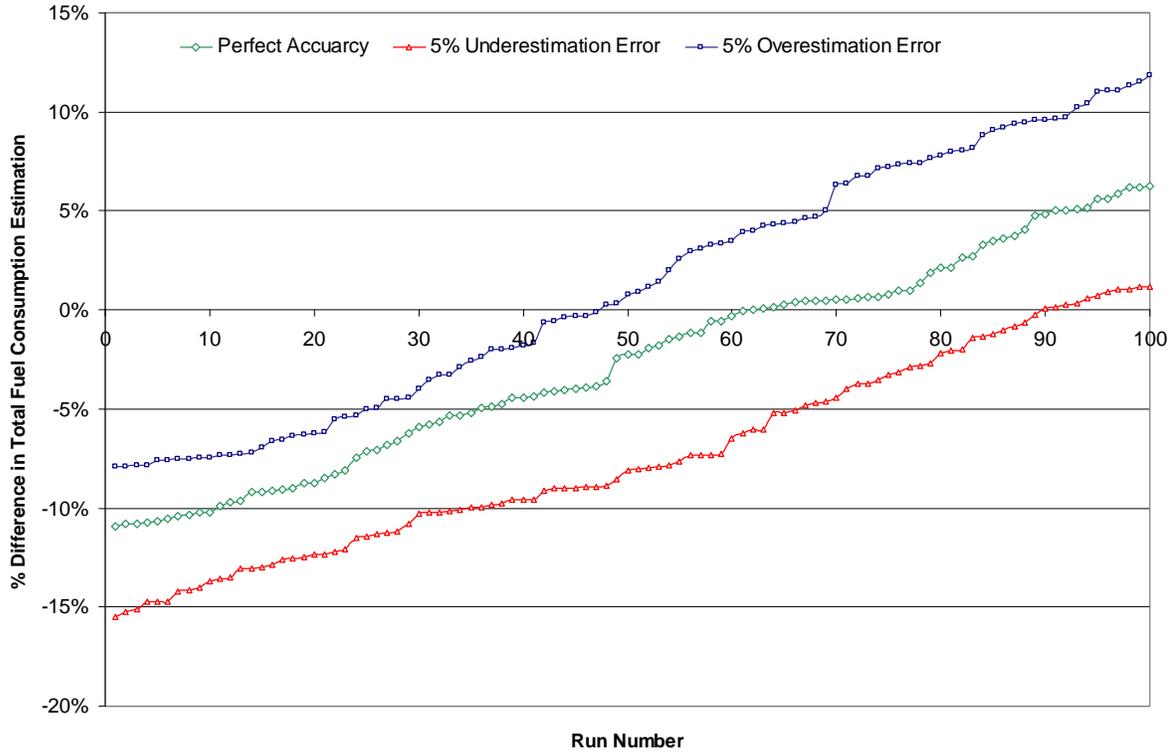


Fig. 62. Fuel Consumption Estimation Errors

Even though it was not possible to calibrate the gathered fuel information because of the reasons stated above, a literature review on this topic showed that the errors introduced by measuring fuel consumption with databus information are small. For example, Mats Bohman (2006) reports that databus fuel consumption estimation was within 1% of the readings obtained using a fuel measurement tube (i.e., a two-meter long tube with known diameter that is used instead of the fuel tank). Similarly, a 2002 EPA study indicates that the fuel consumption obtained from databus information is accurate, as long as severe “spikes” in the data stream are capped (EPA, 2002). For the present study, this precaution was followed by restricting the maximum rate of change for fuel flow to approximately 0.018 (gal/sec)/sec.

Browand, Radovich, and Boivin (2005) indicate that the use of the databus fuel rate signal is accurate and reliable particularly if differences in fuel consumptions are measured rather than absolute values. In other words, systematic errors in the estimation of fuel consumption are not important (and in fact are irrelevant) when comparing fuel economies to, for example, determine if a given type of tires is more efficient than another type. Consider, for example, that the databus always overestimates fuel consumption by a given percentage $p > 1$ and that this factor is intrinsic to that particular databus (i.e., any truck with the same databus would always overestimate fuel consumption by p). Suppose that truck T has the fuel consumption curve shown in Fig. 63 for a given trip t . In that figure, the real fuel

consumption per unit of distance traveled¹⁴ is shown by a continuous line, while the curve obtained from information gathered from the databus with a sensor that overestimates fuel consumption, is shown by the dashed line. For example, at distance D_1 , the real fuel consumption per unit of distance traveled is FCR_{1A} , while the databus would have indicated FCR_{1B} at the same point where

$$FCR_{1B} = FCR_{1A} \times p \quad \text{Eq. (1)}$$

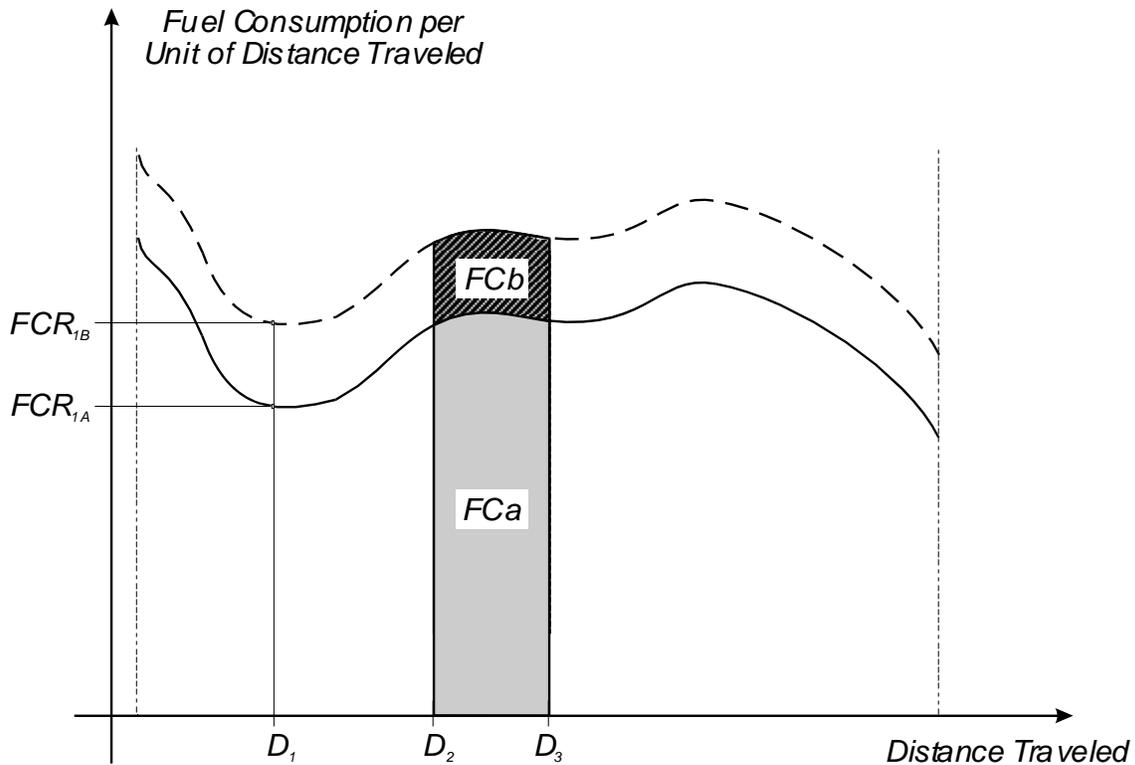


Fig. 63. Fuel Consumption for Truck T

In the same figure, the total fuel consumed between points D_2 and D_3 is computed by calculating the area under the fuel consumption per unit of distance traveled curved. In this example, the actual fuel consumed when truck T traveled between these two points was FCa while the databus would have reported FCb , where:

$$FCb = FCa \times p \quad \text{Eq. (2)}$$

as can be determined using Eq. (1).

Assuming that the distance traveled between D_2 and D_3 is one unit, then the real fuel efficiency (fea) for truck T in trip t_{23} would be:

¹⁴ The databus information is provided in terms of fuel rate per unit of time; this information can be combined with the vehicle speed to obtain fuel consumption per unit of distance traveled.

$$fea = \frac{(D_3 - D_2)}{FCa} = \frac{1}{FCa} \quad \text{Eq. (3)}$$

while the fuel efficiency computed using information obtained from the vehicle databus would have been:

$$feb = \frac{(D_3 - D_2)}{FCb} = \frac{1}{FCb} \quad \text{Eq. (4)}$$

Replacing Eq. (2) into (4) and defining $q = 1/p$ then:

$$feb = \frac{1}{FCa \times p} = \frac{q}{FCa} \quad \text{Eq. (5)}$$

Consider now truck T' which is identical to truck T (i.e., it has the same databus configuration and electronics as well as the same on-board sensors) but it has a different tire configuration. Assume also that T' made the same trip, t , as T did. Fig. 64 shows the fuel consumption per unit of distance traveled for truck T' . Since both vehicles have the same databus and electronics, it can be assumed that the fuel consumption computed using information collected from the databus of truck T' would be larger than the actual fuel consumption by a factor of p . Using the same logic as in the case of truck T , it is possible to determine the actual fuel efficiency for truck T for in trip t_{23} as shown in Eq. (6):

$$fea' = \frac{(D_3 - D_2)}{FCa'} = \frac{1}{FCa'} \quad \text{Eq. (6)}$$

and the fuel efficiency computed using the information from the databus as:

$$feb' = \frac{1}{FCa' \times p} = \frac{q}{FCa'} \quad \text{Eq. (7)}$$

Suppose now that in order to compare the effect of a given characteristic (e.g., type of tires) on the fuel efficiency reported by T and T' , the percentage difference in fuel efficiency between trucks T and T' is computed. Using the actual fuel efficiencies (i.e., fuel efficiencies calculated with no errors) this percentage difference would be:

$$DFEt = \frac{(fea' - fea)}{fea} \times 100 = \frac{\left(\frac{q}{FCa'} - \frac{q}{FCa}\right)}{\frac{q}{FCa}} \times 100 = \left(\frac{FCa}{FCa'} - 1\right) \times 100 \quad \text{Eq. (8)}$$

which was obtained with the help of Eqs. (3) and (6). If this percentage difference in fuel efficiencies is computed using the erroneous (i.e., overestimated) databus fuel consumption then:

$$DFEe = \frac{(feb' - feb)}{feb} \times 100 = \frac{\left(\frac{q}{FCa'} - \frac{q}{FCa}\right)}{\frac{q}{FCa}} \times 100 = \left(\frac{FCa}{FCa'} - 1\right) \times 100 \quad \text{Eq. (9)}$$

which was obtained with the help of Eqs. (5) and (7). Comparing Eqs. (8) and (9) it is clear that:

$$DFEt = DFEe \quad \text{Eq. (10)}$$

which indicates that the percentage difference between the computed fuel efficiencies for trucks T and T' is the same whether or not the actual fuel efficiencies have been measured accurately; as long as the fuel consumption measurement error is systematic.

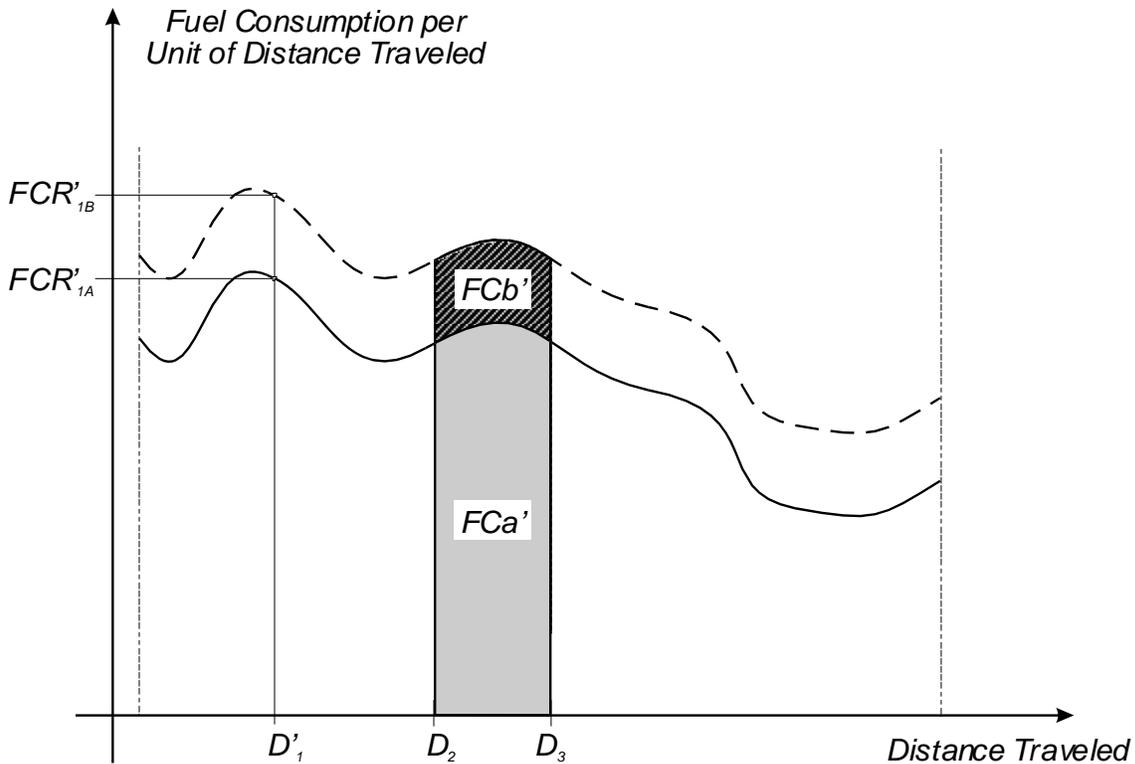


Fig. 64. Fuel Consumption for Truck T'

6.3 DATA ANALYSIS

The main focus of the data analysis is on the effect that different combinations of tires (i.e., NGSWBTs and regular dual tires), mounted on the tractor and trailer, have on the fuel efficiency of Class-8 trucks. The dependency of these fuel efficiencies on the type of tires is studied for the general case in which all the other variables that may affect fuel consumption, such as vehicle weight, traffic conditions, type of terrain, weather, etc. are considered to equally affect all the six vehicles that participated in the experiment. That is, due to the very large database, it can safely be assumed (and proved) that any particular truck has encountered similar (traffic, weather, load, etc.) conditions over

the course of the year-long data collection period as any of the other five trucks. Besides this general case, particular conditions such as the effect that vehicle weight and congestion levels have on the fuel efficiency of the Class-8 trucks equipped with different type of tires are also investigated in this section.

6.3.1 General Statistics

Over the 12-month data collection period, the six participating trucks logged close to 700,000 miles and consumed over 100,000 gallons of fuel while undertaking 1,100 trips¹⁵ and visiting 37 states in the U.S. and one Canadian province. Table 14 below presents a summary of these statistics for each one of the six participating tractors. The header of the table includes information about the type of transmission and tires that each one of these six tractors had. The table also includes information regarding fuel efficiencies for the entire data collection period, for each of the six vehicles as well as their overall fuel efficiency. These calculations were made using fuel consumption information obtained from the vehicles' databus (last row in Table 14) and include both the fuel consumed while the vehicle is moving as well as the fuel spent while idling. Notice that, in general, tractors equipped with the NGSWBTs had higher fuel efficiencies than those equipped with regular dual tires.

Table 14. General Statistics for the Instrumented Tractors

Statistics	T1 (M ¹ -S ^A)	T2 (M ¹ -D ^B)	T3 (A ² -S ^A)	T4 (M ¹ -D ^B)	T5 (A ² -S ^A)	T6 (A ² -D ^B)	Grand Total
Distance Traveled [miles]	106,891	114,095	117,355	124,917	127,626	97,417	688,302
Total Time for Which Data was Collected ³ [hrs]	3,783	4,451	3,779	4,413	4,281	3,067	23,774
Avg. Speed ⁴ [mph]	28.26	25.63	31.05	28.31	29.81	31.76	28.95
Total Fuel Consumed [gal]	15,982	16,701	16,805	19,361	18,494	15,995	103,336
Overall Fuel Efficiency [mpg] From the Databus Sensor	6.69	6.83	6.98	6.45	6.90	6.09	6.66

¹Manual Transmission; ² Automatic Transmission; ³ Includes Idling times; ⁴Distance Traveled/Total Time for Which Data Was Collected (includes idling times); ^A NGSWBTs; ^B Dual Tires

The information collected was further divided into short-haul (less than 100 miles) and long-haul (over 100 miles) trips, and the total, moving, stopped, and idling times were calculated as well as the fuel consumed, for all of the participating trucks combined. That information is presented in Table 15 and Table 16. The “Stop Time” and “Stop Fuel” statistics include the condition in which the vehicle was static (i.e., not moving) and the engine was either running or not; while the “Idling Time” and “Idling Fuel” statistics include only the condition of a static vehicle with the engine running (this includes times when the truck was stopped because of congestion or other type of traffic related delays).

While short-haul trips presented proportionally larger idling times than those shown by long-haul trips (i.e., 69.0% of the total time spent on the trip vs. 49.5% of the total time, respectively, or close to a 3-to-2 ratio), the former consumed a significantly larger proportion of the total fuel for idling purposes than the latter (i.e., a ratio of about 3-to-1, or 21.2% vs. 6.7%, respectively). Notice also that short-haul trips are a very small portion (about 2.0%) of the total trips.

¹⁵ A trip is considered here as a journey in which either the origin or destination is the parking lot of the participating trucking company, with the other end of the journey being any place other than the parking lot of the company. For example, going from Jefferson City, TN (i.e., the place where Schrader is located) to Cincinnati, OH and coming back to Jefferson City, TN would be considered as two trips.

Table 15. General Statistics: Total, Moving, Stopped, and Idling Times for all Trucks by Trip Type

		Time [hrs]	As % of Total Time	As % Stop Time
Short-Haul	Total Time	478		
	Moving Time	96	20.1%	
	Stopped Time	382	79.9%	
	Idling Time	330	70.0%	86.4%
Long-Haul	Total Time	23,309		
	Moving Time	11,763	50.5%	
	Stopped Time	11,546	49.5%	
	Idling Time	11,154	47.9%	96.6%
Total (Short-Haul plus Long-Haul))	Total Time	23,787		
	Moving Time	11,859	49.9%	
	Stopped Time	11,927	50.1%	
	Idling Time	11,483	48.3%	96.3%

Table 16. General Statistics: Fuel Consumed for the Total, Moving, Stopped, and Idling Fuel for All Trucks by Trip Type

		Fuel [gal]	As % of Total Fuel	As % Stop Fuel
Short Haul	Total Fuel	936		
	Moving Fuel	762	81.4%	
	Stopped Fuel	199	21.2%	
	Idling Fuel	199	21.2%	100.0%
Long Haul	Total Fuel	100,936		
	Moving Fuel	96,096	95.2%	
	Stopped Fuel	6,770	6.7%	
	Idling Fuel	6,770	6.7%	100.0%
Total (Short-Haul plus Long-Haul))	Total Fuel	101,872		
	Moving Fuel	96,858	95.1%	
	Stopped Fuel	6,968	6.8%	
	Idling Fuel	6,968	6.8%	100.0%

The information presented in the previous two tables is further expanded and shown in Fig. 65 to Fig. 67 as the distribution of idling time and idling fuel as percentage of total time and total fuel consumed, respectively. Seven intervals of time are considered, ranging from 0-5 minutes (i.e., the vehicle was idling –i.e., vehicle static and engine running– for less than five minutes) to more than 240 minutes (4 hours); with the short intervals corresponding to idling due to traffic conditions (i.e., delays at traffic lights, congestion) and the largest one to overnight parking. For both short-haul and long-haul trips, a significant proportion of idling time and fuel consumed while idling correspond to idling intervals that last between 15 and 60 minutes. Moreover, for long-haul trips (and total trips), the proportion of fuel consumed during those idling intervals is disproportionately larger than the proportion of idling time (it would be expected both to be the same). Those 15-60 minute idling intervals may correspond to congested roadway conditions (e.g., lanes blocked due to crashes), especially those cases in which the time idling is close to 15 minutes; or to loading/unloading

operations, especially those close to 60 minutes. Nevertheless, further investigation is needed to determine more precisely the nature of the idling.

The largest proportion of idling time, and associated fuel consumption, corresponds to overnight parking (idling intervals of more than four hours). In the case of long-haul and total (i.e., short- and long-haul) trips, about 50% of the total idling time, and 45% of the total idling fuel consumed, correspond to idling intervals that last more than four hours (see Fig. 66 and Fig. 67).

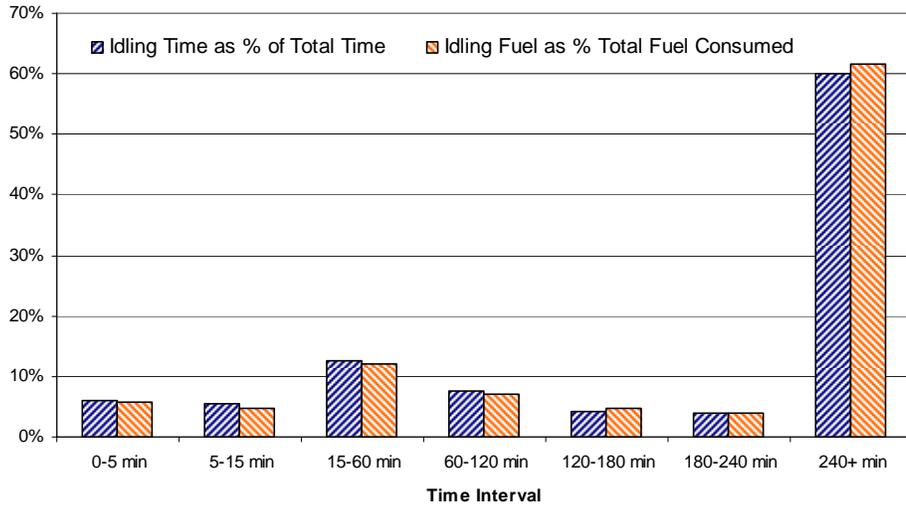


Fig. 65. Distributions of Time Spend and Fuel Consumed while Idling (All Trucks, Short-Haul)

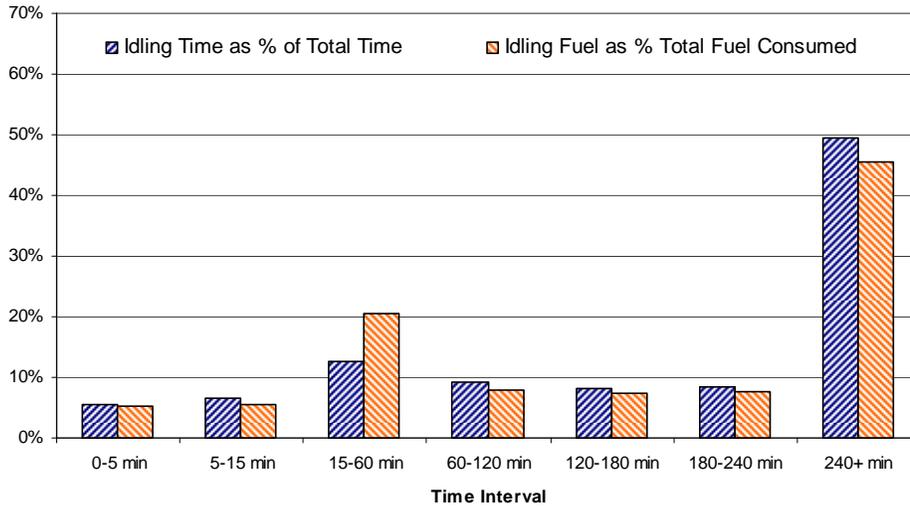


Fig. 66. Distributions of Time Spent and Fuel Consumed while Idling (All Trucks, Long-Haul)

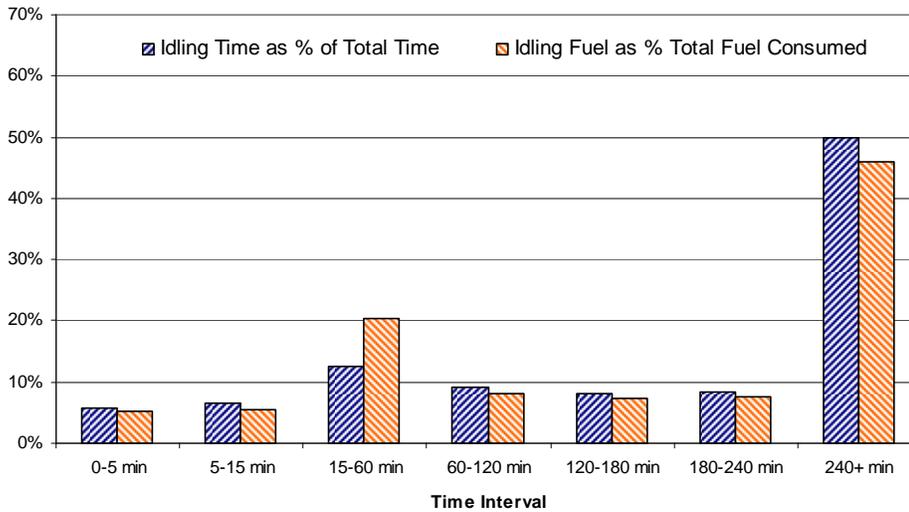


Fig. 67. Distributions of Time Spent and Fuel Consumed while Idling (All Trucks, All Trips)

6.3.2 Class-8 Truck Fuel Efficiency

Using the information presented in Table 14 it is possible to compute the fuel efficiencies of tractors equipped with NGSWBTs and regular dual tires, hauling any type of load. This information is presented in Table 17 and shows that, overall, trucks with tractors equipped with NGSWBT tires present better fuel efficiencies (i.e., above 6% improvement) than those mounted with dual tires, independent of the type of tires on the trailer.

Table 17. Fuel Efficiency: Tractors with NGSWBTs vs. Tractors with Dual Tires (Trailers with Any Type Tire)

Truck Tire Configuration	Fuel Efficiency*
Tractors with NGSWBTs (Trailer with Any Type Tire)	6.86 mpg
Tractor with Dual Tires (Trailer with Any Type Tire)	6.46 mpg
% Difference NGSWBTs vs. Dual Tires	6.19%

* Fuel efficiencies computed using collected databus information.

Similar information is presented in Table 18, but categorized by type of transmission –automatic and manual– and the length of the trip –short-haul and long-haul, and all trips. Notice that in eight out of nine cases, tractors equipped with NGSWBTs outperformed (in some cases by a significant percentage) those tractors mounted with dual tires in terms of fuel efficiency, independently of the type of tires mounted on the trailer. The exception was for short-haul trips and tractors with automatic transmissions. For this case the tractors with dual tires were more fuel efficient than those equipped with NGSWBTs. Notice, however, that as pointed out above, short-haul trips were only about 2.0% of the total trips, and those for which a tractor with automatic transmission was involved, were considerably less (i.e., less than 0.3% of the total trips), which makes the entry on the first row and last column of Table 18 insignificant when compared with entries in the same column for the second and third row of that table. Nevertheless, further studies are needed to explain this observation and to determine if it is statistically significant.

Table 18. Fuel Efficiency* by Transmission Type: Tractors with NGSWBTs vs. Tractors with Dual Tires (Trailers with Any Type Tires)

Trip Type	Manual and Auto			Manual			Auto		
	NGSWBTs (mpg)	Duals (mpg)	% Diff	NGSWBTs (mpg)	Duals (mpg)	% Diff	NGSWBTs (mpg)	Duals (mpg)	% Diff
Short-Haul	5.78	5.71	1.18%	6.50	5.64	15.20%	5.36	5.91	-9.35%
Long-Haul	6.87	6.47	6.20%	6.69	6.64	0.80%	6.95	6.09	14.11%
Overall	6.86	6.46	6.17%	6.69	6.63	0.91%	6.94	6.09	13.95%

* Fuel efficiencies computed using collected databus information.

6.3.2.1 Fuel efficiency comparison when considering tractor and trailer tires

As discussed previously (see section 6.1.4 above), the database containing the information collected for this study was indexed using different criteria. One of these criteria was the type of tires (i.e., duals or NGSWBTs) that any trailer attached to one of the six participating tractors had during any given trip. Using this information, it was possible to divide the database into four categories that reflect the four possible combinations of tires mounted on the tractor and mated trailer, (that is:

1. tractor with duals and trailer with duals,
2. tractor with duals and trailer with NGSWBTs,
3. tractor with NGSWBTs and trailer with duals, and
4. tractor with NGSWBTs and trailer with NGSWBTs),

permitting the isolation of the effect of a given tire combination on the fuel efficiency of Class-8 trucks.

Fig. 68 to Fig. 71 show the areas covered by the participating vehicles for each one of the four truck tire combinations. On these maps, the routes traveled are indicated with circles, and, although it cannot be seen directly on these maps, the majority of the road segments shown were traveled many times during the 12-month data collection period. Notice also that except for two or three trips to Utah (see Fig. 70 and Fig. 71) all of the trips had origins and destinations that were located within the eastern half of the continental U.S. Therefore, it is possible to assume that all the six tractors traveled under the same conditions in terms of weather, traffic, terrain, etc, and that the results of the analysis below are unbiased in terms of conditions other than the type of tires mounted on the tractor and trailer¹⁶.

¹⁶ The other main variable, of course, is the driver of the vehicle. However, since Schrader has a very extensive driver training and follow-up program, it is possible to assume that the effect of the driver in the achieved fuel efficiencies was minimal, i.e., they had only a minimal effect on the variability of the collected data.

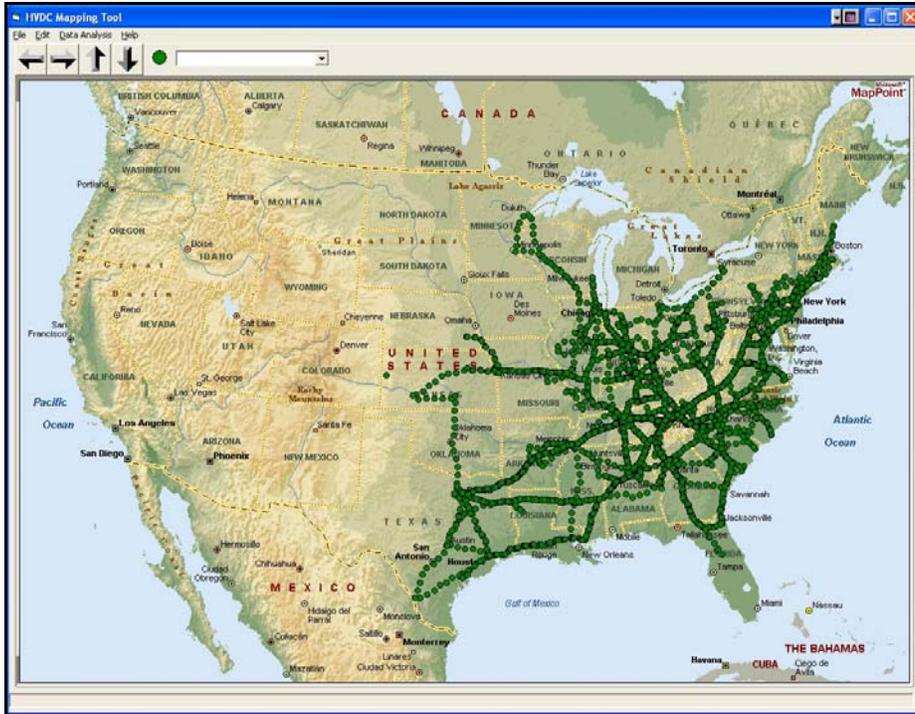


Fig. 68. All Trips with Dual Tires Mounted on Both the Tractor and the Trailer

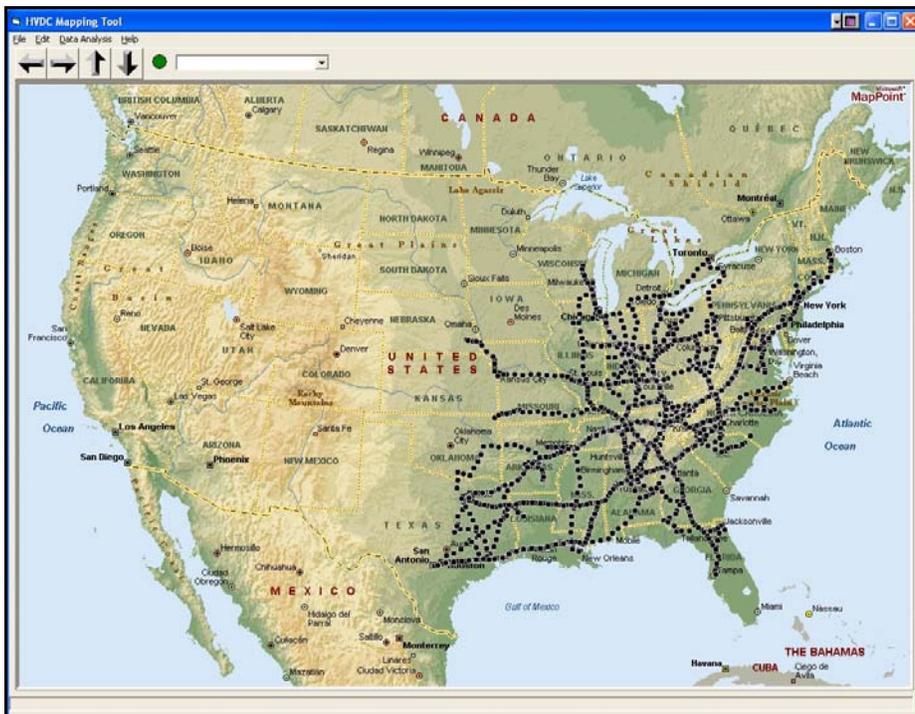


Fig. 69. All Trips with Dual Tires Mounted on the Tractor and NGSWBs Mounted on the Trailer

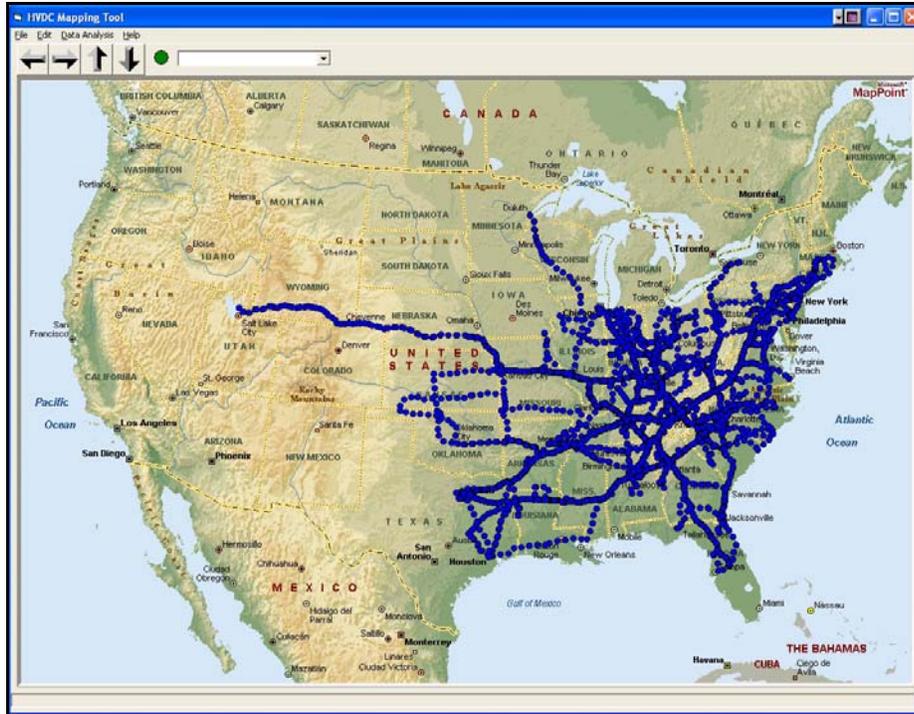


Fig. 70. All Trips with NGSWTs Mounted on the Tractor and Dual Tires Mounted on the Trailer

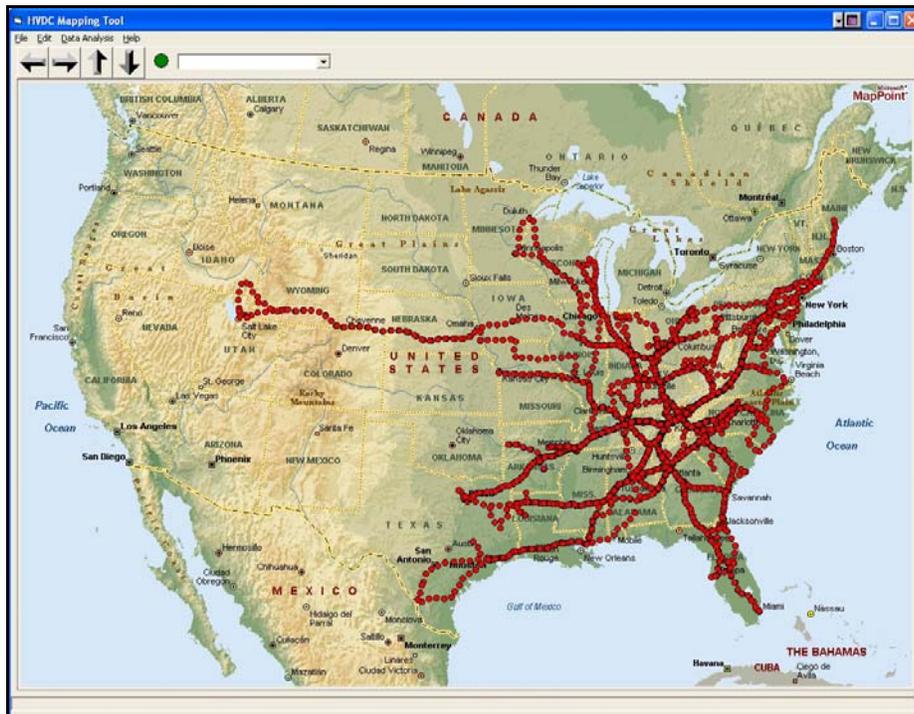


Fig. 71. All Trips with NGSWTs Mounted on Both the Tractor and the Trailer

The almost 700,000 miles logged during the data gathering phase of this study were divided into the four categories mentioned above¹⁷. For each one of these tire-combination categories, and for each one of the tractors that corresponded to that specific category (e.g., tractors 1, 3, and 5 were mounted with NGSWBTs and therefore always belonged to the last two categories; whether it was category 3 or 4 depended on the type of tires that the trailer had on any particular trip), the total distance traveled by that particular tractor during the entire data collection period was divided into 100-mile segments and the fuel consumed while traversing these segments was computed. With these two pieces of information, it was possible to calculate fuel efficiencies for each of the 100-mile segments for any given truck-tire category. Table 19 presents the results of these computations, where the column labeled “Average Fuel Efficiency” contains the average of the fuel efficiencies across all of the 100-mile segments that were generated for each particular truck-tire combination. The last column of the table shows the percent difference in fuel efficiencies when comparing against the base case (i.e., the case in which tractor and the trailer are equipped with dual tires, which is the most common tire set up at the present time in the U.S.). Table 20 is similar to Table 19, except that for any given truck tire combination, the fuel efficiency was computed by dividing the total number of miles logged by the total number of gallons of fuel consumed during the entire data collection period. Notice that, independently of how the calculations are performed (i.e., using 100-mile segments or the total distance traveled during the data collection period), there is always an improvement in fuel efficiency with respect to the base case (duals on the tractor and duals on the trailer). Moreover, that fuel efficiency improvement increases as the number of NGSWBTs increases, with observed improvements of about 6% when either the tractor or the trailer is equipped with NGSWBTs, to more than 9% when both are mounted with NGSWBTs.

Table 19. Fuel Efficiency Comparison by Truck-Tire Configuration (Averages Computed Using Fuel Efficiencies Calculated for 100-Mile Segments)

Truck Tire Configuration	Distance Traveled (miles)	Average Fuel Efficiency ¹ (mpg)	% Diff ²
Duals-Duals	179,503	6.60	0.00%
Duals-NGSWBTs	85,002	7.00	6.00%
NGSWBTs-Duals	190,503	7.03	6.40%
NGSWBTs-NGSWBTs	87,002	7.22	9.29%
	542,010		

¹Fuel efficiencies computed using collected databus information.

²As compared to the Duals-Duals case

Table 20. Fuel Efficiency Comparison by Truck-Tire Configuration (Averages Computed Using Total Distance Traveled and Total Fuel Used)

Truck Tire Configuration	Distance Traveled (miles)	Average Fuel Efficiency ¹ (mpg)	% Diff ²
Duals-Duals	179,503	6.40	0.00%
Duals-NGSWBTs	85,002	6.77	5.69%
NGSWBTs-Duals	190,503	6.83	6.76%
NGSWBTs-NGSWBTs	87,002	7.03	9.84%
	542,010		

¹Fuel efficiencies computed using collected databus information.

²As compared to the Duals-Duals case

¹⁷ There are in reality six categories, since it is possible to have trips with just the tractor and no trailer. However, those two categories (i.e., tractor with duals and tractor with NGSWBTs) constitute not only a very small portion of all trips, but also are cases of very high fuel efficiencies since the tractor is pulling no weight. Those cases were not considered in this analysis.

To statistically corroborate these results, a test of hypothesis was performed. That is, a null hypothesis asserting that there is no difference between the distribution of fuel efficiencies for any tire combination that has NGSWBTs and that of the base case (i.e., all duals) was tested against an alternative hypothesis stating that the average of the distributions of the fuel efficiencies of the former are larger than that of the latter. In other words, calling μ_{xx} the mean of the distribution of 100-mile segment fuel efficiencies, where at least some of the tires (i.e., either those on the tractor, the trailer, or both) are NGSWBTs, and μ_{DD} the mean of the distribution of 100-mile segment fuel efficiencies computed for vehicles with all dual tires; then the null and alternative hypotheses are represented by equations (11) and (12) below.

$$H_o: \mu_{xx} = \mu_{DD} \quad \text{Eq. (11)}$$

$$H_a: \mu_{xx} > \mu_{DD} \quad \text{Eq. (12)}$$

Fig. 72 to Fig. 75 show respectively the distribution of fuel efficiencies computed for the 100-mile segments using the databus-collected information for the following truck tire combinations; Duals-Duals, Duals-NGSWBTs, NGSWBTs-Duals, and NGSWBTs-NGSWBTs. As the figures show, the distributions of fuel efficiencies are very close to normal distributions; moreover, since the sample size for each of the cases is above 800 observations, the Central Limit Theorem (Devore, 1987) applies, and it is possible to assume that the average of any one of the fuel efficiency distributions under consideration is normally distributed, and that it is an unbiased estimator of the true mean μ .

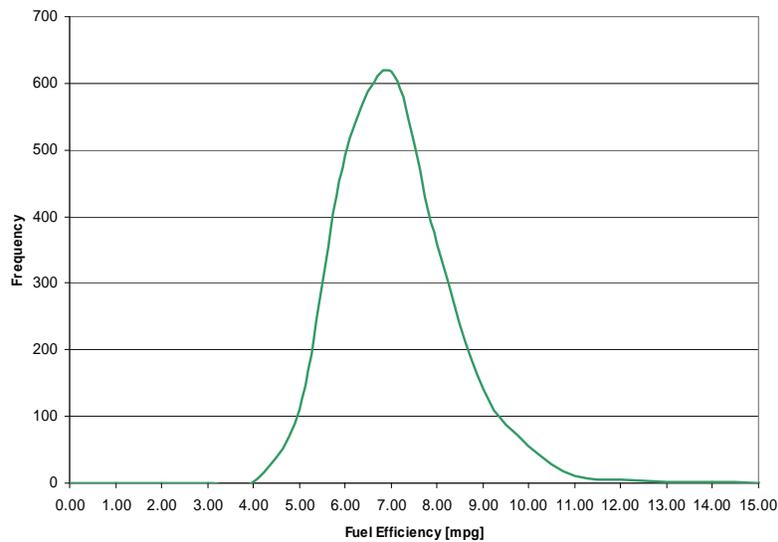


Fig. 72. Distribution of Fuel Efficiencies Computed for 100-Mile Segments (All Trips with Dual Tires Mounted on Both the Tractor and the Trailer)

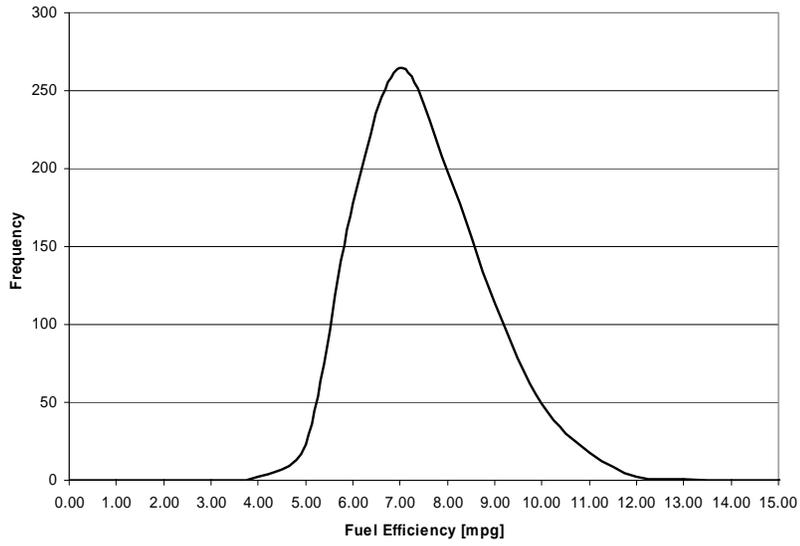


Fig. 73. Distribution of Fuel Efficiencies Computed for 100-mile Segments (All Trips with Dual Tires Mounted on the Tractor and NGSWBTs on the Trailer)

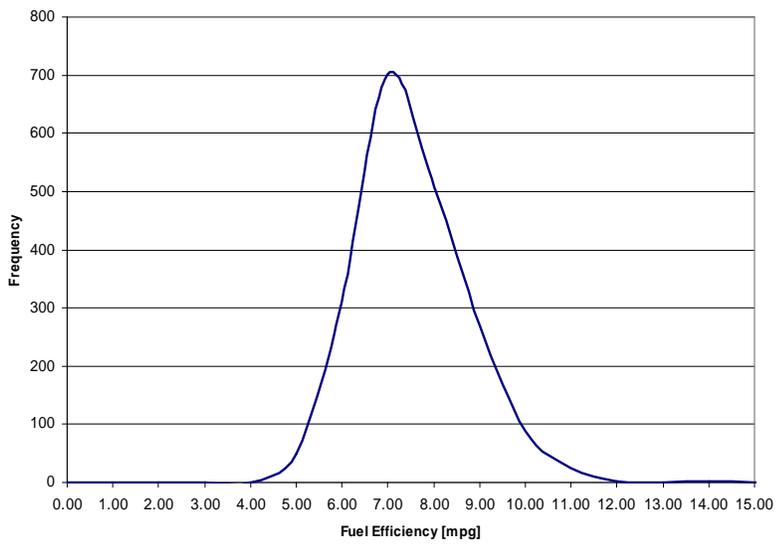


Fig. 74. Distribution of Fuel Efficiencies Computed for 100-mile Segments (All Trips with NGSWBTs Mounted on the Tractor and Duals on the Trailer)

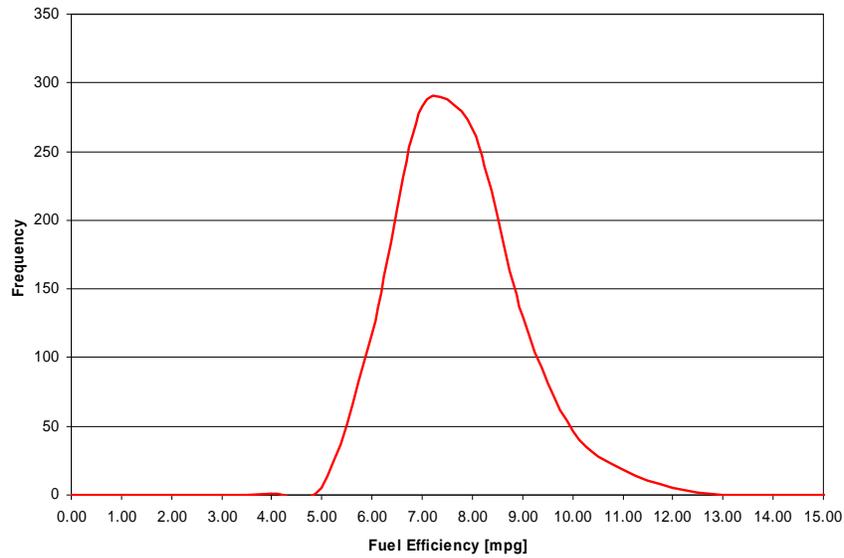


Fig. 75. Distribution of Fuel Efficiencies Computed for 100-mile Segments (All Trips with NGSWBTs Mounted on Both the Tractor and the Trailer)

Fig. 76 and Fig. 77 show sample duty cycles for two randomly selected 100-mile segments corresponding to the Duals-Duals and NGSWBTs-NGSWBTs tire combinations, respectively. The fuel efficiencies calculated for these two 100-mile duty cycles correspond to one observation in each of the distributions shown in Fig. 72 to Fig. 75, respectively. Both correspond to freeway duty cycles; the first one representing operation under free-flow traffic conditions and the second one includes some traffic congestion intervals. The fuel consumed during these real-world duty cycles was used to compute one observation of the fuel efficiency for the two tire combinations.

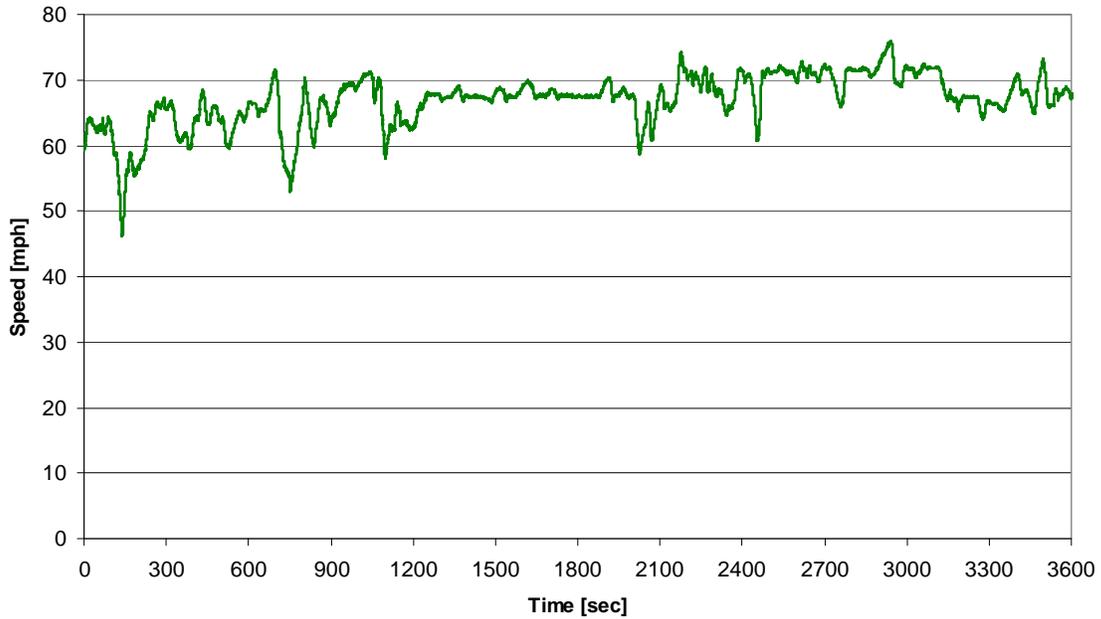


Fig. 76. First Hour of a Duty Cycle Corresponding to a Randomly Selected 100-mile Segment, All Trips with Duals Mounted on Both the Tractor and the Trailer (Segment 22, Truck 2, Fuel Efficiency = 7.16 mpg)

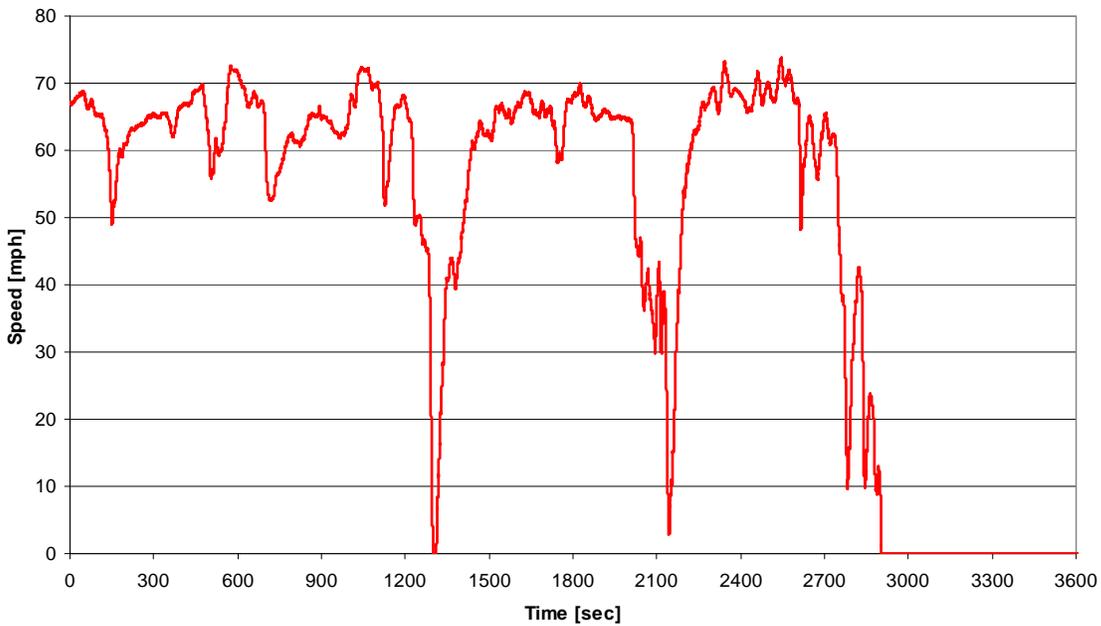


Fig. 77. First Hour of a Duty Cycle Corresponding to a Randomly Selected 100-Mile Segment, All Trips with NGSWTs Mounted on Both the Tractor and the Trailer (Segment 174, Truck 5, Fuel Efficiency = 7.63 mpg)

Table 21 presents a summary of the statistics describing each one of the four fuel efficiency distributions presented in Fig. 72 to Fig. 75. For each one of the truck-tire configurations, the first

three rows of Table 21 show the average (same as the ones presented in Table 19), standard deviation and sample size of each of the distributions. Notice that the minimum sample size is 850 observations (Duals-NGSWBTs) with a maximum of 1,956 observations (100-mile segments) for the NGSWBTs-Duals case. The fourth row in Table 21 presents the mean of the difference between the sample average fuel efficiency of the truck- tire combination of the corresponding column and that of the Duals-Duals case. The fifth row shows the standard deviation of the difference which, together with the mean and sample size, permits the computation of the test statistic value z (a one-tailed test based on the alternative hypothesis shown in Eq. 12 and provided in row six of Table 21). For the three truck- tire configurations that have some or all NGSWBTs, the null hypothesis, which states that there is no difference in terms of fuel efficiency that can be explained by different tire configurations, can be rejected with 100% confidence in favor of the alternative hypothesis, which indicates that on average the fuel efficiencies obtained when using the Duals-Duals combination is lower than in the other cases. This strongly suggests that fuel efficiencies in cases using some or all NGSWBTs are higher than in the case of a truck equipped with all dual tires. In other words, the percent improvements in fuel efficiencies that are achieved when using all NGSWBTs or combinations of duals and NGSWBTs are statistically significant. And as demonstrated in the last sub-section, even if the databus does not measure fuel consumption with total precision, as long as the information collected from the six databuses present the same systematic bias, then the percent differences are still accurate.,.

Table 21. Fuel Efficiency Comparison by Truck-Tire Configuration (Null Hypothesis: All Fuel Efficiency Distributions Are the Same)

	Truck-Tire Configuration			
	Duals-Duals	Duals-NGSWBTs	NGSWBTs-Duals	NGSWBTs-NGSWBTs
Sample Average Fuel Efficiency ¹ (mpg)	6.60	7.00	7.03	7.22
Sample Std. Dev.	1.21	1.32	1.19	1.19
Sample Size	1,798	850	1,956	871
Mean of Difference with Duals-Duals		0.40	0.42	0.61
Std. Dev. of Difference with Duals-Duals		0.05	0.04	0.05
Test Statistic Value (Z)		7.41	10.77	12.43
Reject Ho at Confidence Level =		100.00%	100.00%	100.00%

¹Fuel efficiencies computed using collected databus information.

6.3.2.2 Effect of Vehicle Weight on Fuel Efficiency

The extensive database and powerful search engine created for this study allows researchers to study other aspects of fuel efficiency., For example, studies involving the effects that different tractor/trailer tire combinations have on the fuel efficiency of Class-8 trucks, when additional variables are taken into account, would be of interest. One very important variable affecting fuel efficiency is the weight of the vehicle.

The previous sub-section showed that there were improvements of the fuel efficiency of the types of vehicles studied here when at least some of the tires (either those mounted on the tractor, the trailer, or both) were NGSWBTs. Those results were obtained without controlling for any particular variable (other than the type of tires) since it could be assumed that any of the participating vehicles would experience the same situations (terrain, weather, load) over the course of the year-long experiment. It is, however, important to determine whether the observed increases in fuel efficiency due to the type of tires used is maintained once the data is controlled for vehicle weight. That is, it is important to determine if the gains on fuel efficiency due to the type of tires used are more significant when the

vehicle is hauling light or heavy loads since most of the Class-8 truck trips fall into the second weight category.

To do this, the search engine of the DCGenT Prototype was used to parse the data by truck-tire combination and vehicle load level. The vehicle weight was divided into four categories: 1) Tractor Only (trips made without any trailer), 2) Light Load (total vehicle weight between 24,000lbs and 44,000lbs); 3) Medium Load (total vehicle weight between 44,000lbs and 62,000lbs); and 4) Heavy Load (total vehicle weight between 62,000lbs and 80,000lbs). As in the previous sub-section, 100-mile segments were considered for which the fuel efficiency was computed and counted as one observation. Table 22 presents the results of this analysis. Under each load level category, the column labeled “Avg. FE” contains the average of the fuel efficiencies across all the 100-mile segments in which each particular truck-tire combination was divided, with the column immediately to the right presenting the percent difference in fuel efficiencies when comparing against the base case (i.e., the case in which the tractor and trailer are equipped with dual tires). For all load levels considered, there is always an improvement in fuel efficiency with respect to the base case (i.e., Duals-Duals). Notice also that fuel efficiency improvement increases as the number of NGSWBTs increases. Moreover, for the particular case in which all tires are NGSWBTs, there are considerable improvements in fuel efficiency with respect to the base case (10+%), and those improvements are more significant as the load level increases.

Table 22. Fuel Efficiency as a Function of Load Level and Truck-Tire Configuration

Truck-Tire Configuration	Load Level							
	Tractor Only		Light Load		Medium Load		Heavy Load	
	Avg. FE ¹ (mpg)	% Diff with Duals-Duals	Avg. FE ¹ (mpg)	% Diff with Duals-Duals	Avg. FE ¹ (mpg)	% Diff with Duals-Duals	Avg. FE ¹ (mpg)	% Diff with Duals-Duals
Duals-Duals	9.01	0.00%	8.06	0.00%	7.17	0.00%	6.24	0.00%
Duals-NGSWBTs	NA	NA	8.61	6.75%	7.48	4.34%	6.50	4.22%
NGSWBTs-Duals	NA	NA	8.63	7.06%	7.51	4.76%	6.56	5.16%
NGSWBTs-NGSWBTs	10.52	16.77%	8.79	8.94%	7.93	10.60%	6.88	10.20%

¹Fuel efficiencies computed using collected databus information.

As in the previous subsection, a series of tests of hypothesis were performed to statistically corroborate these results. The null hypothesis (i.e., there is no difference between the distribution of fuel efficiencies for any tire combination that has NGSWBTs and that of the base case; see Eq. 11) was tested against an alternative hypothesis stating that the average of the distributions of the fuel efficiencies of any tire combination that has NGSWBTs are larger than that of the base case (see Eq. 12). Fig. 78 to Fig. 81 show the distribution of fuel efficiencies computed for 100-mile segments for trucks with Duals-Duals, Duals-NGSWBTs, NGSWBTs-Duals, and NGSWBTs-NGSWBTs tire combinations, respectively, for vehicles carrying heavy loads (i.e., total vehicle weight above 62,000 lbs). As the figures show, the distributions of fuel efficiencies are very close to normal distributions; moreover, since the sample size in any case is large, the Central Limit Theorem applies as in the previous case. That is, it is possible to assume that the average of any one of the fuel efficiency distributions under consideration is normally distributed and it is an unbiased estimator of the true distribution mean.

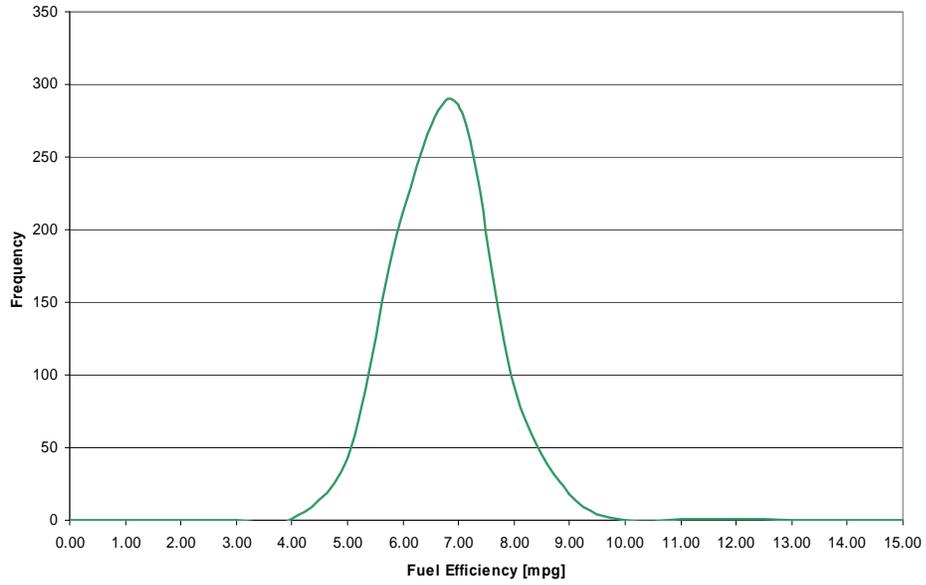


Fig. 78. Distribution of Fuel Efficiencies Computed for 100-mile Segments, All Trips with Dual Tires Mounted on Both the Tractor and the Trailer: Heavy Load Case

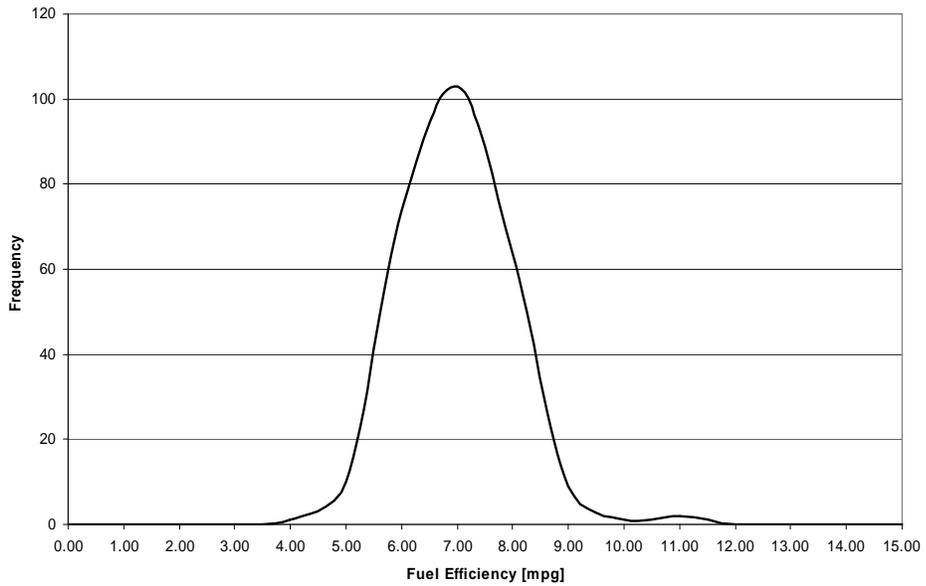


Fig. 79. Distribution of Fuel Efficiencies Computed for 100-mile Segments, All Trips with Dual Tires Mounted on the Tractor and NGSWTs on the Trailer: Heavy Load Case

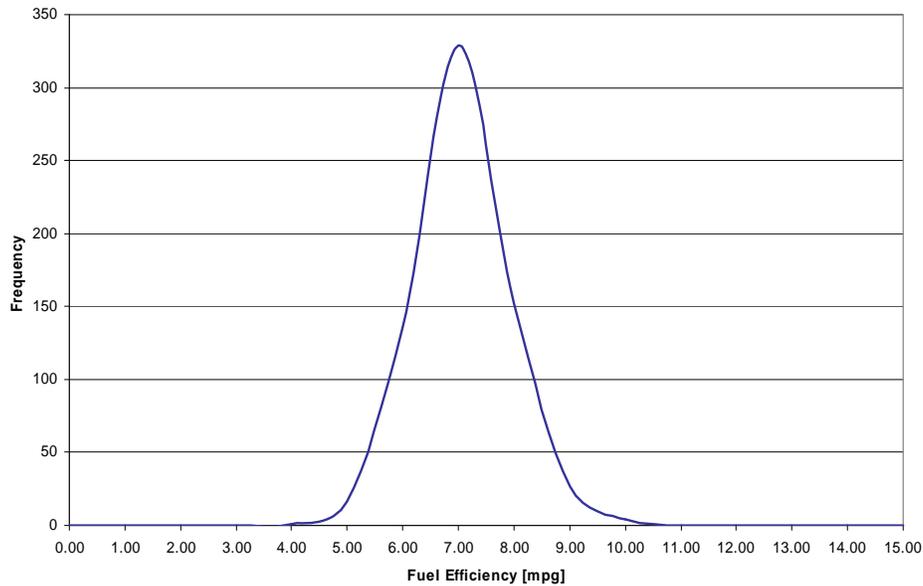


Fig. 80. Distribution of Fuel Efficiencies Computed for 100-mile Segments, All Trips with NGSWBts Mounted on the Tractor and Duals on the Trailer: Heavy Load Case

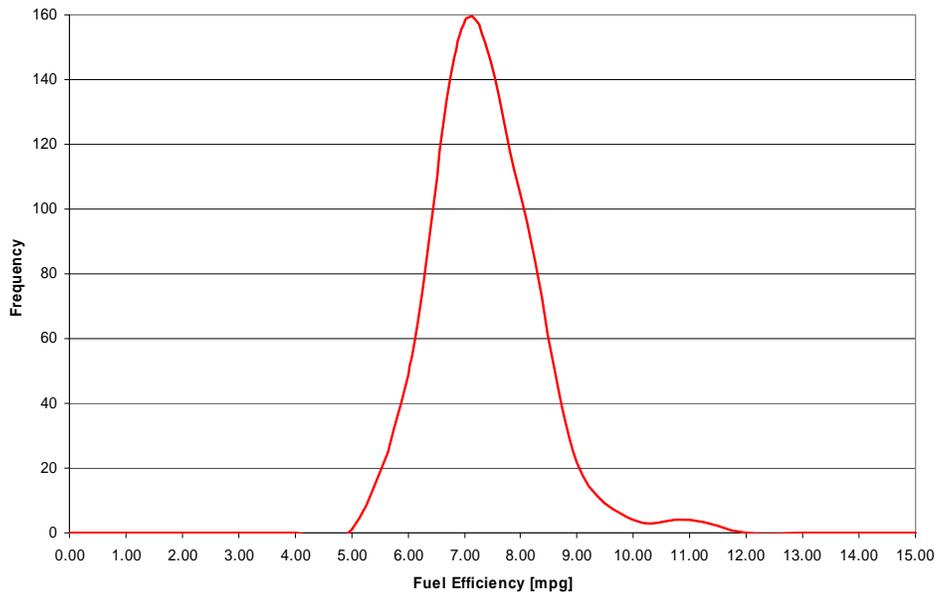


Fig. 81. Distribution of Fuel Efficiencies Computed for 100-mile Segments, All Trips with NGSWBts Mounted on Both the Tractor and the Trailer: Heavy Load Case

Fig. 82 and Fig. 83 show sample duty cycles for two randomly selected 100-mile segments corresponding to the Duals-Duals and NGSWBts-NGSWBts tire combinations, respectively, for vehicles carrying medium loads. The fuel efficiencies calculated for these two 100-mile duty cycles correspond to one observation of the distributions shown in Fig. 78 and Fig. 81, respectively. The first duty cycle (Fig. 82) shows mainly maneuvers around a parking area while the second one is a duty cycle that combines freeways and surface streets. The fuel consumed during these real-world

duty cycles was used to compute one observation of the fuel efficiency for the two tire combinations. As can be seen by the randomly selected duty cycles shown in Fig. 76, Fig. 77, Fig. 82, and Fig. 83, the database created for this project contains very diverse Class-8 Truck duty cycles.

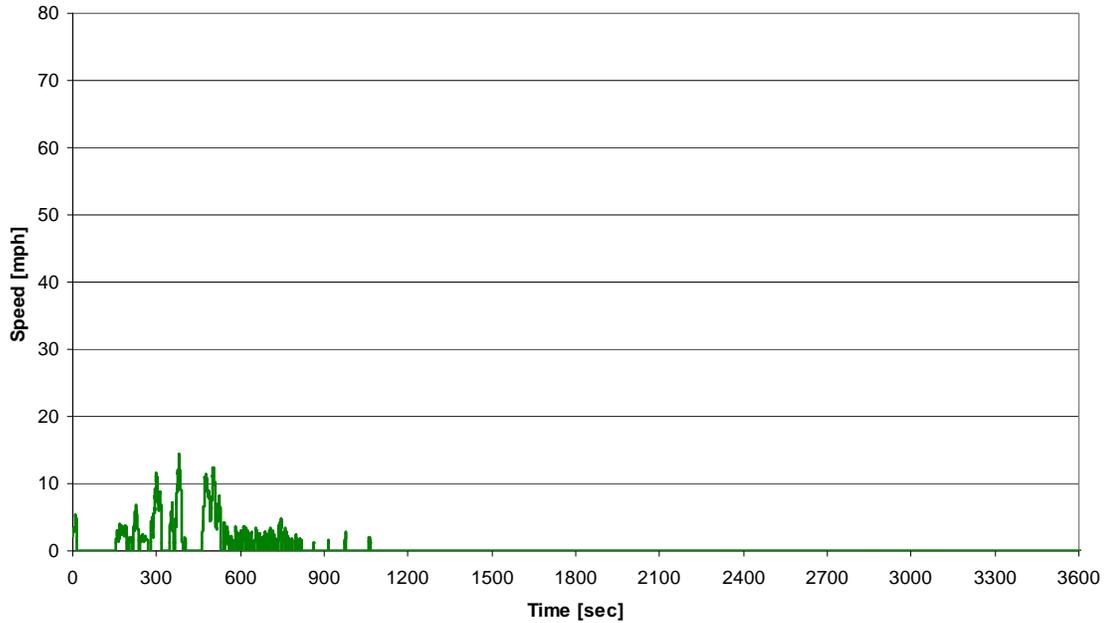


Fig. 82. First Hour of a Duty Cycle Corresponding to a Randomly Selected 100-mile Segment, All Trips with Dual Tires Mounted on Both the Tractor and the Trailer: Medium Load Case (Segment 62, Truck 6, Fuel Efficiency = 5.39 mpg)

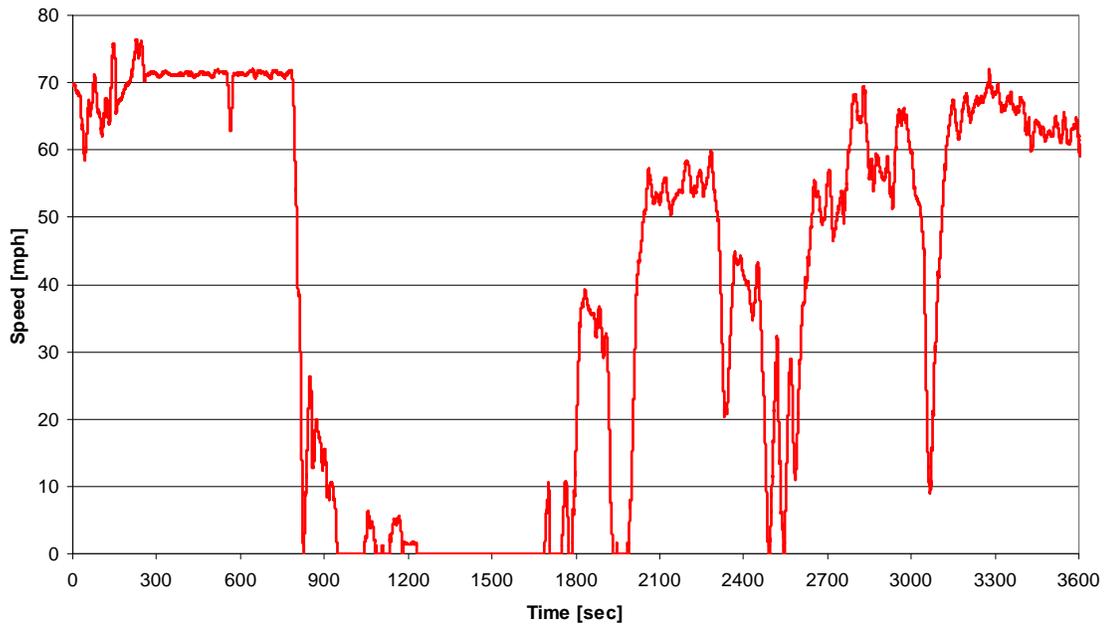


Fig. 83. First Hour of a Duty Cycle Corresponding to a Randomly Selected 100-mile Segment, All Trips with NGSWBs Mounted on Both the Tractor and the Trailer: Medium Load Case (Segment 7, Truck 3, Fuel Efficiency = 7.35 mpg)

A summary of the statistics describing each one of the 12 fuel efficiency distributions corresponding to the truck-tire combinations and load levels (light, medium, and heavy) is presented in Table 23. Within each one of the three load levels in Table 23 and for each one of the truck-tire configurations, the first three rows show the average (same as the ones presented in Table 22), standard deviation and sample size of each of the distributions. The fourth row presents the mean of the difference between the sample average fuel efficiency of the truck-tire combination of the corresponding column and that of the Duals-Duals case. The fifth row shows the standard deviation of the difference which, together with the mean and sample size, permits the computation of the test statistic value z (a one-tailed test based on the alternative hypothesis shown in Eq. 12 and provided in row six). For the three truck-tire configurations that have some or all NGSWBTs, and for any of the three load levels analyzed, the null hypothesis can be rejected with more than 99% confidence in favor of the alternative hypothesis; thus strongly suggesting that fuel efficiencies in these cases are higher than in the case of a truck equipped with all dual tires. In other words, the percent improvements in fuel efficiencies that are achieved when using all NGSWBTs or combinations of duals and NGSWBTs are statistically significant at any vehicle load level.

Table 23. Fuel Efficiency Comparison by Truck-Tire Configuration and Load, Null Hypothesis: All Fuel Efficiency Distributions Are the Same

		Truck-Tire Configuration			
		Duals-Duals	Duals-NGSWBTs	NGSWBTs-Duals	NGSWBTs-NGSWBTs
Light Load	Sample Average Fuel Efficiency ¹ (mpg)	8.06	8.61	8.63	8.79
	Sample Std. Dev.	1.25	1.13	0.96	1.07
	Sample Size	172	76	181	55
	Mean of Difference with Duals-Duals		0.54	0.57	0.72
	Std. Dev. of Difference with Duals-Duals		0.16	0.12	0.17
	Test Statistic Value (Z)		3.37	4.77	4.17
	Reject Ho at Confidence Level =		99.96%	100.00%	100.00%
Medium Load	Sample Average Fuel Efficiency ¹ (mpg)	7.17	7.48	7.51	7.93
	Sample Std. Dev.	1.09	1.16	1.04	1.15
	Sample Size	238	151	286	133
	Mean of Difference with Duals-Duals		0.31	0.34	0.76
	Std. Dev. of Difference with Duals-Duals		0.12	0.09	0.12
	Test Statistic Value (Z)		2.64	3.65	6.24
	Reject Ho at Confidence Level =		99.58%	99.99%	100.00%
Heavy Load	Sample Average Fuel Efficiency ¹ (mpg)	6.24	6.50	6.56	6.88
	Sample Std. Dev.	0.87	0.93	0.81	0.91
	Sample Size	655	264	665	343
	Mean of Difference with Duals-Duals		0.26	0.32	0.64
	Std. Dev. of Difference with Duals-Duals		0.07	0.05	0.06
	Test Statistic Value (Z)		3.95	6.96	10.63
	Reject Ho at Confidence Level =		100.00%	100.00%	100.00%

¹Fuel efficiencies computed using collected databus information.

6.3.2.3 Effect of Vehicle Speed on Fuel Efficiency

Table 24 presents a distribution of distance traveled, fuel consumed, and fuel efficiency by speed and by type of tires for the vehicles participating in this project. The speed bins are divided into 5-mile

intervals, going from 0+ mph (i.e., speed > 0.00 mph) to 85 mph, while the four main columns of Table 24 are organized by the type of tires that were mounted on the tractor and the trailers. The first row of the table contains information about fuel consumed while the vehicle was idling (i.e., the vehicle was static with the engine on) with the rows following presenting information about the distance traveled, fuel consumed, and fuel efficiency for each one of the speed intervals displayed in the first column of the table. The next-to-the-last row shows the totals for both traveled distances and fuel consumed as well as the overall fuel economy for each tire-combination category. The latter are then used to compute the percentage difference in terms of fuel economy between any tire-combination category using NGSWBTs (either combined with dual tires or alone) and the Duals-Duals category, which is the most common tire setup for large trucks at the present time. Notice that the overall fuel efficiencies computed for each tire configuration and the percentage differences with respect to the base case are different from those presented in Table 19 and Table 21. There are two reasons for this difference. First, the fuel efficiencies shown in Table 24 are moving-vehicle fuel efficiencies; that is, they do not take into account the amount of fuel spent while idling. Secondly, there are a few cases in which the vehicles traveled at higher speeds than that which is shown in Table 24; the distance traveled and fuel consumed at those speeds are not shown in the table and therefore not taken into account in the overall fuel efficiency computations.

Table 24. Fuel Economy for Class-8 Trucks as a Function of Speed and Truck-Tire Combination

Speed [mph]	Duals-Duals			Duals-NGSWBTs			NGSWBTs-Duals			NGSWBTs-NGSWBTs		
	Distance Traveled [miles]	Fuel Cons. [gal]	Fuel Eff. ² [mpg]	Distance Traveled [miles]	Fuel Cons. [gal]	Fuel Eff. ² [mpg]	Distance Traveled [miles]	Fuel Cons. [gal]	Fuel Eff. ² [mpg]	Distance Traveled [miles]	Fuel Cons. [gal]	Fuel Eff. ² [mpg]
Idling	N/A	1,858.5	N/A	N/A	967.9	N/A	N/A	1,676.4	N/A	N/A	706.0	N/A
0+ to 5	281	101.8	2.76	148	50.4	2.93	368	124.2	2.97	156	52.8	2.96
5+ to 10	674	198.8	3.39	368	103.2	3.56	808	245.4	3.30	331	98.8	3.35
10+ to 15	723	192.0	3.77	396	98.3	4.03	848	216.5	3.92	343	87.0	3.95
15+ to 20	744	199.1	3.73	404	100.9	4.00	882	221.6	3.98	361	90.5	3.98
20+ to 25	938	228.4	4.11	489	113.6	4.31	1,111	244.2	4.55	462	101.1	4.57
25+ to 30	1,178	266.9	4.41	609	131.5	4.63	1,420	286.9	4.95	580	117.6	4.93
30+ to 35	1,481	336.8	4.40	753	154.2	4.88	1,774	341.1	5.20	708	141.1	5.02
35+ to 40	1,917	403.5	4.75	1,000	193.6	5.17	2,284	433.6	5.27	941	184.3	5.10
40+ to 45	2,955	584.1	5.06	1,543	285.9	5.40	3,380	603.6	5.60	1,350	254.4	5.31
45+ to 50	4,935	907.9	5.43	2,573	447.7	5.75	5,410	872.8	6.20	2,177	360.4	6.04
50+ to 55	9,397	1,629.8	5.77	4,962	811.5	6.11	10,046	1,622.7	6.19	3,877	625.5	6.20
55+ to 60	20,656	3,297.2	6.26	11,707	1,721.9	6.80	22,373	3,257.8	6.87	8,710	1,246.9	6.99
60+ to 65	38,964	5,879.6	6.63	21,472	2,980.8	7.20	34,517	4,840.0	7.13	14,944	2,049.4	7.29
65+ to 70	58,304	8,313.2	7.01	27,931	3,652.2	7.65	65,063	9,256.4	7.03	27,144	3,880.1	7.00
70+ to 75	56,378	7,483.2	7.53	21,751	2,745.5	7.92	66,882	8,435.6	7.93	32,887	4,056.1	8.11
75+ to 85	7,849	808.2	9.71	3,610	403.2	8.95	11,513	911.1	12.64	6,817	512.2	13.31
Total¹	207,374	30,831	6.73	99,714	13,994	7.13	228,680	31,913	7.17	101,790	13,858	7.35
% Diff w/ Duals Duals	0.00%			5.93%			6.53%			9.20%		

¹Total Fuel Consumed does not include fuel consumed while idling. ²Fuel efficiencies computed using collected databus information.

Table 24 also shows that there is a noticeable increase in fuel efficiency for speeds above 70 mph. It is very likely that this increase is due to the vehicle achieving those high speeds while traveling down slope, in which case the fuel consumption should have been comparatively small thus reflecting a higher fuel efficiency. Therefore, this increase in fuel efficiency at higher speeds for these short segments is not expected to be characteristic of all travel at these higher speeds. A preliminary

analysis controlling for the type of terrain showed that fuel efficiencies are, as expected, greatly affected by the type of terrain. Table 25 shows the results of this analysis in which the fuel efficiencies were computed for different types of terrains using the information provided by the databus. Notice that in the case of severe downslopes (i.e., grades that are $< -4\%$) the fuel efficiencies observed are significantly higher than for other types of terrains. Nevertheless, this issue needs to be studied further by performing a similar analysis as the one presented here (i.e., taking into account the speed of the vehicle), but controlling for the type of terrain to isolate its effect on achieved fuel efficiency.

Table 25. Fuel Economy for Class-8 Trucks as a Function of Type of Terrain and Type of Tractor Tires

Type of Terrain	% Total Obs.	Average Fuel Efficiency (mpg)			
		All Trucks	Tractors with Duals	Tractors with NGSWBTs	% Diff NGSWBTs vs. Duals
Severe Upslope ($>4\%$)	0.7%	2.90	2.86	2.94	2.91%
Mild Upslope (1% to 4%)	13.2%	4.35	4.25	4.44	4.35%
Flat Terrain (1% to 1%)	72.4%	7.33	7.08	7.58	7.13%
Mild Downslope (-4% to -1%)	12.6%	15.11	14.64	15.57	6.36%
Severe Downslope ($<-4\%$)	1.1%	23.50	21.82	25.30	15.97%

At the other end of the spectrum, when considering congested conditions (i.e., speeds between 0+ and 20 mph in Table 24), any combination of tires that includes NGSWBTs performs better than the base case. However, for this analyses, the Duals-NGSWBTs tire combination presents the higher percent difference with respect to the Duals-Duals case (6.5%), followed by the NGSWBTs-NGSWBTs (3.5%), and the NGSWBTs-Duals (2.8%) tires combinations. This needs to be studied further by performing a similar analysis as the one presented here, but controlling for the type of class of road (i.e., freeways vs. surface streets) since what can be classified as congestion on a given facility (e.g., freeways) may be normal operations under another one (e.g., arterials and collectors).

Fig. 84 shows the information from Table 24 in a graphical form (bars) and also displays for each speed bin, the percentage of the total distance that is traveled at that speed (curve). It is possible to observe that above 80% of the distance traveled by long-haul Class-8 trucks is done at speeds above 55 mph. Therefore, any gains in fuel economies at these speeds derived from a given tire combination would have a very large impact on the overall fuel economy of these types of trucks. Fig. 84 shows that, except for the Duals-NGSWBTs combination within the 65+ to 70 mph, the combination with all NGSWBTs always performs better and therefore obtains the largest overall fuel efficiency. Nevertheless, further research is needed to determine the reason why both NGSWBTs-Duals and NGSWBTs-NGSWBTs combinations have decreases in fuel efficiencies when the speed bins change from “60+ to 65” to “65+ to 70” mph.

Fig. 85 presents, for each one of the four tire-combination categories, the percentage of total fuel consumed when traveling at different speeds (bars) as well as the average percentage of fuel consumed for each speed bin (curve). As opposed to Table 24, in the case of Fig. 85, the total fuel consumed includes the fuel consumed while idling.

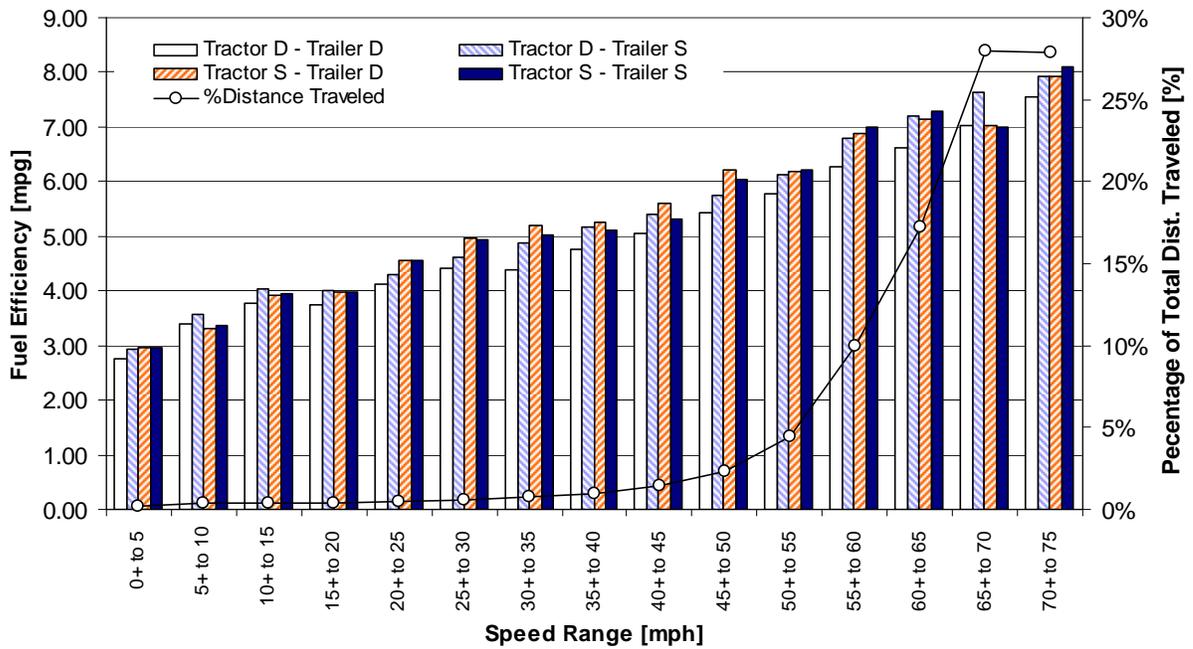


Fig. 84. Class-8 Truck Fuel Efficiency as a Function of Speed and Truck-Tire Combination, and Percentage of Total Distance Traveled as a Function of Speed

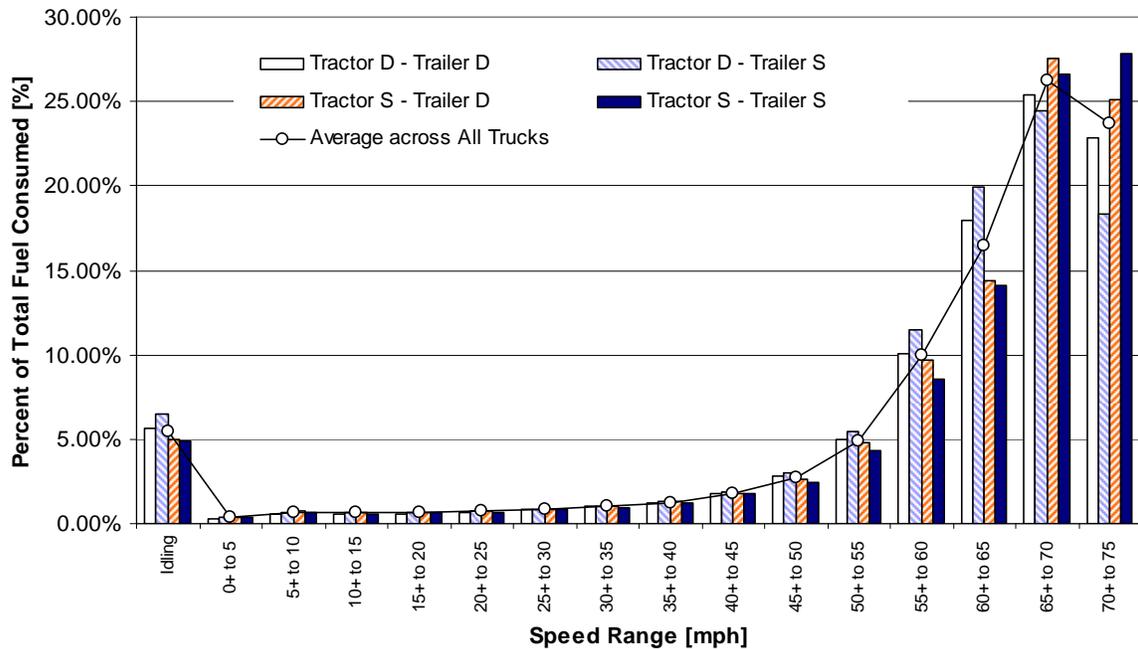


Fig. 85. Class-8 Truck Percent of Total Fuel Consumed as a Function of Speed and Truck-Combination

6.3.2.4 Summary of Fuel Efficiency Study for the NGSWBTs

Improvements in fuel economy are observed to be in the range of about 9-10% for the specific comparisons made in the analyses. The results are summarized in Table 26.

Table 26. Summary of Average Fuel Economy Benefits of NGSWBTs vs. Standard Dual Tires for the Cases Addressed in this Report

Average Fuel Economy	Dual Tires on the Tractor and Trailer	NGSWBTs on the Tractor and Trailer	Improvement with NGSWBTs
From total distance traveled and total fuel consumed	6.40	7.03	9.84%
From 100-mile segments (all vehicle load levels)	6.60	7.22	9.29%
From 100-mile segments for <i>light</i> loads (24,000–44,000 lbs)	8.06	8.79	8.94%
From 100-mile segments for <i>medium</i> loads (44,000–62,000 lbs)	7.17	7.93	10.6%
From 100-mile segments for <i>heavy</i> loads (62,000–80,000 lbs)	6.24	6.88	10.2%

6.4 REFERENCES

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7. LESSONS LEARNED

The HTDC project spanned a period of over three years; covered many facets of research and engineering; and involved many researchers, engineers, technicians, and industry professions; thus the lessons learned were varied. They include both positive and negative lessons. Some lessons learned were immediately incorporated into the testing protocols being employed at the time and allowed for more productive and efficient research and data collection. Other lessons learned were of a nature that did not allow for more immediate or short-term adaptation; however they may be of possible benefit for future research.

For the purposes of this discussion, lessons learned will be discussed in two sections: *Positive* and *Negative*. The negative lessons learned have been separated into *corrected/incorporated* and *unable to correct/incorporate*.

7.1 POSITIVE

Many facets of the partnership development, testing, and data collection proved to be valuable to the overall program in ways that were not originally identified or fully appreciated. These are described in the following positive lessons learned.

7.1.1 Lessons Learned from the Pilot Test

Because of the effort put forth by Dana and ORNL in the Pilot Test and by ORNL in the Build-Up Phase, the DAS system functioned quite well during the FOT. There was very little down-time related to equipment internal to the test vehicle (VBox, eDAQ).

Lesson Learned: *In-situ testing of final equipment configurations, along with an appropriate burn-in period for all systems to be employed in the test is an effective way to insure longevity and robustness of equipment during a real-world FOT.*

7.1.2 Routine Data Collection Procedures

Additional lessons learned in the pilot phase of this project were assimilated during the FOT resulting in a simplification of the task at hand, or an improvement in the quality of the results. Specifically, technical problems that were identified during the Pilot Test were corrected and incorporated in the software and procedures used in this phase. The data uploading and archiving procedures employed in this phase resulted in quick problem diagnosis and minimal data loss.

Lesson Learned: *Data should be downloaded frequently and basic statistics should be generated closely thereafter in order to determine that the sensors are working as expected.*

Lesson Learned: *Data should be backed up often to prevent data losses from memory overflow.*

7.1.3 Fleet Selection

Schrader is a forward-looking, technology-savvy fleet. This facilitated good understanding and insightful communication between Schrader and ORNL regarding the HDTC goals and objectives as well as ORNL's approach to conducting this research. This, in turn, allowed the integration of the data collection equipment within the test vehicles of the FOT to proceed efficiently.

Lesson Learned: A technology progressive fleet helps to ensure the success of a vehicle-based research project.

7.1.4 Equipment Access

Schrader's operations model involved the return of all fleet vehicles to their Jefferson City headquarters each weekend. This allowed ORNL personnel to have weekly access to the test vehicles and the DASs. The distance from ORNL to Schrader was approximately 45 miles, allowing for relatively easy access to the test vehicles and DAS equipment.

Lesson Learned: Periodic access is critical for collecting data and to conduct equipment health monitoring and repairs. Choosing a fleet that has a regular vehicle return schedule as well as one that has its entire fleet on the same return schedule saves valuable research time and ensures regular access to test vehicles and the DASs.

Lesson Learned: Choosing a fleet within a reasonable driving distance reduces data collection and equipment monitoring/repair costs.

7.2 NEGATIVE

Just as with the positive lessons learned, there were arrangements, situations, and events that proved to be detrimental to the overall program in ways that were not originally identified or fully appreciated. These are described in the following negative lessons learned. First, the negative lesson learned that were corrected during the course of the program will be discussed, and lastly the negative lessons learned that were not corrected will be discussed. Knowledge of the latter may be beneficial for future efforts.

7.2.1 Corrected Negative Lessons Learned

7.2.1.1 Fleet procedures

Schrader's standard operating procedure (SOP) for its fleet called for regular (weekly in some cases), pressure washing of the tractors. It was determined that this pressure washing was leading to premature failure of the weather stations due to water infusion into the circuit boards of the devices. Once the cause was determined, ORNL requested that the weather stations be covered to prevent direct high pressure spraying. This protective measure corrected the water infusion problem with the weather stations.

Lesson Learned: A thorough review of partner SOPs to glean possible practices that could be detrimental to equipment is recommended.

Lesson Learned: Pressure washing of truck mounted sensors can cause premature failure.

Lesson Learned: Effective work-arounds can be identified and implemented in the field.

7.2.1.2 Additional duty-cycle data

Just prior to the start of the FOT it was suggested that aerodynamics data relative to the Volvo VN 660 tractors and the dry-box freight trailers would be of interest to collect during the FOT. At that point it was too late to plan for such data collection (the DAS was at capacity, no additional funding for sensors or additional DAS capacity was available, the MOU with Schrader did not identify this type of data collection, the suggested data collection method was not minimally invasive, and there was not sufficient time to instrument the vehicles or test the sensors prior to starting the FOT).

Another performance measure was also suggested after the FOT was nearly half-way complete. The ORNL team was informed via a review organization that had identified relevant performance measures valuable for modeling, that drive torque data was imperative to collect if models such as PSAT were to be calibrated and validated against real-world data. Again, it was too late to add sensors or change the configuration of the DAS. Also, on-board torque data collection, at that time, was too invasive for Schrader to accept, and there was no funding to investigate alternative collection methods or additional equipment. It was decided that the aero data would not be collected, and that drive torque data for one of the tractors would be collected after the FOT was completed – likely via a dynamometer.

Lesson Learned: Early planning, consultation, and input from multiple stakeholders is required to ensure that the developed sensor/DAS suite is adequate for the data needs of the project.

As mentioned in the lesson learned above, drive torque data was required for PSAT usage. At the time of the FOT there did not exist a non-invasive, low-cost method to collect drive-line torque. In order to save the cost of instrumenting all six test tractors and to avoid installing a torque sensor into the driveline of the test vehicle (which would have voided the vehicle's manufacture's warranty), ORNL decided to test one representative test vehicle on a roller-based dynamometer.

Lessons Learned: A real-world FOT has limitations and restrictions not found in test-track testing (i.e. public safety, partner equipment downtime restrictions, and potential voiding of manufacture's warranties). While a work-around was identified and implemented, these limitations need to be fully understood by any research team undertaking a real-world FOT.

7.2.1.3 Road slope

Road slope was considered to be a primary measure of performance to be collected during the FOT. Originally, an analog tilt sensor was tested, but proved to be too noisy and sensitive to acceleration and deceleration of the test vehicle and to the natural harmonics of the test vehicle (2-to-3 Hz). Also tested early in the build-up phase was the use of GPS-based data to determine discrete changes in slope. The randomly occurring offset (sometimes hundred of yards) of the GPS was initially thought to be too problematic to produce accurate results. However, since the test vehicles (over time) cover the same routes more than once, good slope data can be ascertained in repeated segments. By putting these segments together, one can piece together a complete route, thus mapping the slope of an entire section of traveled roadway.

Lesson Learned: Real-world collection of data presents problems that can be overcome using methods that employ the repetitive nature of long-haul operations. In the case of road slope, a sufficiently long FOT is required (multi-month) to collect enough repetitive data to compile complete route information.

7.2.1.4 Weather stations

Initially, the weather stations were installed on the driver's side, fender mounted, rearview mirror of the test vehicles. This proved to be an unacceptable solution due to the vibration induced from the engine and the vehicle-to roadway interface. The mass of the weather station, the length of the mounting pole, and the induced vibration caused the mirror and the weather station to experience violent vibrations. The weather stations were moved to the door-mounted mirrors where they were better isolated from engine and road vibrations.

Lesson Learned: Adding external sensors and systems to a test vehicle can introduce unexpected results. Again, ample shake down testing through all phases of vehicle operation is required to identify problems in advance of the FOT.

7.2.1.5 DAS wiring

Vibration and its effects on electrical connectors are well known. In order to protect against long-term connection problems, a decision was made to “hard wire” as much of the DAS and sensor system as possible and to eliminate as many connectors as possible. While this approach accomplished the goal of eliminating failures due to vibration damage to connections, it made removing the DAS units from the test vehicles very difficult due to the fact that there were no connectors to allow the various sensors and power wires to be removed quickly.

Lesson Learned: For future FOTs using this or a similar DAS, mil-spec electrical connections should be utilized and tested. This will allow for easy removal of the DAS from a given test vehicle for calibration, maintenance, or repair.

7.2.1.5 System design documentation

During the Pilot Test, various DAS and sensor systems were tested to determine the equipment and equipment configurations best suited for the FOT data collection effort. Dana led this effort and gained the expertise necessary to move to the next phase of the program. However, when Dana entered bankruptcy negotiations at the end of the Pilot Test effort, much of this expertise was lost due to personnel changes at Dana. ORNL subsequently had to regain this experience and knowledge during Phase II of the program. To prevent this from happening again in the program, ORNL began to document its efforts in a Systems Design and Operations Document (Appendix D). This document is a detailed, step-by-step instruction manual that calls out the specific equipment used, describes the configuration of this equipment, shows detailed schematics of the systems, and explains the nature of the signals collected and their use.

Lesson Learned: A Systems Design and Operations Document should be developed and deployed for research projects utilizing complex DASs to interface with vehicles systems. This is done to prevent the loss of expertise in the event of personnel changes or entity changes.

7.2.2 Non-Corrected, Negative Lessons Learned

7.2.2.1 Vehicle availability

Because of the nature of long-haul operations, all test vehicles were not always available to ORNL for data down-load on Saturdays and Sundays during the FOT. This situation increased the number of visits required to Schrader to collect the FOT data, prevented in some cases the early detection of issues with the DAS equipment, and in some cases caused the DAS data buffers to fill and overflow (data loss).

Lesson Learned: Even in an operation which allows all of its vehicles to return home each weekend, circumstances do not always allow for their return. Circumstances that contribute to vehicle unavailability include: extended trips, vehicle breakdown, equipment warranty work, and driver schedule. Sufficient planning and budgeting allowances must be factored in to account for this inefficiency.

7.2.2.2 Driver communication

Again, because of the nature of long-haul operation, communications with the drivers of the test vehicles was difficult and indirect. This made getting information from the drivers about equipment issues (i.e. weather station damage), and information to the drivers about ORNL's needs (e.g. increasing the number of weigh tickets so that ORNL could have data to correlate with the data provided by the on-board Air-Weigh system), more problematic and introduced more uncertainty into the process.

Lesson Learned: An effective communication method/protocol is needed with all personnel within all organizations that are partners in research projects of this nature.

7.2.2.3 Travel

While the distance from ORNL to Schrader was approximately 45 miles, allowing weekly access to most of the test vehicles, it required a substantial amount of driving for each data collection event. Now that wireless technology has further improved and has been further adopted by DAS manufacturers, it is recommended that the use of wireless data collection be explored and considered for subsequent data collection efforts.

Lesson Learned: Collecting data remotely adds time and cost considerations that are hard to quantify in the planning stages of a project.

Lesson Learned: Effective wireless data collection could greatly reduce manpower requirements for FOT data collection efforts.

7.2.2.4 Tractor-trailer marriage

Almost all tractor-trailers involved in long-haul trucking operations in the US are not "married." This means that a tractor could pull a different trailer on every run. It is conceivable that a tractor might not pull the same trailer twice, or, if it does, the occurrence will be relatively infrequent. For the HTDC project, marriage was desirable so that the DAS could see the Air-Weigh weigh sensor on the instrumented trailers and gather fuel usage data linked to a specific trailer's tires. It was hoped that Schrader could establish an operational protocol that could "force fit" instrumented tractors to pull instrumented trailers in order to increase the percentage of marriage between the test tractors and the test trailers. However, the data analysis section of this report (Chapter 6) shows that the percentage of marriage was no higher that it would have been if the tractors and trailers were selected at random (the normal process).

Lesson Learned: When working with real-world fleets, the operational needs of partner fleets tend to take precedence over research, when day-to-day decisions in operations are made. It is difficult or perhaps impossible to change the percentage of tractor-trailer marriage.

7.2.2.5 "Calibration" of fuel readings

During the FOT a decision was made to use fuel tickets to corroborate the readings obtained from the truck databus regarding fuel consumption. This would allow for reasonably accurate estimates of fuel consumption to be made using the fuel consumption data from the vehicle data bus. However, as explained in the data analysis section of this report (Chapter 6), there were several problems with the fuel ticket information that severely restricted their usefulness in the assessment and calibration of the information obtained from the databus. Some fuel tickets were missing, and it was impossible to

know if the vehicle was “filled up” or only partially filled during any given fueling. This uncertainty made it impossible to calibrate the on-board fuel consumption sensor.

Lesson Learned: In order to get accurate fuel consumption data and to be able to determine if the on-board fuel consumption sensor can be calibrated, it is recommended that an external fuel sensor be used, if such a sensor can be independently calibrated. This sensor should be deployed for at least 1/3 of the data collection period. If fuel tickets are to be used to calibrate the databus data, then information about fuel time, location, odometer reading, and whether the tank was filled up or not, needs to be collected.

7.2.2.6 Control of experimental variables

In this project, an attempt was made to maintain all relevant variables at the same level across all the participating trucks, except for the type of tires and transmission. It was assumed that all drivers were driving in a similar fashion (a reasonable assumption considering the extensive training and follow up that Schrader provides to its drivers), and that other variables that could not be controlled (e.g. vehicle weight, type of terrain, etc) would equally affect all of the vehicles in a similar manner over the year-long data collection effort. Nevertheless, and to eliminate any potential differences between the participating trucks, it would have been desirable to switch tires among those trucks such that for any given tractor half of the data would have been collected while equipped with dual tires and the other half with the other type of tires. This would have also reduced any influence that drivers may have had in the vehicle fuel efficiency.

Lesson Learned: Steps should be taken to eliminate driver, routing, and vehicle variability in the experimental setup in order to reduce the influence of uncontrollable variables.

7.2.2.7 Control of external data gathered

It is impossible to collect all of the necessary information for a project like this one by just relying on sensors and other equipment. In order to calibrate some of this information, it was necessary to involve the participating trucking company personnel, specifically the staff dealing with the day-to-day operations. Even when the staff has the best of intentions in helping the project (as was the case for Schrader), there are operations procedures and idiosyncrasies that simply cannot be changed. One example was the mating of instrumented tractor and trailers, which was impossible to achieve because of the way in which the company operates (i.e., a driver- or tractor-centered operation), even though the staff tried their best to support the project needs. Another example was the collection of fuel tickets. ORNL asked Schrader to collect weight tickets (at random) to help assess and calibrate the Air-Weigh devices. This worked only for a short while, but rapidly reverted back to obtaining weight tickets when the truck was close to the legal weight limit; which is the logical operation for a trucking company.

Lesson Learned: Requirements that are outside of normal operations for an operating fleet are likely to be unsustainable in the long-run and can only be maintained for short period of times. If external information needs to be gathered, the methodology to collect that information should either enroll the collaboration of the partner for a short period of time, or it should increase the participation of the research team in collaboration with that partner. Any methodology that requires repetitive tasks that are outside of the partner's normal way of operating is likely unachievable.

7.2.2.8 Database manipulation

The project collected a very large amount of information making it difficult to rapidly find and extract segments of data with a given set of attributes.

Lesson Learned: It is recommended that similar future projects use commercial database engines (e.g., an SQL Server) to organize and query the extensive databases that are generated in these types of studies.

8. SUMMARY OF RESULTS AND CONCLUSIONS

During this year-long project, the six instrumented Class-8 trucks logged almost 700,000 miles and consumed over 100,000 gallons of fuel while undertaking 1,100 trips and visiting 37 states in the US and one Canadian province. The vehicles were equipped with a suite of sensors and a DAS that allowed the researchers to collect 60 channels of data at a rate of 5 Hz resulting in a very extensive (290+ GB), and information-rich database. The channels included information such as instantaneous fuel rate, engine speed, gear ratio, vehicle speed, and other information read from the vehicle's databus; spatial information gathered from a GPS device; instantaneous tractor and trailer weight obtained from devices mounted on the six participating tractors and ten trailers; and weather information acquired from an on-board weather station. Three of the six instrumented tractors and five of the ten instrumented trailers were mounted with NGSWBTs and the others with regular dual tires.

8.1 SUMMARY OF COLLECTED DATA

The information that was collected was divided into short- (less than 100 miles) and long- (over 100 miles) haul trips; and the total, moving, stopped, and idling time and fuel consumed were calculated for all of the participating truck combinations. While short-haul trips presented proportionally larger idling times than that experienced in long-haul trips (i.e., 69% of the total time spent of the trip vs. 49.5% of the total time, respectively, or close to a 3-to-2 ratio), the former consumed a significantly larger proportion of the total fuel while idling than the latter (i.e., a ratio of 3-to-1, or 21.21% vs. 6.7%, respectively). It is worth noticing that short-haul trips were a very small portion of total trips (2%).

As expected, the largest proportion of idling time, and in consequence, fuel consumed while idling, corresponded to overnight parking (idling intervals of more than four hours). In the case of long-haul and total (short- and long-haul) trips, about 50% of the total idling time was spent in idling intervals that last more than four hours with about 45% of the total idling fuel consumed in these idling intervals.

8.2 TIRE COMPARISON

The information gathered in the study also permitted the computation of fuel efficiencies for Class-8 trucks as a function of the type of tires mounted on the tractor and trailer. These calculations, which were made using fuel consumption information obtained from the vehicles' databus, showed an overall fuel efficiency above 6.0 mpg. This level of fuel efficiency is on the upper limits of today's large-truck fleets and is mostly a result of Schrader Trucking being a very technologically minded company and its excellent programs in driver training and the extensive vehicle maintenance (including, for example, maintaining a constant tire pressure).

The nearly 700,000 miles logged during the data gathering phase of this study were divided into the four tractor-trailer tire combinations (i.e., Duals-Duals, Duals-NGSWBTs, NGSWBTs-Duals, and NGSWBTs-NGSWBTs) and fuel efficiencies were computed for 100-mile segments for any given category. The results showed that there is always an improvement in fuel efficiency with respect to the base case (Duals-Duals) when NGSWBTs are involved. Moreover, the fuel efficiency improvement increases as the number of NGSWBTs on the truck increases, with observed improvements of around 6% when either the tractor or the trailer was equipped with NGSWBTs, and more than 9% when both were mounted with these type of tires. Due to various circumstances, the

fuel sensor could not be calibrated; however, the literature indicates that the databus information regarding fuel consumption is accurate, with some researchers reporting errors of just 1%. ORNL's limited analysis involving one of the participating trucks and using just a few short segments of data for which complete fuel ticket information was available indicates that the databus for the type of truck and engine used in this study underestimates fuel consumption by less than 8% (note: in these computations it was not possible to determine with 100% accuracy if the fuel tank was full at both the starting and ending point of the data segment used). Assuming that this is a systematic bias, even if the actual fuel efficiencies are erroneous, the percent differences are still accurate as was discussed in Section 6.2.2. Nevertheless, future sensitivity analyses will be performed that will study the differences in fuel efficiencies when instead of systematic biases in the databus readings, random errors (within a certain range) are assumed to be present in those readings.

These results were statistically analyzed by performing a test of hypothesis. The null hypothesis stating that there were no significant differences among any of the four distributions (i.e., one for each truck-tire combination studied) of observed fuel efficiencies was tested against the alternative hypothesis indicating that the average fuel efficiency of any combination that had NGSWBTs was larger than the average fuel efficiency of the base case (Duals-Duals). In any case, it was possible to reject the null hypothesis with 100% confidence in favor of the alternative hypothesis. This strongly suggests that fuel efficiencies in these cases involving NGSWBTs are higher than in the case of a truck equipped with all dual tires. In other words, the percent improvements in fuel efficiencies that are achieved when using all NGSWBTs or combinations of duals and NGSWBTs are statistically significant.

The search engine of the DCGenT Prototype was used to parse the data by truck-tire combination and vehicle load level. The latter was divided into four categories: 1) Tractor Only (trips made without any trailer), 2) Light Load (total vehicle weight between 24,000lbs and 44,000lbs); 3) Medium Load (total vehicle weight between 44,000lbs and 62,000lbs); and 4) Heavy Load (total vehicle weight between 62,000lbs and 80,000lbs). As in the previous case, 100-mile segments were considered for which the fuel efficiency was computed. Once again, for any load level considered, the results of the analysis show that there is always an improvement in fuel efficiency with respect to the base case (i.e., duals-duals) when NGSWBTs are used. In fact, for the particular case in which all tires are NGSWBTs, there was considerable improvement in fuel efficiency with respect to the base case (i.e., improvements that were above 10%), and those improvements were more significant as the load level increased. They were also statistically significant at the 99% level of confidence.

8.3 FUEL EFFICIENCY AND TRUCK SPEED

An analysis of the fuel efficiency of Class-8 trucks as a function of vehicle speed was also conducted. The results of this analysis showed that under congested conditions (i.e., speeds between 0+ and 20 mph) any combination of tires that includes NGSWBTs performs better than the base case. However, in this case the percentage differences with respect to the base case were less than 5%. This result needs to be studied further by controlling for the type of class of road (i.e., freeways vs. surface streets) since what can be classified as congestion on a given facility (e.g., freeways) may be normal operations under another one (e.g., arterials and collectors).

For speeds above 70 mph, there was a noticeable increase in fuel efficiency. It is very likely that this increase was due to the vehicle achieving those high speeds while traveling down slope, in which case the fuel consumption would be comparatively small, thus reflecting higher fuel efficiency. This needs to be studied further by controlling for the type of terrain (mainly, grade) to isolate its effect on achieved fuel efficiency.

9. FUTURE DIRECTIONS

The Heavy Truck Duty Cycle (HTDC) Project has provided a rich source of Class-8 long-haul performance data. This data has breadth in that it addresses a wide range of parameters that can influence performance, and it has depth in that it provides values of particular parameters for large ranges of the values of other parameters. In particular, the fuel efficiency of the test vehicles in terms of the variation in payload, road grade, weather, congestion/road type, etc. Of primary benefit to the ORNL research team has been the experience and lessons learned from the pilot test conducted in 2005 through the completion of the FOT in 2008. This strong experiential base linked with the positive results of the HTDC project suggests future directions in the area of truck-based duty cycles and performance data.

Although Class-8 long-haul operations is responsible for most of the fuel consumed in Class-8 applications, Class-8 short-haul applications in urban and metropolitan areas represent a significantly different set of performance criteria. A future direction of research involves collecting, archiving and analyzing data and information on non-long-haul Class-8 operations.

Class-6 trucks represent the second largest class of fuel consumers in heavy/medium truck spectrum. These trucks have duty cycles that are vocationally dependent, log significantly fewer miles per vehicle year than Class-8 trucks, and often utilize the truck's engine as a source of power for the operation of, for example, the arm of a bucket truck. As a result, a significant portion of the fuel consumed is done by the Power Take-Off (PTO) functions. A future direction of research involves collecting, archiving and analyzing data and information on Class-6 operations in selected vocations.

Hybrid technologies have been demonstrated successfully in smaller vehicles that are less than Class-6. However, many of the truck OEMs are considering hybrid drive applications for heavy- and medium-sized trucks. Although the stop-and-go nature of duty cycles is understood as making the best use of hybrid technologies, and the theory of hybrid applications is well understood, real-world applications may prove to be different. A future direction of research involves the vocational aspects and duty cycles of the various truck classes (3 through 8) to determine the vocations and specific applications that would benefit most from a hybrid platform. Furthermore, for these duty cycles, and for selected vocations, a cost-benefit study will be conducted that clearly illustrates the hybrid technology benefits to various vocations. This study would allow end-users who are considering hybrids to determine if their operation is a good candidate for hybrid technologies and also allow them to determine when the return-on-investment achieves pay-back. A simple "calculator" could be developed with input such as: Vehicle Class (GVWR), Combination/Straight Truck, Total Miles Driven, Average Weight, Total Time Idling, Power Take-Off Time, Driving Environment, etc. The calculator could give a quantitative score (e.g., 1-to-10 or 1-to-100) as to the "fit" for a particular application to go hybrid, and could give an estimate of annual fuel savings.

EPA's SmartWay Program is focused on increasing the energy efficiency and reducing greenhouse gases and air pollution for heavy and medium-sized trucks operating on our highways. SmartWay certification of a fleet assures the public that the owners and operators of the fleet are energy efficiency and environmentally minded. A challenge for the Program is how to certify various classes and vocational application of heavy- and medium-sized trucks. Discussions to date have included a reference truck configuration and representative sets of duty cycles per application/vocation which real-world fleets can compare themselves to. What is lacking is the existence of real-world-based duty cycles for comparison purposes, especially those involving the emissions from these vehicles operating on these duty cycles. Dyno and test track testing offer the opportunity to collect emissions

data on representative duty cycles. Even with such data and information, a challenge for fleet operators will be to map the performance of their fleets onto the expected SmartWay performance. It has been suggested that even within a vocation, drive cycles can vary significantly. One concept that has been suggested is a library of duty cycle segments that have been developed over a wide range of performance characteristics and SmartWay certified by EPA. That is, for a class/vocation of truck, a thorough mapping of performance, fuel efficiency and emissions be produced and evaluated/certified by EPA. Using these segments, a fleet can construct a duty cycle that best represents their operation.

A comparison of real-world performance to the resultant performance per the constructed duty cycle could be made. EPA could construct their libraries much in the same way as was done in the HTDC Project. Both EPA and DOE would benefit from such an effort, and cost sharing might be a possibility. A future direction of research involves working with EPA to define a joint EPA/DOE Program in the collection of Truck Performance Data. In addition, analyses of results would provide an in-depth understanding of the operational idiosyncrasies of these vehicles.

In association with the previous suggested future direction is driver performance data. In informal discussions with fleet operators, poor driver performance can significantly affect fuel efficiencies. In some cases, the effect of a poor driver can overshadow investments by a fleet in technology to improve fuel efficiency. Schrader Trucking has indicated that they believe that their focus on driver training contributes significantly to their strong fuel efficiency performance. In addition, the truck driver is also a primary element in truck safety. The Federal Motor Carrier Safety Administration's (FMCSA's Large Truck Crash Causation Study (<http://ai.fmcsa.dot.gov/ltrccs/default.asp>) indicates that 87 percent of all truck crashes involve cite driver error as a primary cause. However comprehensive data on truck driver performance is lacking. Driver functions such as speed management, rollover avoidance, fuel conservation, engine performance optimization, and generally, steering and braking are not well understood with regard to how they relate to specific duty cycles. A future direction of research involves working with FMCSA and other agencies of DOT involved in truck safety and performance to collect, archive and analyze data related to the fuel efficiency and safety characteristics of heavy- and medium-sized trucks for selected vocations.

Lastly, there is great interest in energy efficiency-minded fleets in gaining a better understanding of the benefits and costs associated with Auxiliary Power Units (APUs). A future direction of research would involve a study of the usefulness of APUs within various real-world-based duty cycles. Such a study would provide evidence of the potential fuel savings that are possible though their use thereby stimulating early adoption of such technologies.

Appendix A
PILOT TEST LETTER REPORT

Heavy Vehicle Duty Cycle (HVDC) Project Phase 1 – Pilot Test Letter Report

February 28 2006

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ACKNOWLEDGEMENTS

The authors wish to gratefully acknowledge the contributions of Mr. Paul Pollock, Mr. Dan Coleman, and Mr. Jim Ridge of Dana Corporation; and Mr. Ibrahim Janajreh and Mr. John Melson of Michelin Americas Research and Development Corp. for their invaluable contributions to this project.

Mr. Pollock has been a Dana champion for this research since 2002, and without his dedication, focus, technical insight and generous partnering spirit, this project would not have been successful.

Mr. Coleman provided strong technical support in this research and provided insights, technical advice and strong enthusiasm which were critical for success.

Mr. Ridge assumed most of the data acquisition responsibilities in this project, including in-vehicle data acquisition across the two Chicago-Portland routes. He played a pivotal role in preparing the sensor suite and electronics, applying technical solutions to complex instrumentation problems, and organizing the trip logistics and data set. He put in long hours in the office, garage, and on the road to see this project become successful.

Mr. Janajreh had an early recognition of the value of this research and recognized the benefits of jointly pursuing this study. His willingness to creatively discuss research directions helped to shape the nature of this work. His untimely passing created a significant void in the project team and he has been missed.

Mr. Melson provided the continuity that was needed in this research after the passing of Mr. Janajreh in August, 2005. His professional and unselfish approach in picking up this project and quickly moving on critical issues prevented it from coming to a halt.

Additionally, we are also very thankful for the contributions of Mr. Ralph Long (CCC) for piloting the test vehicle and for Mr. Kevin Gates (Clark Engineering Services) who provided the instrumentation integration.

We are indebted to the extremely capable team of professionals from Dana, Michelin, CCC, Clark Engineering Services and ORNL for their contributions to this Pilot Test. We sincerely hope that research opportunities continue to emerge that will allow ORNL us to again partner with this outstanding team.

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Letter Report

Phase 1 - Heavy Vehicle Duty Cycle (HVDC) Project

Prepared by: H. E. (Bill) Knee and Gary J. Capps
Oak Ridge National Laboratory
February 28, 2006

1.0 BACKGROUND

This Project involves efforts to collect, analyze and archive data and information related to heavy truck operation in real-world highway environments. Such data and information will be usable to:

- provide input to the Department of Energy (DOE) regarding technology investment decisions,
- support the development and evaluation of the Argonne National Laboratory (ANL) developed class-8 module for the Powertrain System Analysis Toolkit (PSAT),
- provide a real-world-based data archive capable of supporting heavy truck research, and
- provide a means of accounting for real-world driving performance within heavy truck research and analyses.

The Project is being led by the Oak Ridge National Laboratory (ORNL), and involves two industry partners (Dana Corporation [Dana] of Kalamazoo, MI, and Michelin Americas Research and Development Corp. [Michelin] of Greenville, SC) and will have support from ANL. Participation by the US Department of Transportation (USDOT) has been actively sought, but with little success. This lack of success is strongly linked to the unavailability of funding due to a USDOT continuing budget resolution during FY2004 and FY2005. Additionally, although a FY2006 USDOT budget has been agreed to, funding of earmarks amounted to the budget being about 25% over-subscribed to. As of the end of February, 2006, this budget issue had not been resolved. As a result, new USDOT research has not been forthcoming.

2.0 PROJECT OVERVIEW

This project involves efforts to collect, analyze and archive data and information related to heavy truck operation in real-world driving environments. One of the primary deliverables of this project is a set of heavy truck duty cycles based on typical heavy vehicle driving performance generated from a working fleet(s). The project will be conducted in two phases.

Phase 1: Design, Testing and Evaluation of a Duty Cycle Data Collection System.

Phase 2: Fleet Instrumentation, Data Collection, Analyses, and Archiving.

Phase 1 is a 15-month effort that will be completed in March, 2006. Within Phase 1, Pilot Testing to

evaluate the data collection system used to capture relevant vehicle data has been completed. Data from the Pilot Test is currently being analyzed and example duty cycles based on this data are being developed. Preparations for the launch of Phase 2 in April, 2006 are being made.

Phase 2 is an 18-month effort that is scheduled to begin in April 2006 and will be concluded in September 2007. Phase 2 will require: the instrumentation of two-to-ten long-haul heavy trucks; and the collection, over a 12-month period of time, of duty cycle data, and data associated with the duty cycles. Data will be archived in a DOE heavy vehicle data archive system located at ORNL. Data analyses of operational characteristics will also be conducted under Phase 2, and upon agreement by DOE, the data archive system will be made accessible for use by the research community and others. A duty cycle generation tool, based on data collected within the HVDC field test will be developed. Results of the analyses and performance characterization will be published.

2.1 FIELD TESTING

Field tests tend to be relatively expensive when compared to laboratory-based research. Because of this, significant effort has been directed toward leveraging the needs of this project with industry partnerships and with cooperative efforts with other federal agencies. With regard to industry participation, ORNL is partnering with Dana who has generously provided engineering support for instrumentation integration, instrumentation to generate vehicle dynamics data, and has provided access to the Dana Truck Fleet (DTF) which was used in the pilot tested and is a candidate fleet that may be utilized for the HVDC field test. This partnership significantly reduced the Phase 1 costs to DOE, and is allowing the Phase 2 data collection costs to be reasonable. Industry contributions are valued in the multiple-hundred's-of-thousands of dollars. Michelin also provided resources for the pilot test and is expected to continue as a partner during the field test. Michelin provided new standard dual tires for half of the pilot test runs, and new generation single tires for the other half of the runs. Their interest in the testing activities involves the energy efficiency effects of new generation tires vs. standard dual tires. Such information may be useful in accounting for rolling resistance effects.

3.0 PHASE 1 EFFORTS

Phase 1 efforts were centered on the design, testing and evaluation of a duty cycle data collection system.

3.1 PHASE 1 TASKS

Phase 1 efforts were initiated in January 2005. The effort involved nine tasks. Progress in each of the nine tasks is discussed in this section. The nine tasks are:

Task 1: Establishment of Teaming Agreements and Conduct of Outreach to USDOT

Task 2: Identification of Relevant Heavy Truck Performance Measures and Development of a Pilot Testing Plan

Task 3: Procurement/Development of Necessary Sensors and Development of an Integrated Sensor Architecture

Task 4: Development of a Prototype Data Acquisition System (DAS)

Task 5: Installation of the DAS Prototype and Sensor Suites in One Long-Haul Tractor-Trailer

Task 6: Test and Evaluate the Instrumented Tractor-Trailer (Collect Pilot Data)

Task 7: Analyze Pilot Data and Demonstrate Duty Cycle Generation Capabilities

Task 8: Prepare Phase 1 Report

Task 9: Provide Project Management

3.2 PROJECT TEAM

The following table provides a list of HVDC team members from ORNL, ANL, Dana and Michelin.

Program Manager	Keith Kahl (865-946-1236)
Project Manager/Principal Investigator	Bill Knee (865-946-1300)
Technical Manager/Project Engineer	Gary Capps (865-946-1285)
Performance Measurement & ORNL PSAT Expert	Pedro Otaduy (865-946-1344)
ANL PSAT Point-of-Contact	Don Hillebrand (630-252-6502)
Data Analyst	Oscar Franzese (865-946-1304)
Mechanical Engineering Support	Joe Massimini (865-946-1358)
Dana Point-of-Contact	Paul Pollock (269-567-1219)
Dana Systems Engineer	Dan Coleman (269-567-1055)
Michelin Point-of-Contact	John Melson (734-942-0269)
Michelin Point-of-Contact	Ibrahim Janajreh (864-422-4053)

3.3 TASK PROGRESS

Accomplishments in each of the nine task areas are provided below.

3.3.1 Task 1: Establishment of Teaming Agreements and Conduct of Outreach to USDOT

3.3.1.1 Pre-Project Teaming Discussions: Technical discussions regarding a HVDC project were initiated with Dana in 2002. Dana's interests concerned the collection of vehicle dynamics data to support their in-house development of ADAMS-based component and vehicle models. After several years of discussions and meetings between ORNL, DOE and Dana, the project was agreed to, and was initiated in January 2005. In addition, and in anticipation of the initiation of the HVDC project, discussions with the Federal Motor Carrier Safety Administration (FMCSA) were initiated in 2004 with Mr. Martin Walker (Director of FMCSA Research). FMCSA's interest would be primarily in the collection of long-haul naturalistic driving information. Similar studies had been conducted by the USDOT for passenger vehicles and for non-long-haul trucking.

Dana agreed to donate the use of one of their tractor-trailers for the pilot test, provide engineering support to integrate instrumentation on the tractor-trailer at their facilities in Kalamazoo, MI, provide the free use of Dana-owned instrumentation for the pilot test, lead the data acquisition functions, and share with ORNL/DOE any data collected for Dana's use during the pilot test. The cost, during the pilot test, of the fuel, driver, data collection system, and any specialized equipment for the collection of duty cycle information was provided from ORNL project funds. Some engineering support from ORNL was necessary. A verbal agreement to participate as a partner in the HVDC project was provided by Paul Pollock of Dana in January 2005.

In late calendar year 2004, discussions were also initiated with Michelin about their involvement in this project. Their interest was primarily driven by the opportunity to compare the fuel efficiency

performance of their next generation single tires against the standard dual tires used by most of the industry. Because of the energy efficiency aspect of their research interest, Michelin's collaboration on this project was endorsed by DOE. For the pilot test, Michelin provided a full set of new generation single tires for the tractor-trailer, provided a full set of the standard dual tires, and provided the use of a V-Box data collection system at no charge to the project. Data on fuel consumption and associated parameters would be shared with Michelin. A verbal agreement to participate as a partner in the HVDC project was provided by Ibrahim Janajreh of Michelin in January 2005.

3.3.1.2 USDOT/FMCSA/NHTSA and Virginia Tech Interactions: As the project kicked off in January 2005, ORNL re-contacted FMCSA to assess interest in participating in the HVDC project. Although interested, FMCSA, as well as other USDOT agencies were still in a continuing budget resolution, and had been since October 2003. No firm commitment was received from FMCSA. A request was made by FMCSA to keep them informed about the HVDC efforts, and to start a dialogue with Virginia Tech who had conducted some naturalistic driving efforts for FMCSA in the past. Also requested was that ORNL re-communicate with FMCSA after the pilot test ended and before the field test was to be initiated.

Rich Hanowski of Virginia Tech was contacted in 2004 regarding the HVDC pilot test; but because of their lack of funding, no firm commitments were made.

As suggested by FMCSA, ORNL kept FMCSA aware of progress during the pilot test, and initiated discussions with representatives of the National Highway Traffic Safety Administration (NHTSA) (Duane Perrin, Jim Britell and Tim Johnson). In late fall-2005, as the HVDC pilot testing was underway, ORNL arranged a meeting with both FMCSA (Jeff Loftus and Luke Loy) and NHTSA (Tim Johnson and Jim Britell) to discuss HVDC progress and explore interest in the field testing effort. The meetings were held in early December 2005. Again, interest was expressed, but no commitments were made. Additional interactions were pursued in winter, 2005; again, with no commitments made. The window for USDOT participation is closing due to the need to finalize field test instrumentation in March, 2006.

In February, 2006, ORNL contacted Ms. Debbie Freund (FMCSA) and Mr. Bob Carroll (FMCSA) who have been working in the areas of tire inflation systems and driver fatigue/naturalistic driving, respectively. No feedback about joint efforts has been received.

3.3.1.3 Kick-Off Meeting: A Project kick-off meeting was held at Michelin's Research Center in Greenville SC on February 7, 2005. Representatives from Michelin, Dana and ORNL were present. Representatives from ANL and Virginia Tech participated via a conference-call. The meeting went very well with all representatives extremely excited about this work. An initial list of sensors and duty cycle parameters was produced.

3.3.1.4 Memorandums of Agreement: ORNL drafted memorandums of agreement (MOAs) between ORNL and Dana, and ORNL and Michelin, respectively in February, 2005. Copies were forwarded to Dana and Michelin, and a small number of suggested changes were made and finalized in March, 2005. The MOAs were sent to ORNL contracts in April, 2005 and although these documents were not considered to be legally binding, ORNL's contracts office was unable to help project staff

develop versions that could be sent to Dana and Michelin for their signatures. After considerable interaction with ORNL's contracts office through July, 2005, further pursuance of a signed MOU between ORNL and Dana and ORNL and Michelin were abandoned.

3.3.1.5 21st Century Truck: ORNL was invited by the 21st Century Truck Partnership (21CTP) Industry Working Group (IWG), to provide an overview of the HVDC project at a 21CTP-IWG meeting held at DOT's Nassif Building in Washington, DC on March 21, 2005. The presentation was well received, and participants verbally agreed that the baseline data to be collected within the HVDC could be valuable as a benchmark against which the performance of 21CTP technologies could be compared.

3.3.1.6 Post-Pilot Test Discussions: As the pilot testing came to an end in January 2006, discussions regarding the initiation of the field tests became more active. Discussions held in January and February, 2006 identified the candidate fleets for the Field Test, their base of operations, and their hours of operations/yr. In addition, progress was made in determining the roles of Partners in the Field Test buildup, integration, and test conduction.

3.3.2 Task 2: Identification of Relevant Heavy Truck Performance Measures and Development of a Pilot Testing Plan.

The objectives of the HVDC project are to gather real-world long-haul data that can: a) generate duty cycle information on tractor-trailers engaged in long-haul activities, b) support development, testing and evaluation of the ANL class-8 module of the PSAT code, and c) to provide a data archive on long-haul trucking for use by DOE in associated technology decisions, and by researchers involved in energy efficiency studies.

Because funding for the HVDC effort was not unlimited, the primary performance measures to be collected would be those that support PSAT class-8 model development, and the Dana and Michelin interests related to vehicle dynamics and fuel consumption. The method used to compile this information was the development of a performance measurement survey sheet that was prepared and circulated to partners in February, 2005.

3.3.2.1 PSAT Efforts: In order to better understand the performance measures of interest to PSAT, ORNL initiated efforts shortly after the initiation of the project in January 2005 to gather information about PSAT, interface with PSAT developers at ANL, and to get PSAT up and running at ORNL. In January, 2005, ORNL obtained a two-year license from ANL for PSAT, and received the PSAT CD and its USB key. In February, 2005, a copy of Simulink was obtained, but initial efforts to get the simulation system functioning were unsuccessful. Success in running PSAT at ORNL was achieved in March, 2005. Through this experience and with interactions with PSAT staff at ANL, a comprehensive list of PSAT performance measures were identified.

3.3.2.2 Performance Measurement Survey Sheets: The performance measurement survey sheets were sent to Dana, Michelin and ANL in February, 2005 and were completed and returned to ORNL in early March, 2005. Integration of these performance measures with those compiled by ORNL stemming from the PSAT experience provided a long and comprehensive list of candidate performance measures. A draft report on the compiled Performance Measures was completed in

March and provided to the ORNL Program Office for Transportation Energy Efficiency as well as Mr. Lee Slezak (DOE Office of FreedomCar and Vehicle Technologies – OFCVT). In follow-up to the draft report, a conference call among project partners was held on April 7, 2005 to review the Performance Measures. After some refinement, a finalized performance measurement commitment sheet was prepared and circulated to the partners in mid-April, 2005. This sheet was used for partners to commit to providing the associated sensors for collecting this data. The completed sheets were received by ORNL from partners in May, 2005.

3.3.2.3 Data Bus Information: In May, 2005, the data buses (J1939 and J1708) on the test vehicle (Peterbilt 379) were queried to determine the extent of performance measurement data available. The following information was determined to be available from the data bus:

<u>J1939</u>	<u>J1708</u>
Electronic Engine Controller #2	Electronic Transmission Controller #1
Electronic Retarder Controller #1	Electronic Transmission Controller #2
Electronic Transmission Controller #2	Electronic Engine Controller #3
Electronic Engine Controller #3	Engine Temperature
Engine Temperature	Engine Fluid Level/Pressure
Engine Fluid Level / Temperature	Cruise Control / Vehicle Speed
Cruise Control / Vehicle Speed	Inlet / Exhaust Conditions
Fuel Economy	Electronic Engine Controller #2
Inlet / Exhaust Conditions	Electronic Engine Controller #1
Electronic Transmission Controller #1	
Electronic Engine Controller #1	

3.3.2.4 Pilot Test Sensor Data: A meeting was held July 20, 2005 with ORNL engine’s specialists to discuss the various engine sensors required for the project. It was determined that mass air flow will be taken from the data bus, exhaust temperature will be taken using a type-K thermocouple installed in the exhaust manifold and NO_x will be measured in the combined exhaust stream.

A finalized set of 105 channels of data was completed in July, 2005. Appendix A lists the Pilot Test Data Channels.

3.3.2.5 Aerodynamics Data: Several conference calls were conducted in October, 2005 between ORNL, ANL, and Lawrence Livermore National Laboratory (LLNL) staff concerning the collection of aerodynamic data, and the placement of the weather sensor. Timing and funding issues precluded installation of any aero-sensors (a weather station intended to collect weather based data including wind-speed and direction were already included). Additionally, some discussions focused on wind tunnel calibration of a candidate vehicle, and the potential addition of pressure ports. It was suggested that if LLNL could find additional funding, that the addition on aero-sensors could be considered for the field test.

Discussions on the collection of aero-data from the field test were resumed in February, 2006. Because the primary goal for the HVDC Project is to generate Duty Cycle information on a class-8 tractor-trailer operating in a long-haul mode for an extended period of time, detailed aero-data collection was not required. Some additional data (e.g., geographic location, type of location,

elevation, precipitation, barometric pressure, temperature, relative humidity, fuel consumption, gear position, engine torque, load, engine speed, wind speed/direction, etc.) will be collected to augment the duty cycle data for use with testing and evaluating the ANL class-8 PSAT module. Aerodynamics effects in PSAT will be reflected via the effective cross-sectional area of the tractor-trailer, a drag coefficient for the tractor-trailer, temperature, humidity, wind speed and wind direction. At the current time, other than the weather station, no additional aero-based sensors are being planned.

3.3.2.6 Pilot Test Plan: As the project kicked off in January, 2005, effort was put into the development of a Pilot Test Plan. This test plan provided details related to:

- Selection and procurement of the needed sensors and Data Acquisition System (DAS),
- Testing and verification of the DAS and associated sensors,
- Instrumentation of the pilot test vehicle with a sensor suite and DAS for the collection of data relative to predetermined performance measures,
- Testing and evaluation of the instrumented tractor-trailer, and
- Execution of the pilot test (collect pilot data).

From January, 2005 through October, 2005 (just prior to the initiation of the pilot test), the Pilot Test Plan evolved to its final form (see Appendix B). This document was utilized as a guide for conducting pre-pilot test activities as well as pilot test efforts. The Pilot Test Plan will be used as a template for the Field Test Plan.

3.3.2.7 Field Test Signals: In November, 2005, efforts were initiated to define a reduced set of signals (29 signals – See Appendix C) that support PSAT needs and are more amenable to implementation in a truck fleet test. Furthermore, the following measures are considered of high interest and may be included in the field test depending on the budget and sensor availability:

- Vehicle roll, pitch, and yaw
- Steering wheel angle/rate
- Brake system application pressure
- Vehicle GVW
- Vehicle total driveline torque
- Vehicle driveline speeds (front differential vs. rear differential)

3.3.3 Task 3: Procurement/Development of Necessary Sensors and Development of an Integrated Sensor Architecture.

The identification of appropriate sensors to collect pilot data for identified performance measures involved collaboration between all of the project partners. In order to leverage project funding, efforts were directed toward acquiring sensors and data acquisition systems on a borrowed/loaned agreement basis from the partners.

Between January, 2005 and May, 2005, project partners converged on an impressive list of equipment (see Appendix A) that was to be loaned to the project. Equipment that was unique to the collection of PSAT data was either ordered or leased. This equipment was ordered in June 2005, received at ORNL in July 2005 and subsequently sent to Dana Corp. in Kalamazoo, MI for integration into the Pilot Test Vehicle. The equipment includes the following:

- For Vehicle weight – Air-Weigh 5800 (Figure 1).



Figure 1: Air-Weigh 5800

- For weather information – Vaisala WXT510 Weather Transmitter (Figure 2).



Figure 2: Vaisala WXT510

- For Road Surface Temperature – RoadWatch (Figure 3)



Moto Mirror AERO with RoadWatch



RoadWatch Gauge

Figure 3: RoadWatch Equipment

In August, a letter report summarizing the sensor system was prepared and forwarded to DOE (see Appendix D). Figures 4 and 5 show the NGK NO_x/O₂ sensors (Figure 4); and the Omega exhaust gas temperature probe (Figure 5).



Figure 4: NGK Sensor



Figure 5: Omega Temperature Probe

3.3.4 Task 4: Development of a Prototype Data Acquisition System (DAS).

Efforts were spent between April and June, 2005 in identifying candidate data acquisition systems (DAS) for use in the pilot and field tests.

3.3.4.1 Pilot Test DAS: For the Pilot Test, the following DAS were identified:

- Somat EDAQ http://www.somat.com/products/data_acquisition/edaq.htm
- Iotech Logbook <http://www.iotech.com/catalog/daq/logbook.html>
- Prosig p8048 <http://www.prosig.com/p8000/p8048.html>
- LDS/Nicolet Liberty <http://www.niti.com/product39/Liberty>

In July, 2005, the Pilot Test DAS was specified as the SOMAT eDAQ (shown in Figure 6). Because of the need to assess the values of various DAS for pilot testing, and to reduce the total cost of the DAS equipment needed for testing, ORNL leased the system for the pilot testing phase from the National Transportation Research Center, Inc. (NTRCI), in Knoxville, Tennessee. This system was used to benchmark the potential Field Test DAS that were tested during the Pilot Test.

The eDAQ features include:

- Modular (buildable systems)
- Direct connection to strain bridges, accelerometers, pressure, temperature, load cells, quadrature decoders, ICP microphones
- 64 analog channels per unit
- Slaving of multiple units
- 128 vehicle bus channels
- 9V to 48V vehicle battery operation with internal battery backup
- Wireless operation for remote applications
- Shock resistant (20g) and sealed to dust



Figure 6 - SOMAT eDAQ DAS

A Letter Report describing the data acquisition system (DAS) was completed in August 2005 (see Appendix e). Michelin agreed to loan a RaceLogic VBox to the project at no cost to the HVDC project, and it was sent to Dana for integration in September, 2005 along with the Somat eDAQ DAS, Iotech Logbook, and the Oxford RT3100 Inertial Positioning System that had been ordered and received by ORNL.

In August, 2005 ORNL hosted a two-day workshop on the operation of the Somat eDAQ DAS. Dana and ORNL staff participated in this workshop that was held at the National Transportation Research Center (NTRC) in Knoxville, Tennessee.

3.3.4.2 Field Test DAS: For the Field Test the following DAS were initially considered:

- Racelogic VBox III <http://www.racelogic.co.uk/vbox/>
- Iotech Logbook <http://www.iotech.com/catalog/daq/logbook.html>

In November, 2005, the initial Field Test DAS and instrumentation suite was identified and verified as the Somat eDAQ-Lite DAS (see figure 7), the Vaisala WXT510 weather station (shown in figure 2), the vehicle's own J-1939 data bus, and the Racelogic VBox II-Lite GPS (see figure 8). During the field test, the vehicle's data bus and the VBox II-Lite will connect to the DAS via CAN data modules, and the WXT510 will connect via serial port. This sensor suite will allow the DAS to capture the following parameters:

<ul style="list-style-type: none"> ○ Date and Time ○ Wind Speed ○ Wind Direction ○ Rain Accumulation ○ Rain Duration ○ Rain Intensity ○ Barometric Pressure ○ Air Temperature ○ Relative Humidity ○ Latitude ○ Longitude ○ Velocity ○ Heading ○ Altitude ○ Vertical Velocity 	<ul style="list-style-type: none"> ○ Longitudinal Acceleration ○ Lateral Acceleration ○ Slope (calculated) ○ Accelerator Position ○ Fuel Rate ○ Average Economy ○ Gear Position ○ Engine Torque ○ Actual Gear Ratio ○ Driver's Demand Engine Torque ○ Load at Current Speed ○ Engine Speed ○ Engine Oil Temperature ○ Fuel Temperature ○ Vehicle Speed
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Figure 7 : eDAQ-Lite DAS



Figure 8: VBox II-Lite

3.3.5 Task 5: Installation of the DAS Prototype and Sensor Suites in One Long-Haul Tractor-Trailer.

3.3.5.1 Instrumentation: Installation of equipment onto the test vehicle was to have begun in May, 2005. Various staff and equipment unavailability, and difficulty in calibrating some of the test equipment (wheel force transducers) delayed the beginning of instrumentation until August, 2005. At that time sensor integration onto the test vehicle began at Dana's Tech Center in Kalamazoo MI. The sensor and DAS integration was completed in mid-October, 2005. In addition, in August, 2005, concrete ballast, to bring the test vehicle to 80,000 GVW was acquired at the Dana Tech Center. In September, 2005, all ORNL responsible equipment and sensors (see Table 1) had been delivered to Dana for integration.

In August, 2005, a subcontract for driver services for the pilot test was put into place. Services were initiated in mid-October at the initiation of the pilot test. Also in August, and at no cost to the project, the Dana Peterbilt tractor received new paint and extensive mechanical repairs in advance of the upcoming Pilot Test. See Figure 9.

Table 1

ORNL Equipment and Sensors Supplied to the HVDC Project		
	Purpose/MOP	Technology
1	Vehicle Weight	Air-Weigh 5800
2	Accessory Power Usage/DAS Power Usage	Hall Effect Current Transducers
3	DAS to Collect Data and to Test validity for Field Test	IOtech Logbook DAS
4	Fuel Consumption	Nox and O2 Sensor
5	Exhaust Gas Temperature	OMEGA TCs
6	TC extension cables	Support OMEGA TCs
7	Road surface temp	RoadWatch
8	Transmission and Diff Temp	TC in drain plugs
9	Weather	WX510
10	DAS	SoMat eDaq
11	Lat,Long Accel	RT 3100
12	DC-DC Converter	12V to 14V
13	DC-DC Converter	12V to 24V



Figure 9: Pilot Test Tractor (Dana's Peterbilt)

In October, 2005, an ORNL staff member traveled to Dana's Tech Center in Kalamazoo, MI to assist with the integration of sensors onto the test vehicle (See Figures 10 through 27). Sensor integration onto the test vehicle was completed on October 19, 2005, and shakedown testing of the test vehicle, sensors, and DAS was completed on October 21, 2005.

Figures 28 through 31 show the ballast and weather station mounting for the final run of the Pilot Test.

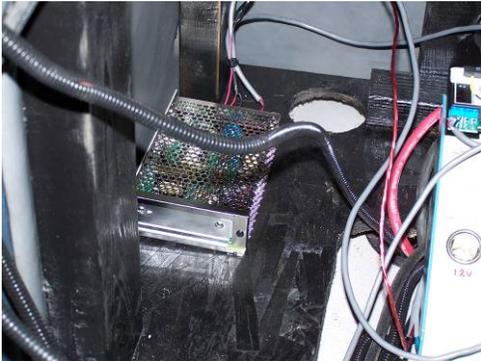


Figure 10: Current Transducer Power Supply

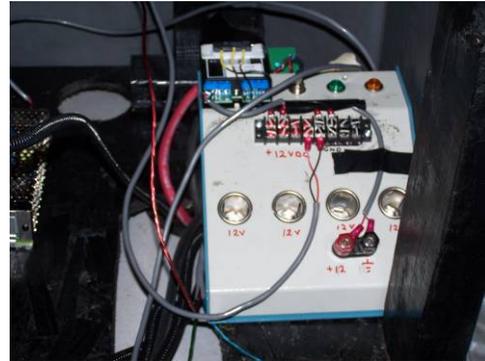


Figure 11: DC Power Distribution Box



Figure 12: Current Transducer at Alternator Output



Figure 13: Engine Compartment



Figure 14: No_x Sensor at the base of the Exhaust Stack

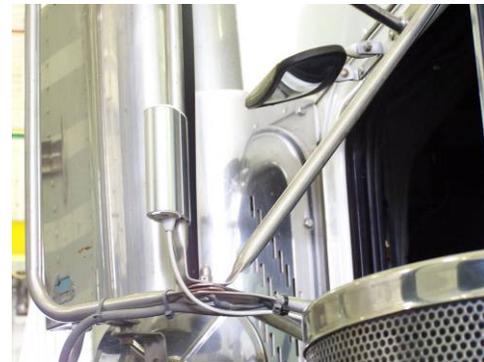


Figure 15: Roadwatch Temp Sensor



Figure 16: Exhaust Gas Thermo-Couple



Figure 17: Wheel Force Transducer on the Steer Axle



Figure 18: Dana Tractor during Integration

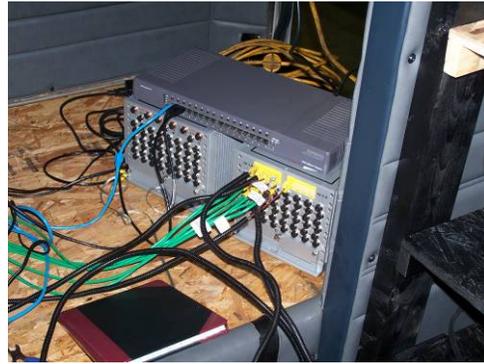


Figure 19: Somat eDAQ DAS in the Tractor's Sleeper



Figure 20: AirWeigh Display on the Trailer



Figure 21: Trailer Axle Tube (Strain Gages; Airweigh; Tire Pressure)



Figure 22: Airweigh System (Trailer Suspension)

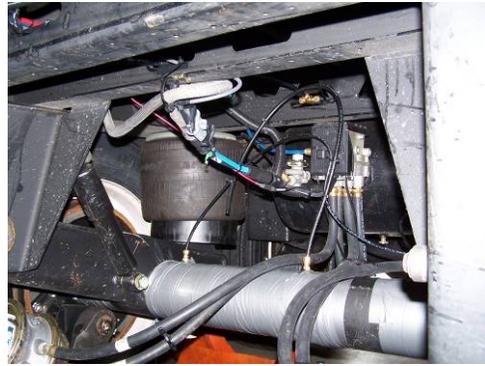


Figure 23: Airweigh System (Trailer Suspension)



Figure 24: Auto Air System (Trailer Tires Only)



Figure 25: Thermocouple in Rear Differential



Figure 26: Wheel Force Transducer (Drive Axle)

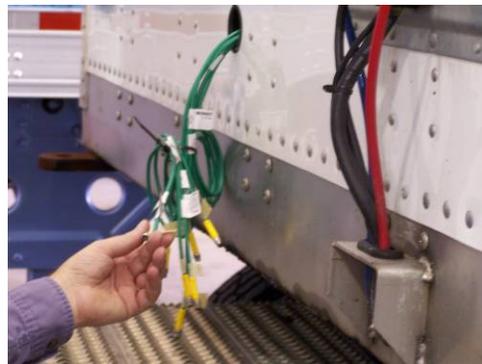


Figure 27: Cable from Trailer Mounted Sensors to eDAQ DAS

3.3.5.2 De-instrumentation: Following the completion of pilot testing in mid-January, 2006, the test vehicle was de-instrumented at the Dana Tech. Center and all of the equipment owned or leased by ORNL was returned.

3.3.6 Task 6: Test and Evaluate the Instrumented Tractor-Trailer (Collect Pilot Data).

Pilot Testing was originally scheduled to have begun in early August, 2005. Because of various delays related to staff engineer availability, availability of equipment, and equipment calibration, pilot testing was not initiated until October 23, 2005. Because of this delay, and because of the need to expedite

initiation of pilot testing, a request was made to Mr. Lee Slezak for his agreement not to engage in the open house for the instrumented truck as originally planned. Several alternatives to conducting the “open house” were suggested including a suggestion to display the Dana Technology Truck outfitted with Pilot Test data instrumentation at the SAE Government-Industry Meeting in the Washington DC area in May 2006.



Figure 28: Trailer Ballast From Mid-Trailer to Nose of Trailer



Figure 29: Trailer Ballast From Rear to Nose of Trailer



Figure 30: VBOXII Prior to the Loading of the Ballast



Figure 31: WXT510 Weather Station Mounted on Side Mirror

Pilot Testing took place from October 23, 2005 through January 19, 2006. This period of time included the holidays and involved considerable bad weather that caused some additional delays.

The map in Figure 32 shows the East-West route, and Figures 33 and 34 show the North-South route (the route traveling South, and the route traveling North respectively). Each route was traveled twice (once with standard dual tires and once with new-generation single tires). It should be noted that the routes taken were not strictly identical, but were very similar.

Two Chicago-to-Portland roundtrip runs were made between October 23, 2005 and November 19, 2005. For the first dataset (collected during the period October 23rd - November 2nd 2005), the truck was mounted with regular dual tires; for the second (November 7th – November 18th 2005) it had new generation singles. During the two round trips 8,500 miles were covered and 220 hours of driving were logged. More than 24 Gigabits of data were collected and saved to

DVD. Figures 35 and 36 show some of the Pilot Test equipment located in the tractor cab.

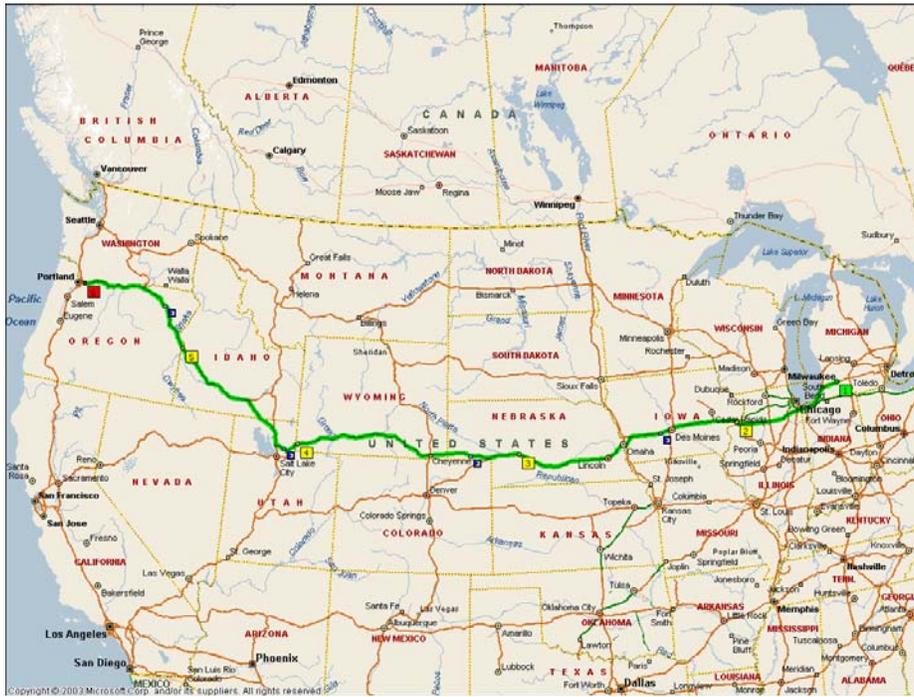


Figure 32: The East-West Route



Figure 34: The North-South Route (Traveling North)



Figure 35: Pilot Test DAS



Figure 36: RT 3100 Inertial GPS

The first Maine-to-Tampa-to-Detroit run ended December 14, 2005. Due to weather delays and truck maintenance, this run took 14 days to complete. This run utilized the new generation single tires and logged 4,581 miles, 114.5 hours of driving, and generated approximately 12 gigabytes of data.

The final route (Maine-to-Orlando-to-Detroit) of the Pilot Test was completed on Thursday, January 19, 2006. This run utilized dual tires on the tractor and trailer and logged 4,616 miles of driving, 90 hours of operation, and approximately 11 gigabytes of data taken over a 10-day period.

3.3.7 Task 7: Analyze Pilot Data and Demonstrate Duty Cycle Generation Capabilities.

3.3.7.1 Pre-Analysis Efforts: As the pilot testing was initiated in October, 2005, the ORNL staff readied itself for the data analysis efforts. One of the main challenges was the extraction of data from the eDAQ software and translation into a spreadsheet or database that is directly usable by the ORNL staff. After contacting eDAQ staff, the eDAQ Application Programming Interface (API) was obtained which allowed ORNL the capability to write (program) the necessary procedures to extract the relevant data from the project data files without the need for significant human intervention. Without this capability, the process would be very time-consuming especially in-light-of the extremely large datasets that were generated. Once the ORNL staff became familiar with the API, a signal extraction strategy for the data sets was developed

It was also felt to be important that ANL be kept in the loop regarding the pilot test data collection effort, and that current versions of PSAT and associated software be available at ORNL. In November, 2005, ORNL installed and tested new versions of Matlab, Simulink and PSAT. The ORNL staff also met with Aymeric Rousseau (ANL) at the NTRC to discuss avenues for collaboration including the sharing of the pilot and field test data. In December, 2005, ORNL provided a copy of one DVD pilot test data disk to Aymeric Rousseau (ANL) for coding and input into PSAT.

3.3.7.2 Pilot Test Data: In December, 2005, ORNL received two sets of data (consisting of ten DVDs per set) collected on the Chicago, Illinois-to-Portland, Oregon-to-Chicago, Illinois runs. Each set of data consisted of more than 100 channels of information which amounted to more than 15 GB per set. ORNL read the information using the InField software provided by the manufacturer of the data collection equipment (eDAQ) and was able to export selected data to other formats for more extensive analysis. This was done manually, since the databases generated by eDAQ have very complicated structures that are not easy to read directly. These sample subsets were mapped using Microsoft MapPoint and some errors in the database were discovered (e.g., problems with the GPS information collected with the VBox equipment, and a few problems with the data stream (especially at the beginning of each data collection period)).

3.3.7.3 Mapping Utility: As the pilot test data started coming in, ORNL began the development of a mapping utility that would allow users to access, in a geo-spatial manner, the information collected during the runs, to select a certain portion of the data on the map, and to view the data for that selected area in a graphical form as well as being able to export the information to other formats (e.g., Excel) for further analysis. This tool is not only essential for the data analysis task, but will provide the basis for a new PSAT-based duty cycle generation tool that has the capability of easily generating duty cycles based on the data collected in the field. This tool will be more fully prototyped during Phase 2.

3.3.7.4 Data Analyses: The data analyses efforts for the pilot test is focused on demonstration of the capability of generating usable duty cycles for input into PSAT based on the data collected. In addition, ORNL staff will look for interesting long-haul characterization statistics including fuel usage vs. tire configuration, emission profiles, etc. The results of the data analyses will be the focus of a stand-alone letter report. A number of lessons learned came from this experience. These included:

- Selection of a DAS that stores data in an easily extractable format
- Time stamping is of critical importance for comparison of data
- If data is for some reason not taken, an indicator should be provided saying that the data was missed (otherwise, data synchronization would be a problem).
- Collection of data can be done at much less than 100Hz. A rate of 2-10Hz is sufficient.
- The data collection rate should be the same for all performance measures.
- Data handling and processing, especially with extremely large data sets can be extremely resource intensive.

3.3.8 Task 8: Prepare Phase 1 Report.

This final report was initiated after all of the pilot testing was completed, and prior to the completion of the data analyses. It reflects efforts in all of the nine HVDC Task areas.

3.3.9 Task 9: Provide Project Management.

ORNL's Project Management efforts involved a number of significant activities. They included oversight of a multi-faceted team, planning and logistics, sponsor-partner interactions, fiscal management, interaction with 21st Century Truck Partnership, and monthly reporting. Some of the major meetings that the HVDC Project Team was involved with included the following:

- A presentation related to project status was provided at the Advanced Vehicle Technologies Analysis and Evaluation (AVTAE) project review meeting held at DOE-HQ on August 16, 2005. At that meeting information on the project was presented and was well received.
- A project review meeting was held with Mr. Lee Slezak on Friday, December 2, 2005 in the Forrestal Building. Project status and FY2006 budget requests were reviewed. The FY06 budget of was discussed and agreed upon to begin the Field Test portion of the project.
- ORNL and Michelin staff met with Mr. Lee Slezak at DOE HQ on Thursday, January 25, 2006 to discuss FY2006 efforts.

4.0 PHASE 2 EFFORTS

Phase 2 of the HVDC effort will involve field data collection on one or more fleets (from two-to-ten tractor trailers) of class-8 tractor trailers engaged in normal vocational/economic activities over a 12-month period of time. A reduced set of data will be collected to focus on PSAT development and evaluation needs and data that compliment the needs of HVDC partners. Phase 2 of the HVDC Project will require 18 months of effort starting in April 2006, and being completed in September, 2007. The field test will involve multiple long-haul runs across the US utilizing volunteer trucks from one or more private fleets.

4.1 PHASE 2 TASKS

Phase 2 efforts will be initiated in April 2005. The effort involves 13 tasks. These tasks are:

- Task 1: Identification of Fleet(s) for Testing
- Task 2: Identification of Needed Instrumentation
- Task 3: Procurement of Instrumentation
- Task 4: Instrumentation of the Fleet(s)
- Task 5: Establishment of a Data Repository
- Task 6: Finalization of the Test Plan
- Task 7: Field Testing (July 2006 through June 2007)
- Task 8: Develop Prototype Heavy Vehicle Duty Cycle Generation Tool
- Task 9: Analyze Field Test Data
- Task 10: Generate Agreed Upon Duty Cycles for PSAT.
- Task 11: Support ANL in PSAT Efforts
- Task 12: Prepare Phase 2 Report with Recommendations for Future Efforts.
- Task 13: De-Instrument Vehicles, or Plan for Phase 3.

5.0 CONCLUSIONS

The efforts engaged in during Pilot Testing were extremely valuable. Failure to invest in pilot testing activities prior to a field test has a strong potential for having something go wrong during the field test. Field hardening of instrumentation or data collection systems, familiarity with such instrumentation and systems, optimal calibration, and just generally pilot testing lessons learned, protocols and procedures are ways of ensuring that once a field test has been initiated, that downtime is kept to a minimum.

The HVDC team obtained considerable experience with the sensors and data acquisition systems utilized during the pilot test. A more optimal data collection frequency rate was determined, and attention was focused on the need for better time stamping and data synchronicity. Additional emphasis in field test design is being placed on the need for continually-mated tractor trailers. Because of this, more than one volunteer fleet may need to be utilized

The handling of the enormous amount of data that was generated in the Pilot Test was discovered to be very resource intensive. The adjustment of data collection rates, the collection of data at the same frequency for all performance measures, and the need to develop some automated data handling/management tools were identified to be necessary and will be addressed in the field test.

Overall, the conduct of the pilot test resulted in the HVDC team to be much more prepared for the conduct of the field test, in the analysis of the data generated and in envisioning capabilities for providing tools for generating custom duty cycle profiles and information.

Appendix A-A
Pilot Test Data Channels

Data #	Performance Measure	Performance Measure Value	Units	Resolution	Sensor or System Output	Sensor Location	Format	eDaq Interface Module	Scan Rate	Mode
1	Date and Time	Time Reference	EST	1 s	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100	Time History
2	Latitude	Route identification; mapping	deg	0.4m CEP	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10	Time History
3	Longitude	Route identification; mapping	deg	0.4m CEP	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10	Time History
4	Altitude	Route mapping; road grade	deg	0.4m CEP	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10	Time History
5	North Velocity	Vehicle speed vector	km/h	0.1 km/h	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10	Time History
6	East Velocity	Vehicle speed vector	km/h	0.1 km/h	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10	Time History
7	Down Velocity	Vehicle speed vector	km/h	0.1 km/h	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10	Time History
8	Forward Velocity	Vehicle speed vector	km/h	0.1 km/h	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10	Time History
9	Lateral Velocity	Vehicle speed vector	km/h	0.1 km/h	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10	Time History
10	Truck Body X Acceleration	Drive Cycle Characterization	m/s ²	10 mm/s ²	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	256	Time History
11	Truck Body Y Acceleration	Drive Cycle Characterization	m/s ²	10 mm/s ²	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	256	Time History
12	Truck Body Z Acceleration	Drive Cycle Characterization	m/s ²	10 mm/s ²	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	256	Time History

Data #	Performance Measure	Performance Measure Value	Units	Resolution	Sensor or System Output	Sensor Location	Format	eDaq Interface Module	Scan Rate	Mode
13	Truck Longitudinal Acceleration	Drive Cycle Characterization	m/s ²	10 mm/s ²	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	256	Time History
14	Truck Lateral Acceleration	Drive Cycle Characterization	m/s ²	10 mm/s ²	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	256	Time History
15	Truck Vertical Acceleration	Drive Cycle Characterization	m/s ²	10 mm/s ²	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	256	Time History
16	Heading Angle	Drive Cycle Characterization	deg	0.2°	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100	Time History
17	Pitch Angle	Describes Vehicle Body Motion, Road Grade	deg	0.2°	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100	Time History
18	Roll Angle	Describes Vehicle Body Motion	deg	0.2°	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100	Time History
19	Truck Body X Angular Rate	Describes Vehicle Body Motion	deg/s	0.01°/s	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100	Time History
20	Truck Body Y Angular Rate	Describes Vehicle Body Motion	deg/s	0.01°/s	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100	Time History
21	Truck Body Z Angular Rate	Describes Vehicle Body Motion	deg/s	0.01°/s	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100	Time History
22	Roll Rate	Describes Vehicle Body Motion	deg/s	0.01°/s	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100	Time History
23	Pitch Rate	Describes Vehicle Body Motion	deg/s	0.01°/s	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100	Time History

Data #	Performance Measure	Performance Measure Value	Units	Resolution	Sensor or System Output	Sensor Location	Format	eDaq Interface Module	Scan Rate	Mode
24	Yaw Rate	Describes Vehicle Body Motion	deg/s	0.01°/s	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100	Time History
25	Slip Angle	Difference between heading & COG	deg	0.25°	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10	Time History
26	Track Angle	Course over ground	deg	0.2°	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10	Time History
27	Distance Traveled	Drive Cycle Characterization	m	?	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	1	Time History
28	Outside Temperature	Drive Cycle Characterization; Aero Modeling; Wear	°F	2° F	Roadwatch	Right Cab Mirror	RS-232 or J1708	CPU or EDIO & J1708 Module	1	CPU Data Stream
29	Road Surface Temp	Wear Evaluations	°F	2° F	Roadwatch	Right Cab Mirror	RS-232 or J1708	CPU or EDIO & J1708 Module	1	CPU Data Stream
30	Wind Speed	Drive Cycle Characterization; Aero Modeling	m/s	0.3 m/s	WXT510	Top Faring Centerline	RS-232	CPU Serial Port	1	CPU Data Stream
31	Wind Direction	Drive Cycle Characterization; Aero Modeling	deg	2°	WXT510	Top Faring Centerline	RS-232	CPU Serial Port	1	CPU Data Stream
32	Rain Accumulation	Drive Cycle Characterization	mm	5%	WXT510	Top Faring Centerline	RS-232	CPU Serial Port	1	CPU Data Stream
33	Rain Duration	Drive Cycle Characterization	s	?	WXT510	Top Faring Centerline	RS-232	CPU Serial Port	1	CPU Data Stream
34	Rain Intensity	Drive Cycle Characterization	Hits/cm ² /h	?	WXT510	Top Faring Centerline	RS-232	CPU Serial Port	1	CPU Data Stream
Data #	Performance Measure	Performance Measure Value	Units	Resolution	Sensor or System Output	Sensor Location	Format	eDaq Interface Module	Scan Rate	Mode

	Measure	Measure Value			System Output	Location		Interface Module	Rate	
35	Barometric Pressure	Drive Cycle Characterization; Aero Modeling	hPa	0.5 hPa	WXT510	Top Faring Centerline	RS-232	CPU Serial Port	1	CPU Data Stream
36	Air Temperature	Repeat Channel #28	°F	0.5° F	WXT510	Top Faring Centerline	RS-232	CPU Serial Port	1	CPU Data Stream
37	Relative Humidity	Drive Cycle Characterization; Aero Modeling	%	3%	WXT510	Top Faring Centerline	RS-232	CPU Serial Port	1	CPU Data Stream
38	Longitudinal Wheel Load	Ride Input at the Wheel	lb	?	Mich Sci LW-1T-25K	Right Steer Wheel End	+/- 10V	High Level SS	256	Burst History
39	Lateral Wheel Load	Ride Input at the Wheel	lb	?	Mich Sci LW-1T-25K	Right Steer Wheel End	+/- 10V	High Level SS	256	Burst History
40	Vertical Wheel Load	Ride Input at the Wheel	lb	?	Mich Sci LW-1T-25K	Right Steer Wheel End	+/- 10V	High Level SS	256	Burst History
41	Overtuning Moment (Mx)	ADAMS Modeling	lbf-in	?	Mich Sci LW-1T-25K	Right Steer Wheel End	+/- 10V	High Level SS	256	Burst History
42	Driving/braking Moment (My)	ADAMS Modeling	lbf-in	?	Mich Sci LW-1T-25K	Right Steer Wheel End	+/- 10V	High Level SS	256	Burst History
43	Steering Moment (Mz)	ADAMS Modeling	lbf-in	?	Mich Sci LW-1T-25K	Right Steer Wheel End	+/- 10V	High Level SS	256	Burst History
44	Longitudinal Wheel Force	Ride Input at the Wheel	lb	?	MTS SWIFT 50T	Left Forward Drive Wheel	+/- 10V	High Level SS	256	Burst History
Data #	Performance	Performance	Units	Resolution	Sensor or	Sensor	Format	eDaq	Scan	Mode

	Measure	Measure Value			System Output	Location		Interface Module	Rate	
45	Lateral Wheel Force	Ride Input at the Wheel	lb	?	MTS SWIFT 50T	Left Forward Drive Wheel	+/- 10V	High Level SS	256	Burst History
46	Vertical Wheel Force	Ride Input at the Wheel	lb	?	MTS SWIFT 50T	Left Forward Drive Wheel	+/- 10V	High Level SS	256	Burst History
47	Overturning Moment (Mx)	ADAMS Modeling	lbf-in	?	MTS SWIFT 50T	Left Forward Drive Wheel	+/- 10V	High Level SS	256	Burst History
48	Driving/braking Moment (My)	ADAMS Modeling	lbf-in	?	MTS SWIFT 50T	Left Forward Drive Wheel	+/- 10V	High Level SS	256	Burst History
49	Steering Moment (Mz)	ADAMS Modeling	lbf-in	?	MTS SWIFT 50T	Left Forward Drive Wheel	+/- 10V	High Level SS	256	Burst History
50	Longitudinal Wheel Load	Ride Input at the Wheel	lb	?	MTS SWIFT 50T	Right Forward Drive Wheel	+/- 10V	High Level SS	256	Burst History
51	Lateral Wheel Load	Ride Input at the Wheel	lb	?	MTS SWIFT 50T	Right Forward Drive Wheel	+/- 10V	High Level SS	256	Burst History
52	Vertical Wheel Load	Ride Input at the Wheel	lb	?	MTS SWIFT 50T	Right Forward Drive Wheel	+/- 10V	High Level SS	256	Burst History
53	Overturning Moment (Mx)	ADAMS Modeling	lbf-in	?	MTS SWIFT 50T	Right Forward Drive Wheel	+/- 10V	High Level SS	256	Burst History

Data #	Performance Measure	Performance Measure Value	Units	Resolution	Sensor or System Output	Sensor Location	Format	eDaq Interface Module	Scan Rate	Mode
54	Driving/braking Moment (My)	ADAMS Modeling		?	MTS SWIFT 50T	Right Forward Drive Wheel	+/- 10V	High Level SS	256	Burst History
55	Steering Moment (Mz)	ADAMS Modeling		?	MTS SWIFT 50T	Right Forward Drive Wheel	+/- 10V	High Level SS	256	Burst History
56	Driveline Speed	VehSim Input	rpm	TBD	Optical Proximity Detector	Input to Drive Axles	TBD	TBD	100	TBD
57	Driveline Torque	VehSim Input	N-m		TorqueTrak 9000 Telemetry System	Input to Drive Axles			100	Time at Level
58	Longitudinal Acceleration	Concept/Prototype Development			Dana Prototype ECU	Between Trailer Tandem; Sprung Mass	Proprietary CAN	eDaq Lite EDIO & CAN Module	100	Burst History
59	Lateral Acceleration	Concept/Prototype Development			Dana Prototype ECU	Between Trailer Tandem; Sprung Mass	Proprietary CAN	eDaq Lite EDIO & CAN Module	100	
60	Vertical Acceleration	Concept/Prototype Development			Dana Prototype ECU	Between Trailer Tandem; Sprung Mass	Proprietary CAN	eDaq Lite EDIO & CAN Module	100	
61	Wheel End Temperature	Bearing life; prototype development	°F		Prototype Temp Sensor	Left forward trailer wheel	Proprietary CAN	eDaq Lite EDIO & CAN Module	1	

Data #	Performance Measure	Performance Measure Value	Units	Resolution	Sensor or System Output	Sensor Location	Format	eDaq Interface Module	Scan Rate	Mode
62	Wheel End Temperature	Bearing life; prototype development	°F		Prototype Temp Sensor	Right Forward Drive Wheel	Proprietary CAN	eDaq Lite EDIO & CAN Module	1	
63	Wheel End Temperature	Bearing life; prototype development	°F		Prototype Temp Sensor	Left rear trailer wheel	Proprietary CAN	eDaq Lite EDIO & CAN Module	1	
64	Wheel End Temperature	Bearing life; prototype development	°F		Prototype Temp Sensor	Right rear trailer wheel	Proprietary CAN	eDaq Lite EDIO & CAN Module	1	
65-67	Trailer Axle Strain	Durability	uE		Rosette Gauge	Center trailer axle tube		High Level SS & SmartModule	256	Burst History
68-69	Trailer Axle Strain	Durability	uE		Half Bridge Gauges	Right side trailer axle		High Level SS & SmartModule	256	Burst History
70-71	Trailer Axle Strain	Durability	uE		Half Bridge Gauges	Left side trailer axle		High Level SS & SmartModule	256	Burst History
72	Steering Angle	Steering Input	Deg		Potentiometer	Steering Gear/Pitman Arm	+/- 5V	High Level SS	10	Time History
73	Brake Treadle Pressure	Brake Application Strength	psi		Pressure Transducer	Brake Treadle			10	
74	Axle Oil Temperature	Axle Oil Operating Temperature Range	°F		Thermocouple	Forward Drive Axle			1	
75	Axle Oil Temperature	Axle Oil Operating Temperatures	°F		Thermocouple	Rear Drive Axle			1	
76	PDU Oil Temperature	PDU Operating Temperatures	°F		Thermocouple	PDU			1	

Data #	Performance Measure	Performance Measure Value	Units	Resolution	Sensor or System Output	Sensor Location	Format	eDaq Interface Module	Scan Rate	Mode
76	PDU Oil Temperature	PDU Operating Temperatures	°F		Thermocouple	PDU			1	
77	Transmission Temperature	Transmission Oil Operating Temperatures	°F		Thermocouple	Transmission			1	
78	Engine Exhaust Temperature	System Efficiency Evaluation	°F		Thermocouple	Manifold Port			1	
79	Engine Nox Sensor	Fuel Usage	PPM			Exhaust Manifold			10	
80	Engine O2 Sensor	Fuel Usage	PPM			Exhaust Manifold			10	
80	Test Equipment Power Usage	Energy Efficiency	w		Hall Effect or Inductive Sensor	TBD			1	
81	Battery Current	System Efficiency Evaluation	ma		Hall Effect or Inductive Sensor	Battery in-line			1	
82	Satellites	Trailer vs. Tractor Vehicle Dynamics			Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	1	
83	Time	Trailer vs. Tractor Vehicle Dynamics			Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	100	
84	Latitude	Trailer vs. Tractor Vehicle Dynamics			Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	10	
85	Longitude	Trailer vs. Tractor Vehicle Dynamics			Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	10	
86	Velocity	Trailer vs. Tractor Vehicle Dynamics			Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	10	

Data #	Performance Measure	Performance Measure Value	Units	Resolution	Sensor or System Output	Sensor Location	Format	eDaq Interface Module	Scan Rate	Mode
87	Heading	Trailer vs. Tractor Vehicle Dynamics			Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	10	
88	Height	Trailer vs. Tractor Vehicle Dynamics			Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	10	
89	Vertical Velocity	Trailer vs. Tractor Vehicle Dynamics			Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	10	
90	Longitudinal Acceleration	Trailer vs. Tractor Vehicle Dynamics			Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	256	
91	Lateral Acceleration	Trailer vs. Tractor Vehicle Dynamics			Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	256	
92	Trigger status	Trailer vs. Tractor Vehicle Dynamics			Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	1	
93	Distance Travelled	Trailer vs. Tractor Vehicle Dynamics			Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	1	
94	Accelerator Pedal Position	Of interest for engine map and model verification	%		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10	
95	Fuel Rate	Fuel consumption modeling verification	L/hr		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10	
96	Average Fuel Economy	Fuel consumption modeling verification	km/L		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10	

Data #	Performance Measure	Performance Measure Value	Units	Resolution	Sensor or System Output	Sensor Location	Format	eDaq Interface Module	Scan Rate	Mode
97	Gear Position	Fuel Consumption Modeling; Driver Behavior	Position		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10	
98	Engine Torque	Fuel Consumption Modeling	%		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10	Time at Level
99	Actual Gear Ratio				CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10	
100	Driver's Demand Engine Torque	Fuel Consumption Modeling	%		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10	
101	Load at Current Speed	Fuel Usage	%		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10	
102	Engine Speed	Fuel Consumption Modeling	rpm		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10	Time at Level
103	Engine Oil Temperature		°C		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10	
104	Fuel Temperature		°C		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10	
105	Vehicle Speed		km/hr		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10	

Appendix A-B
Final Pilot Test Plan

**HEAVY-TRUCK DUTY CYCLE DATA
FROM REAL-WORLD DRIVING ENVIRONMENTS**

Test Plan for Phase 1 Pilot Testing

(This Document Fulfills Milestone M2.1 and Deliverable D2.1 of the Project SOW)

**Prepared by
Oak Ridge National Laboratory**

**For
Department of Energy's Office of Freedom Car and Vehicles Systems**

1.0 BACKGROUND

This Program will involve efforts to collect, analyze and archive data and information related to heavy-truck operation in real-world highway environments over a two-year period of time. Such data and information will be usable to support technology evaluation efforts, and provide a means of accounting for real-world driving performance within heavy truck analyses. The Program will be led by Oak Ridge National Laboratory, will involve two industry partners (Dana Corporation (DANA) of Kalamazoo, MI, and Michelin Americas Research & Development Corporation (Michelin) Greenville, SC) and will have support from Argonne National Laboratory (ANL). Both industry partners are interested in the vehicle dynamics for real world applications in order to validate their computer simulation models of the truck axles, tire performance, and tire-road interface. Dana has agreed to provide access to a test vehicle for the initial phase of the Program (Year 1), and up to ten vehicles for Phase 2 (Year 2). Both Dana and Michelin will provide special instrumentation that will collect data of use to all partners. If DOT is also a partner, additional driver-based behavior characteristics may also be collected.

The Program will be conducted in two phases. These phases are:

Phase 1 – *Pilot Test*: Design, Testing and Evaluation of a Duty Cycle Data Collection System.

Phase 2 – *Field Test*: Fleet Instrumentation, Data Collection and Analyses

This Test Plan will only be concerned with Phase 1 of the Program and will involve a number of tasks that will result in an evaluated and tested data acquisition system (DAS) and sensor suite.

Phase 1 will assure that the hardware, software, and testing protocols are workable and can be utilized in Phase 2 activities. The test will also provide experience in field data management, which will be important factors in establishing the data repository for the field test in Phase 2. Pilot data will be retrieved and analyzed utilizing various software including the PSAT Code. This will be done in order to gain preliminary insights into real-world heavy truck duty cycles, and to test the data collection, management, and handling portion of the system.

2.0 OBJECTIVES, RATIONAL, AND EXPECTED BENEFITS

The instrumented tractor-trailer will be deployed to test:

- DAS/sensor suite/cabling operability/durability over various types of highways, grades and environmental conditions
- DAS/ data collection capabilities
- Data Storage and Downloading protocols
- Down-selection of DAS and sensor suite for Phase 2 Field Test
- Driver interaction with the instrumented vehicle

The pilot data collection task will take place over a three-month period of time. The pilot data will be useful in refining the data repository and will be usable in testing data usability in PSAT and other analysis tools. The pilot data will be input into a temporary data repository and used to exercise the data handling, data manipulation and analysis capabilities. As necessary, a data repository will be developed in Phase 2, and will be defined based on the pilot data. Data from the pilot tests will be utilized to select the needed sensors, to adjust and fine tune the DAS configuration, and make the system(s) ready for more widespread testing in Phase 2.

Furthermore, the pilot testing will permit acquisition of unique data that will be impossible to acquire in field testing. Since the pilot test will be monitored full-time by a data acquisition engineer onboard the vehicle, more advanced instrumentation and data acquisition techniques will be involved.

3.0 APPROACH

This project will involve the instrumenting of a class-8 over-the-road tractor-trailer with a suite of sensors, a pair of DASs, and the operation of this instrumented vehicle to determine the viability of the sensor suite, the DASs, data collection methods, and driver interaction.

This Test Plan will address the following Tasks:

- Selection and procurement of the needed sensors and DASs
- Testing and verification of the DASs and associated sensors
- Instrumenting the Pilot Test vehicle with a sensor suite and DASs that will collect data relative to predetermined Performance Measures (PMs).
- Testing and evaluation of the instrumented tractor-trailer
- Execution of the Pilot Test (collect pilot data).

3.1 Performance Measures

A variety of metrics have been identified as necessary in understanding the Drive Cycle of the test vehicle. There are other metrics of interest relative to durability, ride, and safety that will be collected only during the Pilot Test.

The metrics (Performance Measures) listed in Table 3.1 have been identified as being viable for the Pilot Testing portion of this project. For the purposes of this test plan, PMs are grouped according to location or type (i.e. weather, strain, acceleration, vehicle system, etc.). The ordering is important in the Test Plan for the ease of identifying associated sensors. All data will be acquired in “Time History” mode.

As a part of this test plan the PMs listed in Table 3.1 have been verified by the consortium (down-selected) as necessary to the outcome of the Pilot Testing.

Table 3.1 Measures of Performance and Associated Sensor

Data #	Performance Measure	Performance Measure Value	Units	Resolution/Accuracy	Sensor or System Output	Sensor Location	Format	eDaq Interface Module	Scan Rate
1	Date and Time	Time Reference	EST	1 s	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100
2	Latitude	Route identification; mapping	deg	0.4m CEP	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10
3	Longitude	Route identification; mapping	deg	0.4m CEP	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10
4	Altitude	Route mapping; road grade	deg	0.4m CEP	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10
5	North Velocity	Vehicle speed vector	km/h	0.1 km/h	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10
6	East Velocity	Vehicle speed vector	km/h	0.1 km/h	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10
7	Down Velocity	Vehicle speed vector	km/h	0.1 km/h	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10
8	Forward Velocity	Vehicle speed vector	km/h	0.1 km/h	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10

9	Lateral Velocity	Vehicle speed vector	km/h	0.1 km/h	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10
10	Truck Body X Acceleration	Drive Cycle Characterization	m/s ²	10 mm/s ²	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	256
11	Truck Body Y Acceleration	Drive Cycle Characterization	m/s ²	10 mm/s ²	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	256
12	Truck Body Z Acceleration	Drive Cycle Characterization	m/s ²	10 mm/s ²	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	256
13	Truck Longitudinal Acceleration	Drive Cycle Characterization	m/s ²	10 mm/s ²	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	256
14	Truck Lateral Acceleration	Drive Cycle Characterization	m/s ²	10 mm/s ²	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	256
15	Truck Vertical Acceleration	Drive Cycle Characterization	m/s ²	10 mm/s ²	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	256
16	Heading Angle	Drive Cycle Characterization	deg	0.2°	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100
17	Pitch Angle	Describes Vehicle Body Motion, Road Grade	deg	0.2°	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100
18	Roll Angle	Describes Vehicle Body Motion	deg	0.2°	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100
19	Truck Body X Angular Rate	Describes Vehicle Body Motion	deg/s	0.01°/s	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100
20	Truck Body Y Angular Rate	Describes Vehicle Body Motion	deg/s	0.01°/s	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100
21	Truck Body Z Angular Rate	Describes Vehicle Body Motion	deg/s	0.01°/s	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100
22	Roll Rate	Describes Vehicle Body Motion	deg/s	0.01°/s	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100
23	Pitch Rate	Describes Vehicle Body Motion	deg/s	0.01°/s	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100

24	Yaw Rate	Describes Vehicle Body Motion	deg/s	0.01°/s	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	100
25	Slip Angle	Difference between heading & COG	deg	0.25°	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10
26	Track Angle	Course over ground	deg	0.2°	RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	10
27	Distance Travelled	Drive Cycle Characterization	m		RT3100	Beneath driver's seat	CAN bus	EDIO & CAN Module	1
28	Outside Temperature	Drive Cycle Characterization; Aero Modeling; Wear	°F	2° F	Roadwatch	Right Cab Mirror	RS-232	Log by USB Datafile or by Hand	1
29	Road Surface Temp	Wear Evaluations	°F	2° F	Roadwatch	Right Cab Mirror	RS-232	Log by USB Datafile or by Hand	1
30	Wind Speed	Drive Cycle Characterization; Aero Modeling	m/s	0.3 m/s	WXT510	Top Faring Centerline	RS-232	CPU Serial Port & WX Online Monitor	1
31	Wind Direction	Drive Cycle Characterization; Aero Modeling	deg	2°	WXT510	Top Faring Centerline	RS-232	CPU Serial Port & WX Online Monitor	1
32	Rain Accumulation	Drive Cycle Characterization	mm	5%	WXT510	Top Faring Centerline	RS-232	CPU Serial Port & WX Online Monitor	1
33	Rain Duration	Drive Cycle Characterization	s		WXT510	Top Faring Centerline	RS-232	CPU Serial Port & WX Online Monitor	1

34	Rain Intensity	Drive Cycle Characterization	Hits/c m ² /h		WXT510	Top Faring Centerline	RS-232	CPU Serial Port & WX Online Monitor	1
35	Barometric Pressure	Drive Cycle Characterization; Aero Modeling	hPa	0.5 hPa	WXT510	Top Faring Centerline	RS-232	CPU Serial Port & WX Online Monitor	1
36	Air Temperature	Repeat Channel #28	°F	0.5° F	WXT510	Top Faring Centerline	RS-232	CPU Serial Port & WX Online Monitor	1
37	Relative Humidity	Drive Cycle Characterization; Aero Modeling	%	3%	WXT510	Top Faring Centerline	RS-232	CPU Serial Port & WX Online Monitor	1
38	Longitudinal Wheel Load	Ride Input at the Wheel	lb		Mich Sci LW-1T-25K	Right Steer Wheel End	+/- 10V	High Level SS	256
39	Lateral Wheel Load	Ride Input at the Wheel	lb		Mich Sci LW-1T-25K	Right Steer Wheel End	+/- 10V	High Level SS	256
40	Vertical Wheel Load	Ride Input at the Wheel	lb		Mich Sci LW-1T-25K	Right Steer Wheel End	+/- 10V	High Level SS	256
41	Overturning Moment (Mx)	ADAMS Modeling	lbf-in		Mich Sci LW-1T-25K	Right Steer Wheel End	+/- 10V	High Level SS	256
42	Driving/braking Moment (My)	ADAMS Modeling	lbf-in		Mich Sci LW-1T-25K	Right Steer Wheel End	+/- 10V	High Level SS	256
43	Steering Moment (Mz)	ADAMS Modeling	lbf-in		Mich Sci LW-1T-25K	Right Steer Wheel End	+/- 10V	High Level SS	256
44	Longitudinal Wheel Force	Ride Input at the Wheel	lb		MTS SWIFT 50T	Left Forward Drive Wheel	+/- 10V	High Level SS	256
45	Lateral Wheel Force	Ride Input at the Wheel	lb		MTS SWIFT 50T	Left Forward Drive Wheel	+/- 10V	High Level SS	256

46	Vertical Wheel Force	Ride Input at the Wheel	lb		MTS SWIFT 50T	Left Forward Drive Wheel	+/- 10V	High Level SS	256
47	Overturning Moment (Mx)	ADAMS Modeling	lbf-in		MTS SWIFT 50T	Left Forward Drive Wheel	+/- 10V	High Level SS	256
48	Driving/braking Moment (My)	ADAMS Modeling	lbf-in		MTS SWIFT 50T	Left Forward Drive Wheel	+/- 10V	High Level SS	256
49	Steering Moment (Mz)	ADAMS Modeling	lbf-in		MTS SWIFT 50T	Left Forward Drive Wheel	+/- 10V	High Level SS	256
50	Longitudinal Wheel Load	Ride Input at the Wheel	lb		MTS SWIFT 50T	Right Forward Drive Wheel	+/- 10V	High Level SS	256
51	Lateral Wheel Load	Ride Input at the Wheel	lb		MTS SWIFT 50T	Right Forward Drive Wheel	+/- 10V	High Level SS	256
52	Vertical Wheel Load	Ride Input at the Wheel	lb		MTS SWIFT 50T	Right Forward Drive Wheel	+/- 10V	High Level SS	256
53	Overturning Moment (Mx)	ADAMS Modeling	lbf-in		MTS SWIFT 50T	Right Forward Drive Wheel	+/- 10V	High Level SS	256
54	Driving/braking Moment (My)	ADAMS Modeling	lbf-in		MTS SWIFT 50T	Right Forward Drive Wheel	+/- 10V	High Level SS	256
55	Steering Moment (Mz)	ADAMS Modeling	lbf-in		MTS SWIFT 50T	Right Forward Drive Wheel	+/- 10V	High Level SS	256
56	Driveline Speed	VehSim Input	rpm		CES Optical Proximity Detector	Input to Drive Axles	+/- 10V	High Level SS	100
57	Driveline Torque	VehSim Input	N-m	+/- 1% FS	TorqueTrak 9000 Telemetry System	Input to Drive Axles	+/- 10VDC	High Level SS	100
58	Longitudinal Acceleration	Concept/Prototype Development	g	.01 g	Dana Prototype ECU	Between Trailer Tandem; Sprung Mass	Proprietary CAN	eDaq Lite EDIO & CAN Module	100

59	Lateral Acceleration	Concept/Prototype Development	g	.01 g	Dana Prototype ECU	Between Trailer Tandem; Sprung Mass	Proprietary CAN	eDaq Lite EDIO & CAN Module	100
60	Vertical Acceleration	Concept/Prototype Development	g	.01 g	Dana Prototype ECU	Between Trailer Tandem; Sprung Mass	Proprietary CAN	eDaq Lite EDIO & CAN Module	100
61	Wheel End Vertical Acceleration	Concept/Prototype Development	g	.01 g	Prototype Temp Sensor	Left forward trailer wheel	Proprietary CAN	eDaq Lite EDIO & CAN Module	100
62	Wheel End Vertical Acceleration	Concept/Prototype Development	g	0.5°C	Prototype Temp Sensor	Right Forward Trailer Wheel	Proprietary CAN	eDaq Lite EDIO & CAN Module	100
63	Wheel End Temperature	Bearing life; prototype development	°C	0.5°C	Prototype Temp Sensor	Left forward trailer wheel	Proprietary CAN	eDaq Lite EDIO & CAN Module	1
64	Wheel End Temperature	Bearing life; prototype development	°C	0.5°C	Prototype Temp Sensor	Right Forward Trailer Wheel	Proprietary CAN	eDaq Lite EDIO & CAN Module	1
65-67	Trailer Axle Strain	Durability	uE		Rosette Gauge	Center trailer axle tube		High Level SS & SmartModule	256
68-69	Trailer Axle Strain	Durability	uE		Half Bridge Gauges	Right side trailer axle		High Level SS & SmartModule	256
70-71	Trailer Axle Strain	Durability	uE		Half Bridge Gauges	Left side trailer axle		High Level SS & SmartModule	256
72	Steering Angle	Steering Input	Deg		Potentiometer	Steer Axle/Kingpin	+/- 5V	High Level SS	10
73	Brake Treadle Pressure	Brake Application Strength	psi		Pressure Transducer	Brake Treadle	+/- 5V	High Level SS	10

74	Axle Oil Temperature	Axle Oil Operating Temperature Range	°F	0.1°F	Type K Thermocouple	Forward Drive Axle		Thermocouple Layer	1
75	Axle Oil Temperature	Axle Oil Operating Temperatures	°F	0.1°F	Type K Thermocouple	Rear Drive Axle		Thermocouple Layer	1
76	PDU Oil Temperature	PDU Operating Temperatures	°F	0.1°F	Type K Thermocouple	PDU		Thermocouple Layer	1
77	Transmission Temperature	Transmission Oil Operating Temperatures	°F	0.1°F	Type K Thermocouple	Transmission		Thermocouple Layer	1
78	Engine Exhaust Temperature	System Efficiency Evaluation	°F	0.1°F	Type K Thermocouple	Manifold Port		Thermocouple Layer	1
79	Engine Nox	Fuel Usage	PPM		Engine Nox Sensor	Exhaust Manifold	+/- 5V	High Level SS	10
80	Engine O2	Fuel Usage	PPM		Engine O2 Sensor	Exhaust Manifold	+/- 5V	High Level SS	10
80	Alternator Current	Energy Efficiency	A		Hall Effect or Inductive Sensor	Alternator in-line		High Level SS	1
81	Test Equipment Current Draw	System Efficiency Evaluation	A		Hall Effect or Inductive Sensor	Power Supply Box in-line		High Level SS	1
82	Satellites in View	Trailer vs. Tractor Vehicle Dynamics	#		Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	1
83	Time Since Midnight UTC	Trailer vs. Tractor Vehicle Dynamics	mS	10 mS	Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	100
84	Latitude	Trailer vs. Tractor Vehicle Dynamics	deg	0.00001 Min North	Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	10

85	Longitude	Trailer vs. Tractor Vehicle Dynamics	deg	0.00001 Min West	Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	10
86	Velocity	Trailer vs. Tractor Vehicle Dynamics	knots	0.01	Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	10
87	Heading	Trailer vs. Tractor Vehicle Dynamics	deg	0.01°	Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	10
88	Altitude	Trailer vs. Tractor Vehicle Dynamics	m	0.01 m	Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	10
89	Vertical Velocity	Trailer vs. Tractor Vehicle Dynamics	m/s	0.01	Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	10
90	Longitudinal Acceleration	Trailer vs. Tractor Vehicle Dynamics	g	0.01	Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	256
91	Lateral Acceleration	Trailer vs. Tractor Vehicle Dynamics	g	0.01	Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	256
92	Distance Travelled since Vbox Reset	Trailer vs. Tractor Vehicle Dynamics	m		Racelogic VBOX II	Trailer Van CG	CAN bus	EDIO & CAN Module	1
93	Accelerator Pedal Position	Of interest for engine map and model verification	%		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10
94	Fuel Rate	Fuel consumption modeling verification	L/hr		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10
95	Average Fuel Economy	Fuel consumption modeling verification	km/L		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10
96	Gear Position	Fuel Consumption Modeling; Driver Behavior	Position		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10
97	Engine Torque	Fuel Consumption Modeling	%		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10

98	Actual Gear Ratio				CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10
99	Driver's Demand Engine Torque	Fuel Consumption Modeling	%		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10
100	Load at Current Speed	Fuel Usage	%		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10
101	Engine Speed	Fuel Consumption Modeling	rpm		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10
102	Engine Oil Temperature		°C		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10
103	Fuel Temperature		°C		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10
104	Vehicle Speed		km/hr		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10

3.2 Sensors

The PMs listed in Table 3.1 will be measured by a variety of autonomous sensors and sensors systems. Table 3.1 also lists the associated sensor/system relative to each PM. Some examples of the sensors used to collect the MOPs are shown in Figures 3.1 through 3.5.

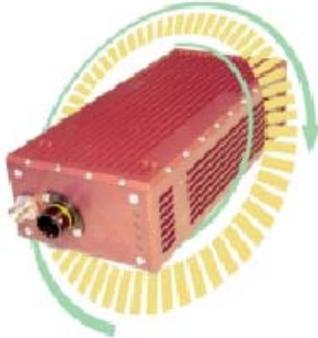


Figure 3.1 RT 3100

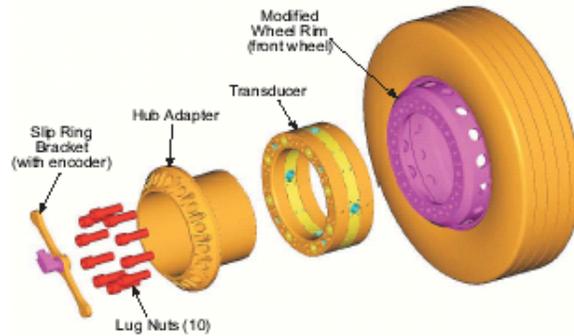


Figure 3.2 MTS Wheel-force Transducer

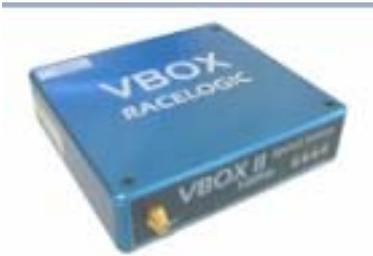


Figure 3.3 Race Logic VBoxII



Figure 3.4 Vaisala WX510 Weather Station



The data acquisition engineer, Jim Ridge, will use a handheld video camcorder to provide a “diary” of traffic conditions, geographical surroundings, and a visual record of the test environment.

The sensor suite that will be used in the Field Test will be a reduced set of the sensors that are being used in the Pilot Test. Data from the Pilot Test will be used in determining the final suite of sensors for the Field Test.

Figure 3.5 AirWeigh

3.3 Data Acquisition System

The SoMat eDaq data acquisition system (leased from NTRCI) will be used to capture data that is germane to the Pilot Test exclusively (See Figure 3.6).



Figure 3.6 SoMat eDaq DAS

In addition, the Somat eDaq Lite (Figure 3.7) will be evaluated and used to acquire all performance measures required for the Field Test, including J1939 CAN vehicle databus information.



Figure 3.7 eDaq Lite

This system must be time synchronized with the eDaq for correlation and analysis. If proven successful in the Pilot Test, the eDaq Lite will be implemented on the Field Test vehicles.

Total power consumption for the sensor suite/DAS will be measured based on the down-selection of sensors and a separate DC supply will be provided for the sensor suite/DAS. This DC supply will be fed from the tractor's alternator and the current will be monitored and subtracted from the "normal" accessory load.

It may be of interest to take measurements with the engine off, i.e., for calibration and for measurement of electric power consumption by the signal acquisition and sensor system.

3.4 Test Vehicles

Figures 3.8 and 3.9 show the DANA supplied test vehicles to be used in the Pilot Test. These

vehicles will be dedicated to the project during the sensor/DAS integration, verification, and the Pilot Test.

53-ft trailers are legal in all states except Hawaii, Maine, Maryland, and Tennessee, where certain restrictions apply. A vehicle width of up to 102 inches is also permissible.



Figure 3.8 Peterbilt 379



Figure 3.9 Wabash Dry Freight Van Trailer

3.5 Sensor and DAS Integration to Test Vehicles

The test vehicles called out in Section 3.4 will be fitted with the sensors listed in Table 3.1. This sensor-to-test-vehicle integration will take place at Dana’s Commercial Vehicle Systems Division in Kalamazoo, MI.

In order for the Pilot Test data to be complete, the tractor and trailer will need to be “mated” for the duration of the testing. However, the interconnection data cabling will be installed in a manner that will allow for easy separation of tractor-trailer combination by the use of mating cable connectors. Trailer cable runs to and from the sensors will be routed in a manner that will

allow for sustained testing such as that which will be required in the Field Testing. Interior runs will not interfere with cargo movement or be susceptible to damage from cargo or loading machinery. Exterior runs will be protected from the environment and damage from impact and tractor articulation. An external enclosed raceway (conduit) is expected to be the best method. Cabling will pass to and from the conduit via protrusions in the side of the trailer.

Tractor cable runs to and from sensors will be routed in a manner to allow for sustained testing and occupant safety. Consideration will be given to shielding these cables from engine/exhaust heat and damage from objects thrown from the roadway. Cable runs will have termination/inspection points to allow for trouble shooting without cable removal.

The DAS will be shock mounted in the tractor cab using vehicle vibration dampening mounts or equivalent.

3.6 Sensor/DAS Verification and Calibration

All sensors, cabling, and the DAS will be verified for operation and calibrated after the initial integration. This verification (pre-Pilot Testing) will take place at the Eaton Proving Grounds in Marshall, MI.

4.0 PILOT TEST

Pilot Testing will take place over a three-month period and will involve testing the instrumented tractor-trailer in a loaded condition. Various routes will be driven to collect data similar to what will be required in the Field Test.

4.1 HVDC Daily Log Sheet

Each day, during the pre-trip inspection, the Test Engineer will initial an HVDC Daily Log Sheet (Figure 4.1). The names of the driver and Test Engineer will be recorded along with the day's date. Tire pressure for each tire will be also be recorded (see Section 4.3) prior to driving. During the days driving, fuel purchase and mileage at fuel purchase will be recorded along with vehicle weight (before and after fueling). If desired the driver can list his "miles driven per state" to fulfill his logbook requirement. Additionally, the Test Engineer can use the HVDC Daily Log Sheet as a Checklist for daily and periodic events.

conventional 6x4 tractor, while the drive and trailer axles shall be loaded up to the limit of 17,000-lbs per axle.

4.3 Tires

The duty cycle testing will evaluate the effect of tire type on vehicle fuel economy. Michelin will provide the tires shown in Table 4.1 for HVDC testing.

Table 4.1 Tire Sizes and Types

No. of Tires	Tire	Size
2	XZA3	275/80R22.5
8	XDA-HT	275/80R22.5
8	XT1	275/80R22.5
4	Xone XDA-HT PLUS	445/50R22.5
4	Xone XTE	445/50R22.5

For each duty cycle route, the vehicle will be configured with standard dual tires (275/80R22.5) for the first run. On the repeat route, the vehicle will be configured with new generation singles tires (445/50R22.5). The route verses tires are shown in Table 4.2.

Table 4.2 Tires Per Route

	Steer	Drive	Trailer
Chicago-Portland #1	XZA3	XDA-HT	XT1
Chicago-Portland #2	XZA3	XOne XDA-HT Plus	XOne XTE
Maine-Miami #1	XZA3	XDA-HT	XT1
Maine-Miami #2	XZA3	XOne XDA-HT Plus	XOne XTE

The pressure shall be maintained at 116 psi for steer, 104 psi for drive and trailer dual tires, and 120 psi for drive and trailer new generation single tires. Tire pressure will be monitored, maintained, and recorded manually on the HVDC Daily Log Sheet. The driver will check and log tire pressure as part of the pre-trip inspect prior to driving each day.

4.4 Fuel

During the Pilot Test (as will be during the Field Testing), fuel will be purchased where convenient and practical for the driver. For the Pilot Test ORNL and Dana will share the cost of the fuel.

The driver will record the amount of fuel at each fill-up and the miles driven between fill-ups on the HVDC Daily Log Sheet (Figure 4.1) for cross-checking of fuel usage sensors. Each tank will be filled to a predetermined index mark on the tank to reduce the error in determining the amount of fuel required for a given fill-up.

It is known that the total energy density of fuel will vary from production run-to-production run and from season-to-season. During the Pilot Testing Phase fuel sampling and assaying may be done to determine the energy density variability in order to relate this to total fuel consumption.

4.5 Pilot Test Routes

Jim Ridge, Dana Product Engineer, will handle the data acquisition responsibilities. ORNL will cover the cost of the driver for the Pilot test. Ralph Long of Commercial Carrier Consultants (CCC) will be the driver. Wilber Thomas will be the backup driver in the event of Ralph's unavailability.

FMCSA hours of service rules will be followed and may require the team to "stand down" at times to "reset" the driver's driving clock. The current hours of service rules are as follows:

- Driver can only have 14 hours combined driving and on-duty time
- On-duty time is any time that the driver is on "on-the-clock"
- Driver may not drive after 14 hours of driving and on-duty time
- Driver may only drive 11 hours after 10 hours off-duty
- Driver may not drive after 60/70 hours on duty in 7/8 days
- Driver can reset his 7/8 day clock by standing down 34 hours

The Pilot Test will consist of operating the test vehicle over predetermined routes and on Interstate and state highways. The routes and schedule currently under consideration are outlined below in Table 4.3.

Table 4.3 HVDC Routes

Route Name	Interstate	Estimated Days To Complete
Kalamazoo MI Portland OR	I-80/I-84	5
Portland OR Kalamazoo MI	I-84/I-80	5
Kalamazoo MI Bangor ME	I-94, I-80	2
Bangor ME to Miami FL	I-95	6
Naples FL to Detroit MI	I-75	3

Figure 4.2 depicts the proposed Kalamazoo to Portland route, with anticipated evening layovers:



Figure 4.2 Kalamazoo to Portland Route

4.6 Data Storage and Transfer

Data from the DAS will be recorded onto the laptop’s hard drive and onto flash drive for temporary redundancy. Then the data will be permanently burned onto DVD media. Once the DVD burn is verified as valid, the data will remain on the hard drive and be removed from the flash drive. The data transfer will be done at predetermined intervals based on the number of data channels, sampling rate, and hours of operation. The DVDs will be pre-labeled and sequenced for installation. It is recommended that a duplicate copy of the data be burned and be periodically mailed back to Dana in pre-paid mailers to insure that the data collected is independent of the test vehicle environment.

5.0 PILOT TEST SCHEDULE

The schedule in Tables 5.1 through 5.3 is shown only as a guide for the driving phase of the project. The actual dates and stops will be dictated by the road team and the hours-of-service rules. They need only follow the routes as called out in Section 4.5.

Table 5.1 October Route and Schedule

OCTOBER 2005						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
2	3	4	5	6	7	1/8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
Chicago to Portland, via I80 and I84	OPEN	Portland to Chicago, via I84 and I80				
Kalamazoo to Des Moines	Des Moines to Cheyenne	Cheyenne to Ogden	Ogden to Boise	Boise to Portland	Portland, OR	Portland to Boise
30	31					
Portland to Chicago, via I84 and I80	Portland to Chicago, via I84 and I80					
Boise to Ogden	Ogden to Cheyenne					

Table 5.2 November Route and Schedule

NOVEMBER 2005						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1 Portland to Chicago, via I84 and I80 Cheyenne to Des Moines	2 Portland to Chicago, via I84 and I80 Des Moines to Kalamazoo	3 Chicago to Portland Duty Cycle Data Review Vehicle Maintenance	4 Chicago to Portland Duty Cycle Data Review Vehicle Maintenance	5
6	7 Chicago to Portland Duty Cycle Data Review Vehicle Maintenance, Training	8 Chicago to Portland Duty Cycle Data Review Vehicle Maintenance, Training	9 Chicago to Portland Duty Cycle Data Review Vehicle Maintenance, Training	10 Chicago to Portland, via I80 and I84 Kalamazoo to Des Moines	11 Chicago to Portland, via I80 and I84 Des Moines to Cheyenne	12 Chicago to Portland, via I80 and I84 Cheyenne to Ogden
13 Chicago to Portland, via I80 and I84 Ogden to Boise	14 Chicago to Portland, via I80 and I84 Boise to Portland	15 Reset Driver's Clock Portland	16 Reset Driver's Clock Portland	17 Portland to Chicago, via I84 and I80 Portland to Boise	18 Portland to Chicago, via I84 and I80 Boise to Ogden	19 Portland to Chicago, via I84 and I80 Ogden to Cheyenne
20 Portland to Chicago, via I84 and I80 Cheyenne to Des Moines	21 Portland to Chicago, via I84 and I80 Des Moines to Kalamazoo	22 Chicago to Portland Duty Cycle Data Review Vehicle Maintenance, Training	23 Chicago to Portland Duty Cycle Data Review Vehicle Maintenance, Training	24 Thanksgiving	25 Optional Vacation Day	26
27	28 Bangor to Miami, I-95 Kalamazoo to Rochester	29 Bangor to Miami, I-95 Rochester to Bangor	30 Bangor to Miami, I-95 Bangor to Philadelphia			

Table 5.2 December Route and Schedule

DECEMBER 2005						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
				1	2	3
				Bangor to Miami, I-95	Bangor to Miami, I-95	Bangor to Miami, I-95
				Philadelphia to Fayetteville	Fayetteville to Jacksonville	Jacksonville to Miami
4	5	6	7	8	9	10
Reset Driver's Clock	Reset Driver's Clock	Naples to Detroit, I-75	Naples to Detroit, I-75	Naples to Detroit, I-75	Bangor to Miami Duty Cycle Data Review	
Miami	Miami	Miami to Macon	Macon to Knoxville	Knoxville to Detroit	Vehicle Maintenance, Training	
11	12	13	14	15	16	17
Bangor to Miami Duty Cycle Data Review	Bangor to Miami, I-95	Bangor to Miami, I-95	Bangor to Miami, I-95	Bangor to Miami, I-95	Bangor to Miami, I-95	Bangor to Miami, I-95
Vehicle Maintenance, Training	Kalamazoo to Rochester	Rochester to Bangor	Bangor to Philadelphia	Philadelphia to Fayetteville	Fayetteville to Jacksonville	Jacksonville to Miami
18	19	20	21	22	23	24
Reset Driver's Clock	Reset Driver's Clock	Naples to Detroit, I-75	Naples to Detroit, I-75	Naples to Detroit, I-75		
Miami	Miami	Miami to Macon	Macon to Knoxville	Knoxville to Detroit		Christmas Eve
25	26	27	28	29	30	31
Christmas						

6.0 OVERALL PROJECT SCHEDULE

The overall schedule for the HVDC Project (Pilot Test Phase) is shown in Table 6.1.

Test Plan Task	Apr-05	May-05	Jun-05	Jul-05	Aug-05	Sep-05	Oct-05	Nov-05	Dec-05
Sensor Identification									
Sensor Selection									
DAS Design/Select									
Sensor Procurement									
DAS Procurement/Fabrication									
Sensor/DAS Testing and Verification									
Sensor and DAS Integration to Test Vehicles									
System Verification									
Pilot Testing									

Table 6.1 Overall Project Schedule (Pilot Test Phase)

End of Test Plan

Appendix A-C
Field Test Signals

	Performance Measure	Performance Measure Value	Units	Accuracy	Sensor or System Output	Sensor Location	Format	eDaq Interface Module	Scan Rate (Hz)
1	Average Fuel Economy	Fuel consumption modeling verification	km/L		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10
2	Gear Position	Fuel Consumption Modeling; Driver Behavior	Position		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10
3	Engine Torque	Fuel Consumption Modeling	%		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10
4	Actual Gear Ratio		-		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10
5	Driver's Demand Engine Torque	Fuel Consumption Modeling	%		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10
6	Load at Current Speed	Fuel Usage	%		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10
7	Engine Speed	Fuel Consumption Modeling	rpm		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10
8	Engine Oil Temperature		°C		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10

	Performance Measure	Performance Measure Value	Units	Accuracy	Sensor or System Output	Sensor Location	Format	eDaq Interface Module	Scan Rate (Hz)
9	Fuel Temperature		°C		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10
10	Vehicle Speed		kmh		CAN J1939	Vehicle Network	CAN J1939	eDaq Lite Vehicle Network	10
11	Latitude		minutes	3 m	VBOX II Lite	Cab	CAN J1939	eDaq Lite Vehicle Network	5
12	Longitude		minutes	3 m	VBOX II Lite	Cab	CAN J1939	eDaq Lite Vehicle Network	5
13	Height		m	10 m	VBOX II Lite	Cab	CAN J1939	eDaq Lite Vehicle Network	5
14	Vertical velocity		kmh	0.2 kmh	VBOX II Lite	Cab	CAN J1939	eDaq Lite Vehicle Network	5
15	Velocity over ground		kmh	0.2 kmh	VBOX II Lite	Cab	CAN J1939	eDaq Lite Vehicle Network	5
16	Longitudinal acceleration		g	1%	VBOX II Lite	Cab	CAN J1939	eDaq Lite Vehicle Network	5

	Performance Measure	Performance Measure Value	Units	Accuracy	Sensor or System Output	Sensor Location	Format	eDaq Interface Module	Scan Rate (Hz)
17	Lateral acceleration		g	1%	VBOX II Lite	Cab	CAN J1939	eDaq Lite Vehicle Network	5
18	Heading		deg true north	0.2°	VBOX II Lite	Cab	CAN J1939	eDaq Lite Vehicle Network	5
19	Distance		m	0.05%	VBOX II Lite	Cab	CAN J1939	eDaq Lite Vehicle Network	5
20	Satellites		#	-	VBOX II Lite	Cab	CAN J1939	eDaq Lite Vehicle Network	5
21	Time		s	0.05 s	VBOX II Lite	Cab	CAN J1939	eDaq Lite Vehicle Network	5
22	Wind Speed	Drive Cycle Characterization; Aero Modeling	m/s	0.3 m/s	WXT510	Top Faring Centerline	RS-232	eDaq Lite Basic DIO	10
23	Wind Direction	Drive Cycle Characterization; Aero Modeling	deg	2°	WXT510	Top Faring Centerline	RS-232	eDaq Lite Basic DIO	10
24	Rain Accumulation	Drive Cycle Characterization	mm	5%	WXT510	Top Faring Centerline	RS-232	eDaq Lite Basic DIO	10

	Performance Measure	Performance Measure Value	Units	Accuracy	Sensor or System Output	Sensor Location	Format	eDaq Interface Module	Scan Rate (Hz)
25	Rain Duration	Drive Cycle Characterization	s	?	WXT510	Top Faring Centerline	RS-232	eDaq Lite Basic DIO	10
26	Rain Intensity	Drive Cycle Characterization	Hits/cm ² /h	?	WXT510	Top Faring Centerline	RS-232	eDaq Lite Basic DIO	10
27	Barometric Pressure	Drive Cycle Characterization; Aero Modeling	hPa	0.5 hPa	WXT510	Top Faring Centerline	RS-232	eDaq Lite Basic DIO	10
28	Air Temperature	Repeat Channel #28	°F	0.5° F	WXT510	Top Faring Centerline	RS-232	eDaq Lite Basic DIO	10
29	Relative Humidity	Drive Cycle Characterization; Aero Modeling	%	3%	WXT510	Top Faring Centerline	RS-232	eDaq Lite Basic DIO	10

Appendix A-D
Sensor System Letter Report

Letter Report
SUMMARY OF RELEVANT HEAVY TRUCK PERFORMANCE MEASURES
March 11, 2005

INTRODUCTION

The list of signals and their recommended sensors are shown in tabular form below. A simplified rendition is presented initially below that is split into two complementary sets. The first set addresses information needs for defining duty cycles for existing and future heavy truck simulation programs. The second set reflects the desire to collect field data needed to benchmark simulations of vehicle performance in conjunction with a duty cycle.

These lists are preliminary and thus are not closed to amendments at this time.

The main objective of this sensor selection is to provide a sound benchmark for making decisions related to technology investments in the future. It intends to meet data needs for PSAT, vehicle dynamics and driver performance studies.

The table tentatively identifies where each parameters may be used and measured. Those with TBD identify their need to be determined. We expect to eliminate all TBDs and enhance the table content as we received feedback from the project partners.

For reference purposes, a literal copy of the description of this task in the project's SOW has been included as an appendix to this letter report.

LIST OF SIGNALS AND SENSORS FOR DUTY CYCLE DEFINITION

All signals should have a common time reference. Some signals although apparently redundant will facilitate checks and balances.

- Ignition key position ON/OFF,

- Vehicle ground velocity, vertical velocity and heading,
- Vehicle position (longitude, latitude, altitude,)
- Vehicle acceleration (longitudinal and lateral,)
- Distance traveled.

- Outside air temperature,
- Wind speed and direction,
- Barometric pressure,
- Outside air humidity,
- Rain duration,
- Rain accumulation and
- Rain intensity.

RaceLogic's
VBox-5042

Vaisala's
WXT510
Weather
transmitter

List of signals for Heavy Truck Performance Benchmark definition

- Vehicle weight, including load, driver/passengers and fuel.
 - Instantaneous fuel consumption rate and fuel usage,
 - Main accessory energy usage,
 - Battery state-of-charge (SOC), voltage and current,
 - Clutch and brake pedal positions,
 - Break trigger time, distance traveled, brake chamber pressure and brake application count,
 - Throttle and gear box positions,
 - Axle and transmission oil temperatures,
 - Engine brake status, exhaust temperature, speed and torque,
 - GVW and GAWR,
 - Road surface temperature,
 - Traffic conditions
 - Longitudinal, lateral, and vertical Acceleration at vehicle center-of-mass,
 - Vehicle roll, pitch, and yaw and their rates of change,
 - Longitudinal, lateral, and vertical wheel load,
 - Tri-axial wheel moments and acceleration on B-Pillar, unsprung axles, and tractor frame,
 - Strain in steer axle, drive axle and trailer axle,
 - Wheel torque, steering wheel angle/rate and torque
 - Tire wear and pressure.
- Power consumption by the test instrumentation.

Expanded list in Tabular form

Performance Measure	Data #	Units	Sensor or System Output	Performance Measure Value	Sensor Location	Sensor or System Output Provider
Time Reference	0	TBD		Synchronization		TBD
Ignition Position	1	On/Off	ECM	Drive Cycle Characterization.	J1939	Tractor
Vehicle Ground Speed	2	km/h	Vbox/RT3100	Drive Cycle Characterization	Cab	Michelin/NTRCI
Vehicle Vertical Speed	3	km/h	Vbox/RT3100	Drive Cycle Characterization	Cab	Michelin/NTRCI
Vehicle Heading	4	deg North	VBox/RT3100	Drive Cycle Characterization	Cab	Michelin/NTRCI
Vehicle Position Longitude	5	minutes	VBox/RT3100	Drive Cycle Characterization	Cab	Michelin/NTRCI
Vehicle Position Latitude	6	minutes	VBox/RT3100	Drive Cycle Characterization	Cab	Michelin/NTRCI
Vehicle Position Altitude	7	m	VBox/RT3100	Drive Cycle Characterization; Gravitational Energy Modeling	Cab	Michelin/NTRCI
Vehicle Longitudinal	8	G	VBox/RT3100	Drive Cycle Characterization	Cab	Michelin/NTRCI

Performance Measure	Data #	Units	Sensor or System Output	Performance Measure Value	Sensor Location	Sensor or System Output Provider
Acceleration						
Vehicle Lateral Acceleration	9	G	VBox/RT3100	Drive Cycle Characterization	Cab	Michelin/NTRCI
Distance traveled	10	m	VBox/RT3100	Drive Cycle Characterization	Cab	Michelin/NTRCI
Outside Temperature	11	°C	WXT510/Roadwatch	Drive Cycle Characterization; Aero Modeling; Wear	Cab Roof/Mirror	ORNL
Wind Speed	12	km/h	WXT510	Drive Cycle Characterization; Aero Modeling; Wear	Cab Roof	ORNL
Wind Direction	13	deg	WXT510	Drive Cycle Characterization; Aero Modeling; Wear	Cab Roof	ORNL
Barometric Pressure	14	hPa	WXT510	Drive Cycle Characterization; Aero Modeling; Wear	Cab Roof	ORNL
Humidity	15	%	WXT510	Drive Cycle Characterization; Aero Modeling; Wear	Cab Roof	ORNL
Rain Duration	16	s	WXT510	Drive Cycle Characterization.	Cab Roof	ORNL
Rain Accumulation	17	mm	WXT510	Drive Cycle Characterization.	Cab Roof	ORNL
Rain Intensity	18	Hits/cm ² /h	WXT510	Drive Cycle Characterization.	Cab Roof	ORNL

Performance	Signal #	Units	Sensor or System	Performance	Sensor	Sensor or
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Measure			Ouput	Measure Value	Location	System Output Provider
Vehicle Weight	19	lb	Operator	Efficiency Evals		
Occupants Weight	20	lb	Operator	Efficiency Evals		
Load Weight	21	lb	Operator	Efficiency Evals		
Fuel Weight	22	lb	Operator	Efficiency Evals		
Instantaneous Fuel consumption Rate	23	kg/hr	ECM/Fuel Flow/Exhaust Gas Meas.	Fuel Consumption Modeling Validation	J1939/Remote Sensor	Tractor/Michelin
Fuel Usage	24	Gal	Gauge	Mpg	Tractor	TBD
Main Accessory Energy Usage	25	kw	ECM	Non-drive Energy Usage	J1939	Tractor
Battery EOC	26	%	TBD	System Efficiency Evaluation		
Battery Voltage	27	VDC	ECM	System Efficiency Evaluation	J1939	Tractor
Battery Current	28	Amp	ECM	System Efficiency Evaluation	J1939	Tractor
Clutch Pedal Position	29	%	ECM/Pedal Sensor	Driver Behavior	J1939/Cab	Tractor
Brake Pedal Position	30	%	ECM/Pedal Sensor	Model Validation	J1939/Cab	Tractor
Break Trigger Time	31	s	VBox/RT3100	Fuel Consumption Modeling; Wear	Cab	Michelin/NTRCI
Distance from Break Trigger	32	m	VBox/RT3100	Fuel Consumption Modeling; Wear	Cab	Michelin/NTRCI
Brake Chamber Pressure	33	Psi	Pressure Transducer	Brake Application Strength	Input to Chamber	DANA
Brake Application Count	34	Counts	ECM	Durability/Wear	J1939	TBD
Throttle Position	35	%	ECM/Pedal Sensor	Model Validation	J1939/Cab	Tractor
Gear position	36	Position	ECM or derived	Fuel Consumption Modeling; Driver Behavior	J1939	Tractor
Axle Oil Temperature	37	°C	Thermocouple	Axle Efficiency	Axle Tube	DANA
Transmission Temperature	38	°C	Thermocouple	Transmission Efficiency	Transmission	DANA
Engine Brake Status	39	ON/Off	ECM	Fuel Consumption Modeling; Wear	J1939	Tractor
Engine Exhaust Temp	40	°C	Thermocouple	System Efficiency Evaluation	Manifold Port	ORNL
Engine Speed	41	rpm	ECM	Fuel Consumption Modeling	J1939	Tractor
Engine Torque	42	N-m	ECM	Fuel Consumption Modeling	J1939	Tractor
GVW	43	lb	AirWeigh 5800	Wear Study; Fuel Consumption Modeling	Cab/Air Suspension System	ORNL

GAWR	44	lb	AirWeigh 5800	Wear Study; Fuel Consumption Modeling	Cab/Air Suspension System	ORNL
Road Surface Temp	45	°C	Roadwatch	Wear Evaluations	Mirror	ORNL
Traffic Conditions	46	N/A	Camera	Drive Cycle Impact	Cab	DANA
Longitudinal, Lateral, and Vertical Acceleration at Vehicle CG	47-49	G's	Oxford RT-3100	Overall Cab Ride; Drive Cycle Characterization.	Tractor Cab	NTRCI
Vehicle Roll, Pitch, and Yaw	50-52	Deg	Oxford RT-3100	Describes Vehicle Body Motion	Cab	NTRCI
Vehicle Roll, Pitch and Yaw Rate	53-55	Deg/s	Oxford RT-3100	Describes Vehicle Body Motion	Cab	NTRCI
Longitudinal, Lateral, and Vertical Wheel Load	56-58	lb	Swift 50T Wheel Force Transducer	Primary Indicator of Ride Input at the Wheel	Wheel End	DANA
Tri-axial Wheel Moments	59-61	lbf-in	Swift 50T Wheel Force Transducer	Used for Modeling	Wheel End	DANA
Tri-Axial Accel on B-Pillar	62-64	G's	Crossbow Accelerometer	Ride Harshness at Driver's Head/Shoulders	Cab	TBD
Tri-Axial Accel of Unsprung Axles	65-67	G's	PCB Accelerometer	Ride Harshness	Axle	DANA
Tri-Axial Accel on Tractor Frame	68-70	G's	PCB Accelerometer	Ride Quality of Sprung Mass	Tractor Frame	DANA
Steer Axle Strain	71-73	uE	Rosette Gauge	Durability	Axle	DANA
Drive Axle Strain	75-76	uE	Rosette Gauge	Durability	Axle	DANA
Trailer Axle Strain	77-79	uE	Rosette Gauge	Durability	Axle	DANA
Wheel Torque	80	N-m		Drivetrain Characterization		
Steering Angle/Rate	81	Deg	Steering Effect	Steering Input	Steering Column	DANA
Steering Wheel Torque	82	N-m	Steering Effect	Steering Input	Steering Column	DANA
Tire Wear	83	mm	Depth Gauge	Wear Modeling	N/A	Michelin
Tire Pressure	84-100	kPa	Tire Maintenance System	Rolling Resistance; Tire Wear	External Rig	DANA
Test Equipment Power Usage	101	w	TBD	Energy Efficiency	TBD	TBD

APPENDIX

Task 2: Identification of Relevant Heavy Truck Performance Measures and Development of a Pilot Testing Plan

Efforts under this task will involve the identification of performance measures that are needed to support the development of real-world duty cycles for heavy vehicle driving, and for analysis purposes utilizing various software including the PSAT Code. Performance measures may include: engine speed, vehicle speed, engine load, transmission/gear, grade, altitude above sea level (alternatively – barometric pressure), vehicle location, exhaust temperature, throttle pedal input, and exhaust back pressure. Other information such as load weight, fuel inventory, steering wheel angle, brake pedal pressure, road condition, and traffic conditions might also be useful. If other organizations such as DOT are involved in this Program, driver measures such as fatigue, physical workload, cognitive workload, distraction, etc., may also need to be collected. Members of the 21st Century Truck Partnership, members of the CAMP Partnership, and DOT's IVI Program will be consulted to help identify the appropriate types of data of interest to DOT to collect during this program. Partnerships with Universities may also be pursued in order to capitalize on previous and related DOT research with these Universities.

A comprehensive list of performance measures will be identified and considered candidate measures for data collection. The list will be finalized as technologies for collecting the candidate measures are considered. It is desirable to collect such data from existing on-board systems (e.g., Engine Control Modules [ECMs]), or utilizing commercial-off-the-shelf (COTS) sensor technologies. Several of the measures might require some modest sensor development efforts. Measures that require a significant investment in data collection technologies will not be considered. Such measures however may be capable of being inferred from surrogate measures.

Once the performance measures are identified, the specific tractor-trailers identified, and plans for procuring data acquisition capabilities are defined, a pilot test plan will be developed that will provide details of the pilot testing activity. It is expected that Pilot Testing will be done for the tractor-trailers being in commercial service on the Chicago-Seattle (and return) route. This route is a candidate for consideration because of the variability in conditions that can be experienced on this route including topology, weather, and urban/rural driving environments. The test plan will also include protocols for managing the data collected during the field test.

Appendix B
SCHRADER MEMORANDUM OF UNDERSTANDING

Memorandum of Understanding No. MOU-UTB-2007001
between
UT-Battelle, LLC
and
Schrader Trucking Company, Inc.
regarding the
Collection of Heavy Truck Duty Cycle Data

This Memorandum of Understanding (MOU) is by and between **SCHRADER TRUCKING COMPANY, INC.** (Partner) and **UT-BATTELLE, LLC** (UT-Battelle), hereinafter jointly referred to as the “Parties”. Oak Ridge National Laboratory (ORNL) is a facility of the Department of Energy (DOE), managed and operated by UT-Battelle, a limited liability company, organized and existing under the laws of the State of Tennessee, pursuant to its contract DE-AC05-00OR22725 with the DOE. All actions by UT-Battelle under this MOU will be conducted under the authority of, and in accordance with, the terms of its contract with the DOE. In the event of an inconsistency between this MOU and the terms of UT-Battelle’s contract, UT-Battelle will apply the contract’s terms.

BACKGROUND. The purpose of this MOU is for ORNL, in support of DOE’s Office of Freedom Car, in partnership with Schrader Trucking, Michelin Americas Research, Inc. (Michelin), and Dana Corporation (Dana), to collect Heavy Truck Duty Cycle (HTDC) data on class-8 tractor-trailers during their normal vocation. This MOU will explain the project and set forth the roles and responsibilities of ORNL and Schrader Trucking. It should be noted that for the purposes of this MOU, the roles and responsibilities of Michelin or Dana will be represented by ORNL.

This project will collect data from various on-board sensors and the tractor’s J-1939 or J-1708 data bus to be used in the Power-Train Systems Analysis Toolkit (PSAT) under development by the Argonne National Laboratory (ANL). The data collected will be of a vehicle performance nature (*vehicle speed, engine speed, engine torque, fuel consumption rate, wind speed, direction, road grade, etc.*). The data collected will be available to Schrader Trucking both in raw form and in a post-processed, analyzed form, at no charge. The data collected will in no way be used to find fault or violation in Schrader Trucking’s operation (i.e. speeding, hours-of-service violations, etc.). The data that is collected will not ultimately be connected to a specific driver or vehicle, or to Schrader Trucking, but will be of a “generic” performance nature.

The testing portion of this effort (integration and Field Test) is expected to begin with the instrumentation and baseline testing of vehicles for a two (2) month period of time and actual Field Test being conducted for a minimum of 12 months.

ROLES AND RESPONSIBILITIES. ORNL will instrument six (6) tractors and ten (10) trailers (test vehicles) from Schrader Trucking’s fleet. The instrumentation of the test vehicles will take place at Schrader Trucking (1923 Slate Road, Jefferson City, TN) during non-operational times (weekends) and will not affect their normal operation. The test tractors shall be of the same make, model, year, and have the same engines, and differentials. Five (5) of the ten (10) trailers chosen for this research shall be designed for new generation wide-based single tires (NGWBST) and five (5) of trailers shall be designed for standard dual tires.

During the course of the testing, ORNL will need access to the DAS located inside each of the test tractors to download test data. This will need to be done approximately every one to two weeks at Schrader Trucking during non-operational hours and will require about 30 minutes of time per vehicle. ORNL will also inspect the Data Acquisition System (DAS), sensors, and tires at this time.

ORNL will supply and install the following equipment:

- **Weather Station** – To be mounted on the driver's side fender mirror bracket
- **GPS Antenna** – To be mounted on the cab roof
- **DAS** – To be velcro-mounted to floor in bunk
- **Air-Weigh Self Weighing System** – Display to be mounted on dash of cab and under trailer
- **New Generation Wide-Based Single Tires (NGWBST)** – To be mounted on tractor drive wheels and trailer wheels
- **Standard Dual Tires** – To be mounted on tractor drive wheels and trailer
- **Steer Tires** – To be mounted on the tractor steer axles

Five (5) of the six (6) tractors will be fitted with new tires. Three tractors (3) will be fitted with NGWBST on their drive position and two (2) will be fitted with standard dual tires on the drive position. These five (5) tractors will all be fitted with standard steer tires. The sixth tractor (6th) will not be fitted with new tires, but will enter the Field Test with the tires currently on it.

Two (2) of the ten (10) trailers will be fitted with standard dual tires. The remaining eight (8) trailers will keep the tires that they currently have.

Each tractor and trailer will be fitted with special sensors related to the Field Test data requirements. This equipment, when installed, will not affect the safe operation of the vehicle, nor will it interfere with the operator of the vehicle. Further, it will not require interaction with the operator of the vehicle. This equipment is valued at approximately \$60,000 per vehicle and is self-insured by the government for loss or damage. It is expected that Schrader Trucking and its operators will take customary and reasonable steps to protect this equipment from damage and theft.

ORNL initiated the instrumentation of the test vehicles during the month of September 2006. The instrumentation of the vehicles will be completed in the month of October 2006 and baseline testing will be conducted for a 30-day period. Installation of the test tires on the test vehicles will be completed by mid-November and the 12-month Field Test will begin as the tires are installed.

Partner roles for this MOU:

ORNL

- Design project and collect data
- Provide all needed equipment
- Provide equipment installation
- Provide required tires for the test vehicles
- Provide for the cost to install test tires and associated wheels
- Provide wheels (as needed) for the NGWBSTs
- Provide for equipment removal at the end of the project
- Provide funding for 50% of weigh tickets for test tractors
- Provide raw data and analyzed results

Schrader Trucking

- Provide six tractors and ten trailers as described above
- Provide access to the test vehicles for equipment and tire installation
- Provide access to the test vehicles for data collection
- Provide miles driven and fuel quantity purchased during the Field Test for cross-verification with the data collected
- Provide information of any vehicle performance change (major engine or transmission repair, tire change, etc.)
- Provide funding for 50% of weigh tickets for test tractors
- Provide weight tickets for each test tractor's load

In the event of equipment or sensor failure, ORNL may or may not elect to repair/replace the equipment and continue the testing. In the event of tire damage, ORNL has the option of replacing the tire at no cost to Schrader Trucking and continuing to use the tractor or trailer in the Field Test or discontinuing use of the tractor or trailer in the Field Test and having tires provided by Schrader remounted and installed.

In the event that the test tires are "worn-out" before the end of the Field Test, Schrader Trucking will replace the tires as needed as a part of their normal course of operation. While ORNL will provide for all equipment, installation, and research personnel, no funding is available to augment Schrader Trucking's operation of these vehicles.

MOU-UTB-2007001

Schrader Trucking Company, Inc. and UT-Battelle, LLC

POINTS-OF-CONTACT. Each Party will designate a Point-of-Contact for implementation of this MOU. The designated Points-of-Contact are:

UT-BATTELLE, LLC

NAME: Gary Capps
TITLE: Staff Engineer
PHONE: 865/946-1285

SCHRADER TRUCKING COMPANY, INC.

NAME: Philip Schrader	NAME: Thomas Hodge
TITLE: Co-Owner, Schrader Trucking	TITLE: Co-Owner, Schrader Trucking
PHONE: 865/471-7615	PHONE: 865/262-1086

AMENDMENTS. This MOU may be amended in writing and signed by both parties.

TRANSFER RIGHTS. It is understood and agreed that this MOU is entered into by UT-Battelle and that administration of this MOU may be transferred from UT-Battelle to DOE or to its designee.

EXPORT CONTROL. (a) The Parties agree to adhere to all applicable U.S. export laws and regulations; (b) Each Party acknowledges that it is responsible for its own compliance with all U.S. export control laws and regulations; and (c) Each Party acknowledges it will not knowingly export directly or indirectly, through its affiliates, licensees, or subsidiaries, any export controlled hardware, software, or technical data in the performance of this MOU without a required license which will be obtained by the responsible party from the appropriate U.S. Authority.

EFFECTIVE DATE & TERMINATION. This MOU will be in effect through December 2007 and is effective upon the date of the last signature. It may be extended by mutual agreement of the Parties. Either Party may terminate this MOU by giving written notice to the other Party with the termination occurring 30 days thereafter.

AUTHORIZED SIGNATURES. The individuals whose signatures appear below hereby certify that they are authorized to sign on behalf of the respective Parties to this MOU. This MOU will be executed in triplicate, and is not effective until signed by all Parties.

UT-BATTELLE, LLC

By: _____

Name (*printed*): Dana C. Christensen

Title: Associate Lab Director
Energy & Engineering Sciences

Date: _____

SCHRADER TRUCKING COMPANY, INC.

By: _____

Name (*printed*): Philip Schrader

Title: Co-Owner, Schrader Trucking

Date: _____

By: _____

Name (*printed*): Thomas Hodge

Title: Co-Owner, Schrader Trucking

Date: _____

DEPARTMENT OF ENERGY

By: _____

Name (*printed*): Lee Slezak

Title: Manager, Advanced Vehicle Systems
Simulation & Evaluation Team
Office of FreedomCAR &
Vehicle Technologies Program

Date: _____

Appendix C
FIELD OPERATIONAL TEST PLAN

Note: Partner sensitive information has been marked as such and removed from the original document.

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National Transportation Research Center

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Heavy-Truck Duty Cycle Data from Real-World Driving Environments: Field Operational Test and Data Analysis

A Test Plan for a Program Focused on
the Characterization of Heavy Truck
Duty Cycles from Real-World Driving
Environments

Phases 2 & 3: Field Operational Test
Launch and Conduction

*Collection, Analysis, and Archiving of
Real-World-Based Heavy Truck
Driving Characteristics and Duty
Cycle Data to Support the
Development and Evaluation of
PSAT, Provide the Department of
Energy a Basis for Technology
Investment Decisions, and to
Establish a National Data Archive in
Support of Heavy Truck Energy
Efficiency Research.*

**HEAVY-TRUCK DUTY CYCLE DATA
FROM REAL-WORLD DRIVING ENVIRONMENTS**

Test Plan for Field Operational Test
(This Document Fulfills Milestone M14 and Deliverable D12 of the Project SOW)

**Prepared by
Oak Ridge National Laboratory**

For
Department of Energy's Office of Freedom Car and Vehicles Systems

1.0 BACKGROUND

This Program involves efforts to collect, analyze and archive data and information related to heavy-truck operation in real-world highway environments. Such data and information will be useful to support technology evaluation efforts, and provide a means of accounting for real-world driving performance within heavy truck analyses. The Program is led by the Oak Ridge National Laboratory, and involves three industry partners (Dana Corporation of Kalamazoo, MI, Michelin Americas Research and Development Corporation Tire of Greenville, SC, and Schrader Trucking of Jefferson City, TN) and has support from the

Argonne National Laboratory (ANL) with regard to this project's relationship with PSAT development and evaluation. Michelin Tire will provide tires for the project and is interested in gathering data on the long-term real-world performance of their New-Generation Single Wide-Based Tires (NGSWBT) – especially with regard to the fuel savings aspect of NGSWBTs. Schrader Trucking will provide six (6) tractors and ten (10) trailers for use in the Field Operational Test (FOT).

The Program is being conducted in three phases. These phases are:

Phase 1 – Pilot Test: Design, Testing and Evaluation of a Duty Cycle Data Collection System. This phase is complete.

Phase 2 – Field Operational Test Launch: Fleet Instrumentation, Field Testing Begins, Initial Data Collection and Data Verification.

Phase 3 – Field Operational Test Conduction: On-going FOT, Data Analysis, and Data Repository.

This Test Plan will only be concerned with Phases 2 and 3 of the Program as the data collection effort of Phase 1 was completed in January 2006. Phase 2 will involve a number of tasks that will result in the instrumentation and fielding of six test vehicles with a data acquisition system (DAS) and sensor suite. Additionally, this Test Plan will include the Phase 3 processes for data collection from the test vehicles, as well as for data verification and storage.

2.0 ACRONYMS, TERMS, AND DEFINITIONS

ANL – Argonne National Laboratory

DAS – Data Acquisition System

DOE – U.S. Department of Energy

FOT – Field Operational Test

HTDC – Heavy Truck Duty Cycle Project

NGSWBT – New Generation Single Wide-Based Tires

ORNL – Oak Ridge National Laboratory

PSAT – Powertrain System Analysis Toolkit

SDOD – System Design and Operations Document

Schrader – Schrader Trucking

3.0 OBJECTIVE

The objective of this Test Plan is describe the necessary technical steps and call out the needed equipment to collect, retrieve, and transfer for data analysis pre-determined signals for the HTDC FOT.

4.0 APPROACH

Phases 2 and 3 of the project will involve the instrumentation of six (6) Class-8 over-the-road tractor-trailers with a suite of sensors/DAS and the operation of this instrumentation to collect, store, and transfer signals related to the vehicle's duty cycle.

This Test Plan will describe in Section 4.0 the:

- Measures of Performance
- Sensors
- DAS
- Test Vehicles
- Truck and Equipment Details
- Sensor and DAS Integration to Test Vehicles
- Sensor/DAS Verification and Calibration
- Power Measurement

4.1 Performance Measures

A variety of metrics have been identified as necessary in understanding the Drive Cycle of the test vehicle. Signal importance, cost, sensor survivability, and practicality have all be considered in deriving the List of Signals for the FOT in Table 4.1.

Table 4.1: Measures of Performance and Associated Sensors

	Signal	Sensor
1	Instantaneous Fuel Economy	J1939 Vehicle Data Bus
2	Average Fuel Economy	J1939 Vehicle Data Bus
3	Fuel Rate	J1939 Vehicle Data Bus
4	Total Fuel Used	J1939 Vehicle Data Bus
5	Total Idle Fuel Used	J1939 Vehicle Data Bus
6	Current Gear	J1939 Vehicle Data Bus
7	Selected Gear	J1939 Vehicle Data Bus
8	Output Shaft Speed	J1939 Vehicle Data Bus
9	Actual Engine - Percent Torque	J1939 Vehicle Data Bus
10	Actual Gear Ratio	J1939 Vehicle Data Bus
11	Driver's Demand Engine - Percent Torque	J1939 Vehicle Data Bus
12	Percent Load at Current Speed	J1939 Vehicle Data Bus
13	Engine Speed	J1939 Vehicle Data Bus
14	Engine Oil Temperature	J1939 Vehicle Data Bus
15	Fuel Temperature	J1939 Vehicle Data Bus
16	Front Axle Speed	J1939 Vehicle Data Bus
17	High Resolution Total Vehicle Distance	J1939 Vehicle Data Bus
18	Accelerator Pedal Position	J1939 Vehicle Data Bus

	Signal	Sensor
19	Total Idle Hours	J1939 Vehicle Data Bus
20	Maximum Vehicle Speed Limit	J1939 Vehicle Data Bus
21	Total Power Takeoff Hours	J1939 Vehicle Data Bus
22	Clutch Switch	J1939 Vehicle Data Bus
23	Brake Switch	J1939 Vehicle Data Bus
24	Cruise Control Enable Switch	J1939 Vehicle Data Bus
25	Cruise Control Active	J1939 Vehicle Data Bus
26	Cruise Control Accelerate Switch	J1939 Vehicle Data Bus
27	Cruise Control Resume Switch	J1939 Vehicle Data Bus
28	Cruise Control Coast Switch	J1939 Vehicle Data Bus
29	Cruise Control Set Switch	J1939 Vehicle Data Bus
30	Battery Electrical Potential (Voltage)	J1939 Vehicle Data Bus
31	Tractor Drive Axles Weight	Air-Weigh
32	Tractor Steer Axle Weight	Air-Weigh
33	Trailer Weight	Air-Weigh
34	Tractor Serial Number	Air-Weigh
35	Trailer Serial Number	Air-Weigh
36	Latitude	VBOX
37	Longitude	VBOX
38	Altitude	VBOX
39	Vertical velocity	VBOX
40	Velocity over ground	VBOX
41	Longitudinal acceleration	VBOX
42	Lateral acceleration	VBOX
43	Heading	VBOX
44	Satellites	VBOX
45	Time UTC	VBOX
46	Wind Speed	Weather Station
47	Wind Direction	Weather Station
48	Rain Intensity	Weather Station
49	Barometric Pressure	Weather Station
50	Air Temperature	Weather Station
51	Relative Humidity	Weather Station
52	Tire Flag	Calculated from Air-Weigh data
53	Road Grade	Calculated from VBOX data
54	Placeholder B	none
55	Placeholder C	none
56	Placeholder D	none
57	Placeholder E	none
58	Stationary Latitude	Calculated from VBOX data
59	Stationary Longitude	Calculated from VBOX data

	Signal	Sensor
60	Tractor-Trailer Marriage	Calculated from Air-Weigh data

4.2 Sensors

The signals listed in Table 4.1 will be measured by a variety of autonomous sensors and sensors systems. Table 4.1 also lists the associated sensor/system relative to each signal. These sensor/sensor systems and the DAS are shown in Figures 4.1 through 4.4.



Figure 4.1: VBOX II Lite



Figure 4.2: Air Weigh Scale



Figure 4.3: Vaisala Weather Station



Figure 4.4: J1939 Vehicle Data Bus Connector

4.3 Data Acquisition System

The SoMat eDAQ-lite shown in Figure 4.5 will be used to capture data from the sensors in Section 4.2.



Figure 4.5: SoMat eDAQ DAS

4.4 Test Vehicles

Schrader Trucking will provide six (6) 2005 Volvo VNL tractors, along with ten (10) trailers. These vehicles will be instrumented with the DAS and sensor suite, and will then continue in real-world operation. Table 4.2 lists the instrumented tractors and trailers by Schrader identifying number and by manufacture vehicle identification number (VIN), and Figure 4.6 shows a typical Schrader tractor-trailer used in the FOT.

Table 4.2: Instrumented Tractors and Trailers

Tractor Number	VIN	Trailers	VIN
[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]
[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]
[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]
[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]
[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]
[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]
[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]
[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]
[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]
[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]
[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]
[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]
[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]
[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]
[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]	[Partner Sensitive Information]



Figure 4.6: Schrader Tractor and Trailer

4.5 Truck and Trailer Details

Tables 4.3 and 4.4 contain information regarding the test vehicles. To minimize the complications arising from different data buses, all trucks are the same make and model (Volvo VNL 2005). To maximize the usefulness of the data collected in the FOT, the vehicles chosen represent both transmission types and three different tire types. Table 4.5 contains trailer information.

Table 4.3: Test Truck Information

Truck	DAS	Transmission	Tires
[Partner Sensitive Information]	4	Manual	Existing Dual
[Partner Sensitive Information]	1	Manual	X-One
[Partner Sensitive Information]	2	Manual	Dual
[Partner Sensitive Information]	3	Auto	X-One
[Partner	5	Auto	X-One

Sensitive Information]			
[Partner Sensitive Information]	6	Auto	Dual

Table 4.5: Test Trailer Information

Trailer	Test Tire Type	VIN	Suspension	AirWeight TTG	Serial Number	Identifier (16 LSB of SN)
[Partner Sensitive Information]	Dual Michelin	[Partner Sensitive Information]	VANTRAAX.4742 HKA180-16	706	20038370	49890
[Partner Sensitive Information]	Dual Michelin	[Partner Sensitive Information]	VANTRAAX.4742 HKA180-16	707	20038378	49898
[Partner Sensitive Information]	Generic Dual	[Partner Sensitive Information]	VANTRAAX.4742 HKA180-16	708	20038372	49892
[Partner Sensitive Information]	Generic Dual	[Partner Sensitive Information]	VANTRAAX.4883 HKA180-16	709	20038376	49896
[Partner Sensitive Information]	Generic Dual	[Partner Sensitive Information]	VANTRAAX.5431 HKA180-16	710	20038374	49894
[Partner Sensitive Information]	Single Michelin	[Partner Sensitive Information]	slider suspension # HKANT 40 K	701	20038377	49897
[Partner Sensitive Information]	Single Michelin	[Partner Sensitive Information]	slider suspension # HKANT 40 K	702	20038373	49893
[Partner Sensitive Information]	Single Michelin	[Partner Sensitive Information]	slider suspension # HKANT 40 K	703	20037752	49272
[Partner Sensitive Information]	Single Michelin	[Partner Sensitive Information]	slider suspension # HKANT 40 K	704	20038371	49891
[Partner Sensitive Information]	Single Michelin	[Partner Sensitive Information]	slider suspension # HKANT 40 K	705	20038375	49895

4.6 Instrumentation Details

Table 4.4: Equipment

TTG HTDC FTS Unit 1, Truck # [Partner Sensitive Information], [Partner Sensitive Information], Manual Transmission, X-One Tires			
Instrument	Serial Number	TTG ID	Currently Installed Firmware/Software Rev # and Date
VBOX	006868	TTG 001	VBOXTools 1.2.1 (Build 090), Firmware 2.0.1 (Build 90)
eDAQ	0315	TTG 101	TCE V3.8.6d (17Jul 2006), MPB - V3_8_6d(V4.3d); Power - V2.2; DIO_1 - V1_2; Vaisala WXT
Weather Station	B2140054	TTG 201	Vaisala Configuration Tool Version 2.00 r.2
CAN Module	EMCAN.03-0469	TTG 401	V2.0, Checked 7/10/2006
J1708 Module	EMLIN.01-0185	TTG 501	V2.0, Checked 7/10/2006
Air-Weigh Truck Comlink	10004649	TTG 601	Identifier: 43177 (16 Least Significant Bits of SN)
Air-Weigh Display	4399	TTG 611	Calibration: Steer: Ratio 3.1267, Offset 7341. Drive: Ratio 17.862, Offset 25.

TTG HTDC FTS Unit 2, Truck # [Partner Sensitive Information], [Partner Sensitive Information], Manual Transmission, New Dual Tires			
Instrument	Serial Number	TTG ID	Currently Installed Firmware/Software Rev # and Date

VBOX	006879	TTG 002	VBOXTools 1.2.1 (Build 090), Firmware 2.0.1 (Build 90)
eDAQ	0329	TTG 102	TCE V3.8.6d (17Jul 2006), MPB - V3_8_6d(V4.3d); Power - V2.2; DIO_1 - V1_2; Vaisala WXT
Weather Station	B2140053	TTG 202	Vaisala Configuration Tool Version 2.00 r.2
CAN Module	EMCAN.03-0450	TTG 402	V2.0, Checked 7/10/2006
J1708 Module	EMLIN.01-0173	TTG 502	V2.0, Checked 7/10/2006
Air-Weigh Truck Comlink	10004428	TTG 602	Identifier: 42956, software: r104h114
Air-Weigh Display	4222	TTG 612	r103h116, Calibration: Steer: Ratio 3.1267, Offset 7341. Drive: Ratio 17.862, Offset 25.

TTG HTDC FTS Unit 3, Truck # [Partner Sensitive Information], [Partner Sensitive Information], Auto-Shift Transmission, X-One Tires			
Instrument	Serial Number	TTG ID	Currently Installed Firmware/Software Rev # and Date
VBOX	006941	TTG 003	VBOXTools 1.2.1 (Build 090), Firmware 2.0.1 (Build 90)
eDAQ with HLS board	0350	TTG 103	TCE V3.8.6d (17Jul 2006), MPB - V3_8_6d(V4.3d); Power - V2.2; DIO_1 - V1_2; Vaisala WXT
Weather Station	B2510011	TTG 203	Vaisala Configuration Tool Version 2.00 r.2
CAN Module	EMCAN.03-0424	TTG 403	V2.0, Checked 7/10/2006
J1708 Module	EMLIN.01-0182	TTG 503	V2.0, Checked 7/10/2006
Air-Weigh Truck Comlink	10004647	TTG 603	Identifier: 43175 (16 Least Significant Bits of SN)
Air-Weigh Display	4397	TTG 613	Calibration: Steer: Ratio 3.1267, Offset 7341. Drive: Ratio 17.862, Offset 25.

TTG HTDC FTS Unit 4, Truck # [Partner Sensitive Information], [Partner Sensitive Information], Manual Transmission, Existing Dual Tires			
Instrument	Serial Number	TTG ID	Currently Installed Firmware/Software Rev # and Date
VBOX	006942	TTG 004	VBOXTools 1.2.1 (Build 090), Firmware 2.0.1 (Build 90)
eDAQ	0354	TTG 104	TCE V3.8.6d (17Jul 2006), MPB - V3_8_6d(V4.3d); Power - V2.2; DIO_1 - V1_2; Vaisala WXT
Weather Station	B2510010	TTG 204	Vaisala Configuration Tool Version 2.00 r.2
CAN Module	EMCAN.03-0457	TTG 404	V2.0, Checked 7/10/2006
J1708 Module	EMLIN.01-0184	TTG 504	V2.0, Checked 7/10/2006
Air-Weigh Truck Comlink	10004646	TTG 604	Identifier: 43174 (16 Least Significant Bits of SN)
Air-Weigh Display	4398	TTG 614	Calibration: Steer: Ratio 3.1267, Offset 7341. Drive: Ratio 17.862, Offset 25.

TTG HTDC FTS Unit 5, Truck # [Partner Sensitive Information], [Partner Sensitive Information], Auto-Shift Transmission, X-One Tires			
Instrument	Serial Number	TTG ID	Currently Installed Firmware/Software Rev # and Date
VBOX	006944	TTG 005	VBOXTools 1.2.1 (Build 090), Firmware 2.0.1 (Build 90)
eDAQ	0369	TTG 105	TCE V3.8.6d (17Jul 2006), MPB - V3_8_6d(V4.3d); Power - V2.2; DIO_1 - V1_2; Vaisala WXT
Weather Station	B2510012	TTG 205	Vaisala Configuration Tool Version 2.00 r.2
CAN Module	EMCAN.03-0473	TTG 405	V2.0, Checked 7/10/2006
J1708 Module	EMLIN.01-0191	TTG 505	V2.0, Checked 7/10/2006
Air-Weigh Truck Comlink	10004645	TTG 605	Identifier: 43173 (16 Least Significant Bits of SN)
Air-Weigh Display	4396	TTG 615	Calibration: Steer: Ratio 3.1267, Offset 7341. Drive: Ratio 17.862, Offset 25.

TTG HTDC FTS Unit 6, Truck # [Partner Sensitive Information], [Partner Sensitive Information], Auto-Shift Transmission, New Dual Tires			
Instrument	Serial Number	TTG ID	Currently Installed Firmware/Software Rev # and Date
VBOX	006945	TTG 006	VBOXTools 1.2.1 (Build 090), Firmware 2.0.1 (Build 90)
eDAQ	0229	TTG 106	TCE V3.8.6d (17Jul 2006), MPB - V3_8_6d(V4.3d); Power - V2.2; DIO_1 - V1_2; Vaisala WXT
Weather Station	A3610011	TTG 206	Vaisala Configuration Tool Version 2.00 r.2
CAN Module	EMCAN.03-0323	TTG 406	V2.0, Checked 7/10/2006
J1708 Module	EMLIN.01-0171	TTG 506	V2.0, Checked 7/10/2006
Air-Weigh Truck Comlink	10004648	TTG 606	Identifier: 43176 (16 Least Significant Bits of SN)
Air-Weigh Display	4395	TTG 616	Calibration: Steer: Ratio 3.1267, Offset 7341. Drive: Ratio 17.862, Offset 25.

4.6 Sensor and DAS Integration to Test Vehicles

The test vehicles called out in Section 4.4 will be fitted with the sensors listed in Section 4.2, with the exception of the J1939 Vehicle Data Bus, which already exists on the vehicle. The sensor-to-test-vehicle integration will take place at the Schrader truck yard.

Cable runs to and from sensors will be routed in a manner to allow for sustained testing and occupant safety. Consideration will be given to shielding these cables from engine/exhaust heat and damage from objects thrown from the roadway. Cable runs will have termination/inspection points to allow for trouble shooting without cable removal. The step-by-step integration process is described in the System Installation section of the System Design and Operations Document (SDOD).

4.7 Sensor/DAS Verification and Calibration

All sensors, cabling, and the DAS will be verified for operation after the initial integration. This verification will take place at Schrader Trucking. Verification information is included in the Operational Procedures section of the SDOD.

All fuel information collected from the truck data bus will be calibrated when enough fuel receipts are collected. One Air-Weigh tractor scale will be calibrated at a certified scale by following the Manual Calibration Procedure in the Air-Weigh tractor scale manual. The remaining Air-Weigh tractor scales will then be calibrated by following the Ratio and Offset Calibration Procedure in the Air-Weigh tractor scale manual. The Air-Weigh trailer scales will be calibrated according to the Pre-Programmed Calibration Procedure in the Air-Weigh trailer scale manual. The eDAQ, VBOX, and Weather Stations have been calibrated at the factory.

4.8 Power Measurement

An operating DAS system and complete sensor system will be measured for power consumption. It will be verified that the system is operating in an acceptable range. For this testing, an ammeter will be placed in series with the power wiring to the DAS and sensors. The current drawn will then be measured while all components of the DAS and sensors are turned on.

5.0 FIELD OPERATIONAL TEST

5.0 Field Operational Test Tasks

This section will address the following Tasks:

- Equipment Procurement
- Equipment Configuration and Build-up
- Equipment to Vehicle Integration

- On-Vehicle Testing
- Vehicle Deployment Methodology
- Data Transfer Protocol

5.1 Equipment Procurement and Bill of Materials

ORNL will procure all items needed for the construction of the six DASs. No individual component or circuit design is expected to be necessary nor are such efforts planned. Specialized cabling will be procured through special fabrication shops and smaller standard items will be procured via ORNL AVID system or via local purchase. The component procurement is planned for early in Phase 2 to allow for long lead items. The Bill of Materials for the DAS is shown in Table 4.4.

5.2 Equipment Configuration and Build-up

Each DAS will be built and assembled per the SDOD Wiring Diagrams section. This will include the completed backplane assembly for each test vehicle and interconnection to all removable sensors, systems power, and system triggers.

Individual sensors will be configured and formatted for assimilation into the DAS. Memory will be formatted, IP addresses set, and final sampling rates will be determined and set for the DAS. A connection point for downloading data will be configured into the system. Configuration will follow the Configuration Procedures section of the SDOD.

5.3 Equipment to Vehicle Integration

ORNL will install the DASs and their associated remote sensors and cabling into each test vehicle via ORNL staff or contractor. The installation will be done in accordance with DOT, OSHA, and IEEE standards and will not interfere with the driver or the operation of the test vehicle. Furthermore, the equipment will be installed in such a way as to be “transparent” to the vehicle operator and will be done in such a way that driver interaction will be minimal or not required. The installation will not damage the structure of the test vehicles, affect their appearance once the equipment is removed, or decrease the value of the tractor-trailer beyond normal depreciation. Integration steps are listed in the System Installation section of the SDOD.

5.4 On-Vehicle Testing

A shakedown test of the DAS will be performed on each fleet test vehicle. The test will verify that each sensor and the DAS are functioning in the desired manner. Any problems encountered during this testing will be addressed and solved before the vehicle enters the FOT. Testing information is included in the Data Upload Checklist and the Operational Procedures section of the SDOD.

5.5 Vehicle Deployment Methodology

Initially, only one test vehicle will be deployed. This vehicle will be closely monitored for sensor and DAS function. If possible, the driver will be interviewed regarding interference issues during daily tasks. During the initial launch, data will be extracted from the test vehicle and analyzed to validate sensor and DAS operation as well as its value to the core objectives of this project. These core objectives include: establishment of a data archive and duty cycle generation tool, as well as the capability of generating duty cycle data for use in, and evaluation of the Class 8 module of PSAT. After the initial launch, the remaining test vehicles will enter the FOT. The initial release of only one truck will allow for any problems to be corrected before they affect the entire fleet. During vehicle deployment, data will continue to be archived and integrated into both the data archive and the duty cycle generation tool.

Vehicle Deployment Tasks
Install Air-Weigh
Calibrate Air-Weigh
Install DAS, VBOX, and cables (to power, Air-Weigh, and Vehicle Data Bus)
Install Weather Station
Install VBOX antenna
Install Tires

5.6 Data Transfer Protocol

Data will be downloaded from the DAS via a laptop on a weekly basis until any problems with the system are worked out. All trucks are most likely to be present at Schrader Trucking on Saturday. Each Saturday, ORNL staff will travel to Schrader Trucking to download the data and verify that all sensors are functioning. The data will be brought back to ORNL for further verification and storage. This way, if a sensor is not collecting valid data, the problem can be addressed quickly.

After verification that all equipment is functioning correctly, data download visits will be reduced to every two weeks. Each DAS has storage capacity enough for one month of data. However, all six trucks are not always present on any given Saturday. Downloads every two weeks will prevent the DAS from reaching its limit unless the truck is not present two visits in a row. Schrader Trucking staff or a contractor may also be hired to download data every two weeks, with ORNL staff visiting every month to inspect the system and bring the data back to ORNL. Data verification will continue throughout the entire FOT.

6.0 SPECIFICS OF DATA UPLOAD

This section will address the following details in the data upload process:

- Preparation for Travel to Schrader Trucking

- Directions
- At Schrader Trucking
- Upon Return to NTRC
- Safety Information For Student Travel to Schrader Trucking
- Summary of Data Upload Tasks

6.1 Preparation for Travel to Schrader Trucking

The tools and supplies listed in Table 6.1 should be loaded into the vehicle for travel to Schrader Trucking. If a government vehicle is to be used, the tools and supplies should be loaded into the trunk of the vehicle while the building is open on Friday. The vehicle keys can then be kept for travel on Saturday.

Table 6.1: Tools and Supplies for Data Upload

Necessary:
Laptop with Power Cord
Portable Hard Drive
Pen and Paper
Data Upload Checklist
Seals
Wire Cutters
May Be Needed:
CAT-5 Cable Extension
Battery Pack with Attached Inverter
USB to Serial Adapter, Weather Station Service Cable, 9V Battery
VBOX RS232 to Serial Cable (May Be Stored with VBOX)
Spare VBOX Antenna
Multimeter
Extension Cord
Extra Cables, Wires, Alligator Clips, Wire Connectors
Wire Termination Kit
Wire Coat Hanger
Cable Ties
Silicone, Isopropyl Alcohol, and Paper Towels or Cloth
Double Sided tape, Electrical Tape, Duct Tape
Screwdrivers, Allen & Torx Wrenches, Adjustable Wrenches, Wire Strippers, Pliers
Weather Station Clamps
Spare 5 Amp Fuses, No-Skid, Wire Loom, Air Filter for Fan Covering
Flashlight

6.2 Directions

Start address:	2360 Cherahala Blvd Knoxville, TN 37932
End address:	1923 Slate Rd Jefferson City, TN 37760
Distance:	45.2 mi (about 1 hour 8 mins)

Directions		
	1. Head east from Cherahala Blvd - go 0.2 mi	0.2 mi
➔	2. Turn right at Hardin Valley Rd - go 0.4 mi	0.4 mi
⬅	3. Turn left onto the ramp - go 0.2 mi	0.2 mi
➔	4. Bear right at TN-162 S - go 2.3 mi	2.3 mi 2 mins
	5. Continue on Pellissippi Pky - go 0.2 mi	0.2 mi
	6. Take the I-40/I-75 ramp to Nashville/Knoxville/Chattanooga - go 1.4 mi	1.4 mi 2 mins
	7. Merge into I-40 E/I-75 N - go 8.0 mi	8.0 mi 9 mins
	8. Continue on I-40 E toward Knoxville - go 8.9 mi	8.9 mi 10 mins
	9. Take the US-11E/US-25W/US-70 exit 394 - go 0.2 mi	0.2 mi
⬅	10. Turn left at Asheville Hwy - go 6.0 mi	6.0 mi 7 mins
	11. Continue on Andrew Johnson Hwy - go 9.0 mi	9.0 mi 12 mins
	12. Continue on US-11E N - go 7.9 mi	7.9 mi 11 mins
⬅	13. Turn left at N Chucky Pike - go 0.3 mi	0.3 mi
➔	14. Turn right at Slate Rd - go 0.3 mi	0.3 mi
	15. Arrive at 1923 Slate Rd Jefferson City, TN 37760	

6.3 At Schrader Trucking

Upon arrival at Schrader Trucking, the shop (Figure 6.2) will be notified at (865) 471-7050 (Ext 8). The shop will then open the gate and provide access to trucks [Partner Sensitive Information] if they are available. Data can then be uploaded from each of the six trucks by following the Data Upload checklist (Figure 6.1) in the Operational Procedures section of the SDOD. Any necessary repairs will be made at the point

stated in the Data Upload checklist. The shop will then be notified of departure. The upload process includes checking the condition of the equipment installed on each truck, especially the weather station and GPS antenna. The location and normal condition of the equipment is shown in Figures 6.3 to 6.7.

HTDC Data Upload Checklist					
Name:		Date:		Truck ID	
Driver:		Start time:		DAS No.	
Comments: (Driver/ Carrier)					
This procedure begins with the ignition turned ON and the computer turned ON.					
	1) Check that the DAS is sealed. Open it, check inside, check cables, check that fan is not blocked.				
	Comments:				
	2) Verify that the eDAQ is ON and running. (Green light on, yellow light blinking)				
	3) Connect the computer to the eDAQ.				
	4) Open TCE (Start > All Programs > SoMat TCE eDAQ V3.8.6d > SoMat TCE eDAQ V3.8.6d)				
	5) Monitor the channels to identify potential problems (Ctrl+5; close when finished)				
	Comments:				
	6) Press Ctrl+6 to end the run				
	7) Press Ctrl+E to end the test.				
	8) Press Ctrl+7 to upload the data. Click OK. Save in the file path shown below.				
	C:\Documents and Settings\gcp\Desktop\yyyyymmdd\HTDC_0_yyyymmdd				
	yyyy - year mm - month dd - date				
	0 - DAS #	File Name:			
	9) While the data is being uploaded, check that the GPS antenna cable is still securely attached.				
	Comments:				
	10) As data upload continues, check the weather station (cable, mounting, orientation, visible damage)				
	Comments:				
	11) When the data upload is complete, repeat (press Ctrl+7), saving in the following file path and format:				
	F:\yyyyymmdd\HTDC_0_yyyymmdd				
	yyyy - year mm - month dd - date				
	0 - DAS #	File Name:			
	12) In TCE, select FCS Setup > Set FCS Clock and click Yes.				
	13) If any sensors or parts need to be replaced, turn off the eDAQ, replace parts, and turn back on.				
	Replacing parts? NO YES - detail below				
	14) Press Ctrl+O and open the appropriate setup file, based on the Truck number				
	In folder C:\Program Files\SoMat\Tce_eDAQ_3.86d\Work\HTDC0a				
	Setup File Name:				
	15) Press Ctrl+2 to initialize the test (several checks of the setup file and eDAQ will be run).				
	16) Press Ctrl+3 to start a new run.				
	17) Close the TCE software.				
	18) Unplug the cable from the computer and return to the DAS box. Seal the box.				
The ignition may be turned OFF at this time. The computer may be turned OFF as well.					
Other Comments					
Signed:				Date:	

Figure 6.1: Data Upload Checklist



Figure 6.2: Schrader Shop, Far Left

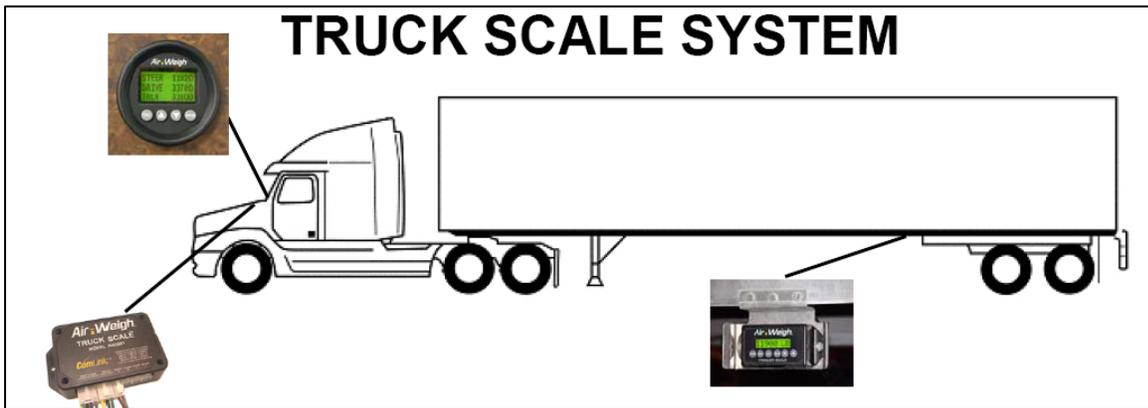


Figure 6.3: Air-Weigh System Components and Locations (Display, Truck Scale, and Trailer Scale)



Figure 6.4: Weather Station

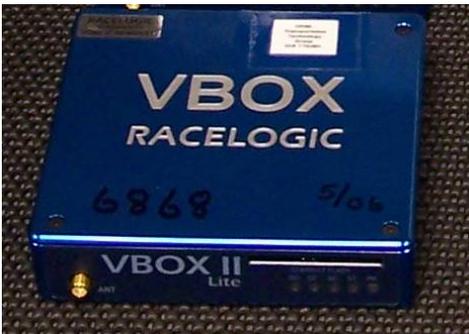


Figure 6.5: VBOX and Truck Cab Storage Space



Figure 6.6: GPS Antenna and Tractor Top Location

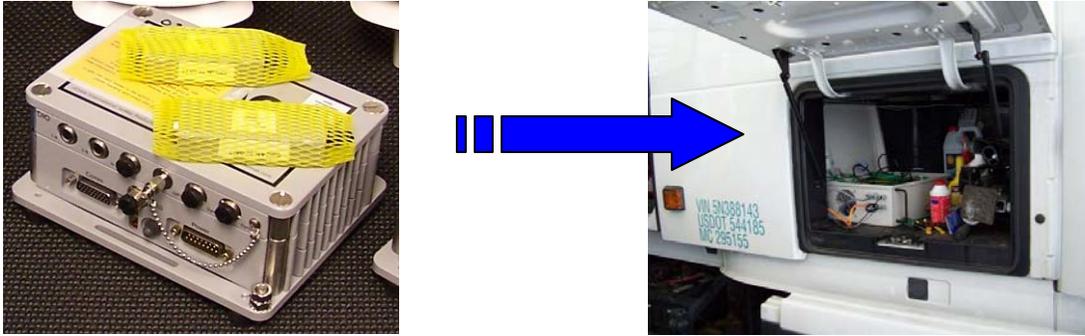


Figure 6.7: eDAQ Lite with two Vehicle Bus Modules, and Truck Cab Storage Space

6.4 Upon Return to NTRC

Upon return to the lab, the data retrieved from Schrader Trucking will be copied to the lab's remote computer and backup drive, following the HTDC Data Storage procedure from the Operational Procedures section of the SDOD. The laptop clock time will also be set according to the HTDC Data Storage procedure.

HTDC Data Storage

This procedure is to be completed immediately after data is uploaded from the DAS (Routine Data Upload procedure). Two copies have been saved: one on the laptop and one on the orange portable USB drive. This procedure is specifically designed for periodic storage of data collected during the HTDC field operational test.

- 1) Upload the sif files (folder yyyyymmdd, where yyyy=year mm=month & dd=day of the latest data upload) from the laptop (C:\Documents and Settings\gcp\Desktop\yyyyymmdd) to the 250MB drive in L118 (F:\yyyyymmdd).
- 2) Copy the sif files from the orange portable drive (G:\yyyyymmdd) to the remote computer at ORNL. (\\Cappsgj-htdc\HTDC SIF A\yyyyymmdd)
- 3) Delete the yyyyymmdd folder from the laptop and from the orange portable USB drive when finished working with them.
- 4) Type the notes from the weekend into Upload Notes.xls on the ORNL computer (\\Cappsgj-htdc\HTDC SIF A\Upload Notes.xls). Make a backup copy on the laptop.
- 5) Sync the laptop clock with the UTC time zone from <http://www.time.gov>. It should be five hours ahead of Eastern Standard Time, or four hours ahead of Eastern Daylight Time (before Oct. 29, 2006 or after March 11, 2007).

So far, there should be two copies of each sif file:

- 250MB drive in L118
- remote computer at ORNL

The data can then be deleted from the orange portable drive and the laptop.

- 6) Download the yyyyymmdd folder to the data analysis computer from the ORNL computer.
- 7) Translate the sif files into ASCII and store them on the data analysis computer. At this time the data is pre-processed and separated into files that cover just a day worth of data for each truck. General statistics (min, max, averages, standard deviations and other statistics) where appropriate are also generated. A summary of errors (i.e. sensor failures, out-of range values) as well as valid data is also generated.
- 8) Make a backup copy of the ASCII files on a local 250MB drive.
- 9) When an Excel file of route, weight, and fuel information is received by email, store it in the data analysis computer, and back it up in the ORNL computer. (\\Cappsgj-htdc\HTDC SIF A\yyyyymmdd)

6.5 Safety Information For Student Travel to Schrader Trucking

A student traveling to Schrader Trucking should be aware of the following:

- While traveling to Schrader, from Schrader, or while at Schrader and you become sick or injured (or have any other problems: i.e. car trouble, issues getting into truck lot, unclear about your assignment, etc.), immediately do what you need to do to protect yourself and or obtain aid.

If possible, then contact Gary Capps and explain the situation. If Gary is not available, contact Bill Knee. If Bill is not available, contact the Lab Shift Superintendent (LSS). This phone is answered 24-hours.

Emergency Contact info:

ORNL

Gary Capps' Cell – [Information Removed]

Bill Knee's Cell – [Information Removed]

ORNL Lab Shift Superintendent – 865 574 6606

Local Ambulance, Fire, and Police 911

Schrader Trucking

Main Office – 865 471 7050

Phil Schrader's Cell – [Partner Sensitive Information]

Chris Barnard's Cell – [Partner Sensitive Information]

In the event of an automobile accident, if you are able, contact the local police (911) and notify the LSS. Also, if you are able, an accident report form should be completed. There should be one in the dash of each government vehicle.

- General Steps to be taken for this offsite effort:
 - 1) In advance of traveling to Schrader, please be sure that Gary or Bill has been notified of your plans and have approved.
 - 2) Reserve government vehicle
 - 3) Fill out form ORNL-143 and fax to LSS
 - 4) Upon arrival at Schrader, call 865 471 7050 (Ext 8), notify the shop that you have arrived, and ask that the gate be opened.
 - 5) Immediately travel to the shop via vehicle, and inform them that you will be collecting data from the six test vehicles. (They already know that someone will be coming each Saturday to collect data.)
 - 6) Travel to the south end of the parking area where these six trucks are located and park the government vehicle in a safe location
 - 7) Use caution while in the lot and watch for truck traffic

- 8) After you have downloaded the data, please notify the shop that you are leaving the lot
 - 9) In the event that you must go into the Schrader shop: 1) do not work around any vehicle that is on the lift or jacks; 2) do not enter the shop if welding is in progress; 3) do not enter or work in the shop if you feel that work currently being conducted in the shop is not safe.
- Please note that you are authorized by SULI only to work 40 hours per week. Please reduce your Monday through Friday hours by the amount that you plan to work on Saturdays.

6.6 Summary of Data Upload Tasks

Table 6.2 summarizes the tasks involved in data upload, along with the day of the week best suited for completion of each task.

Table 6.2: Weekly HTDC Project Tasks

Monday	Unload tools and supplies from government vehicle, return keys. Copy the previous weekend's data to the remote computer and backup drive, and sync the laptop clock.
Tuesday	
Wednesday	Check that the spreadsheet from Schrader's database had been uploaded to the remote computer.
Thursday	Reserve government vehicle, fill out form ORNL-143 and fax to LSS.
Friday	Get government vehicle keys and load tools and supplies into trunk.
Saturday	Travel to Schrader Trucking for data upload.
Sunday	

Appendix D
SYSTEM DESIGN AND OPERATIONS DOCUMENT

Oak Ridge National Laboratory
National Transportation Research Center

H. E. (Bill) Knee
Oak Ridge National Laboratory
National Transportation Research Center
2360 Cherahala Blvd.
Knoxville, TN 37932
Phone 865 946-1300
Email: kneehe@ornl.gov

Argonne National Laboratory
Center for Transportation Research

Don Hillebrand
Argonne National Laboratory
Center for Transportation Research
9700 S Cass Ave
Chicago, IL 60439
Phone 630 252-6502
Email: hillebrand@anl.gov

Heavy-Truck Duty Cycle Data from Real-World Driving Environments: Field Operational Test and Data Analysis

System Design and Operations for
a Program Focused on the
Characterization of Heavy Truck
Duty Cycles from Real-World
Driving Environments

Collection, Analysis, and Archiving of Real-World-Based Heavy Truck Driving Characteristics and Duty Cycle Data to Support the Development and Evaluation of PSAT, Provide the Department of Energy a Basis for Technology Investment Decisions, and to Establish a National Data Archive in Support of Heavy Truck Energy Efficiency Research.

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1. BACKGROUND

This Program involves efforts to collect, analyze, and archive data and information related to heavy-truck operation in real-world highway environments. Such data and information will be useful to support technology evaluation efforts and provide a means of accounting for real-world driving performance within heavy truck analyses. The Program is being led by the Oak Ridge National Laboratory, will involve two industry partners (Dana Corporation of Kalamazoo, MI and Michelin Tire of Greenville, SC), and will have support from the Argonne National Laboratory (ANL) with regard to this projects relationship with PSAT development and evaluation. Both industry partners are interested in the vehicle dynamics for real-world applications in order to validate their computer simulation models of the truck's axles, tire performance, and tire-road interface. In addition, Michelin remains interested in gathering data on the long-term real-world performance of their New-Generation Single Wide-Based Tires (NGSWBT) – especially with regard to the fuel savings aspect of NGSWBTs.

The overall Program consists of three phases:

Phase 1 – Pilot Test: Design, Testing and Evaluation of a Duty Cycle Data Collection System.

Phase 2 – Field Test Launch: Fleet Instrumentation, Field Testing Begins, Initial Data Collection and Data Verification

Phase 3 – Field Test Conduction: On-going Field Test, Data Analysis, and Data Repository

This document will address the design of the data acquisition system and sensor suite used in Phases 2 and 3. In addition, it will include all procedures followed in these phases.

2. LIST OF DATA COLLECTED

The following 60 signals are collected through various sensors on six instrumented Class-8 trucks.

Table 2.0: List of Signals Collected

	Signal	Sensor
1	Instantaneous Fuel Economy	J1939 Vehicle Data Bus
2	Average Fuel Economy	J1939 Vehicle Data Bus
3	Fuel Rate	J1939 Vehicle Data Bus
4	Total Fuel Used	J1939 Vehicle Data Bus
5	Total Idle Fuel Used	J1939 Vehicle Data Bus
6	Current Gear	J1939 Vehicle Data Bus
7	Selected Gear	J1939 Vehicle Data Bus
8	Output Shaft Speed	J1939 Vehicle Data Bus
9	Actual Engine - Percent Torque	J1939 Vehicle Data Bus
10	Actual Gear Ratio	J1939 Vehicle Data Bus
11	Driver's Demand Engine - Percent Torque	J1939 Vehicle Data Bus
12	Percent Load at Current Speed	J1939 Vehicle Data Bus
13	Engine Speed	J1939 Vehicle Data Bus
14	Engine Oil Temperature	J1939 Vehicle Data Bus
15	Fuel Temperature	J1939 Vehicle Data Bus
16	Front Axle Speed	J1939 Vehicle Data Bus
17	High Resolution Total Vehicle Distance	J1939 Vehicle Data Bus
18	Accelerator Pedal Position	J1939 Vehicle Data Bus
19	Total Idle Hours	J1939 Vehicle Data Bus
20	Maximum Vehicle Speed Limit	J1939 Vehicle Data Bus
21	Total Power Takeoff Hours	J1939 Vehicle Data Bus
22	Clutch Switch	J1939 Vehicle Data Bus
23	Brake Switch	J1939 Vehicle Data Bus
24	Cruise Control Enable Switch	J1939 Vehicle Data Bus
25	Cruise Control Active	J1939 Vehicle Data Bus

	Signal	Sensor
26	Cruise Control Accelerate Switch	J1939 Vehicle Data Bus
27	Cruise Control Resume Switch	J1939 Vehicle Data Bus
28	Cruise Control Coast Switch	J1939 Vehicle Data Bus
29	Cruise Control Set Switch	J1939 Vehicle Data Bus
30	Battery Electrical Potential (Voltage)	J1939 Vehicle Data Bus
31	Tractor Drive Axles Weight	Air-Weigh
32	Tractor Steer Axle Weight	Air-Weigh
33	Trailer Weight	Air-Weigh
34	Tractor Serial Number	Air-Weigh
35	Trailer Serial Number	Air-Weigh
36	Latitude	VBOX
37	Longitude	VBOX
38	Altitude	VBOX
39	Vertical velocity	VBOX
40	Velocity over ground	VBOX
41	Longitudinal acceleration	VBOX
42	Lateral acceleration	VBOX
43	Heading	VBOX
44	Satellites	VBOX
45	Time UTC	VBOX
46	Wind Speed	Weather Station
47	Wind Direction	Weather Station
48	Rain Intensity	Weather Station
49	Barometric Pressure	Weather Station
50	Air Temperature	Weather Station
51	Relative Humidity	Weather Station
52	Tire Flag	Calculated from Air-Weigh data
53	Road Grade	Calculated from VBOX data
54	Placeholder B	none
55	Placeholder C	none
56	Placeholder D	none
57	Placeholder E	none
58	Stationary Latitude	Calculated from VBOX data
59	Stationary Longitude	Calculated from VBOX data
60	Tractor-Trailer Marriage	Calculated from Air-Weigh data

3. LIST OF EQUIPMENT

The following equipment is used to acquire the data.

Table 3.0: List of Equipment

Equipment	Quantity	Product Name
Air-Weigh Tractor Scale	6	Air-Weigh 5800 Series Tractor Scale
Air-Weigh Trailer Scale	10	Air-Weigh 5800 Series Trailer Scale
Weather Station	6	Vaisala Weather Transmitter WXT510
VBOX	6	Racelogic VBOX II Lite
Truck with J1939 Data Bus	6	2005 Volvo VNL
eDAQ	6	SoMat eDAQ-lite
Laptop Computer	1	ACER TravelMate 4202WLMi Notebook

4. OVERVIEW OF SENSORS, LOCATION, AND COLLECTION METHODOLOGY

Each of the six trucks is instrumented to access four sources of data (Air-Weigh, Weather Station, VBOX, and Vehicle Data Bus) connected to a central data storage unit - the eDAQ. Data is retrieved approximately biweekly from each eDAQ using a laptop computer. The following is an overview of each component of the system.

4.1. Air-Weigh

The Air-Weigh system measures steer, drive, and trailer axle weights through pressure measurements in the vehicle suspension system. It also provides serial numbers for tractor and trailer identification. The data from the Air-Weigh follows the J1708 communication protocol and is accessed by tapping into the display wiring in the dashboard fuse panel.

The instrumented tractors and trailers are part of a drop-and-hook operation in which the trailer that is paired with a particular tractor often changes. The Air-Weigh trailer scale sends data to the tractor over existing power cables, eliminating the need for additional wiring connections during a trailer change. The six instrumented tractors are paired with trailers from a pool of about 150. ORNL does not have control over which trailer is paired with which tractor. To increase the chances that an instrumented trailer is paired with an instrumented tractor, four more trailers than tractors are instrumented with Air-Weigh trailer scales.

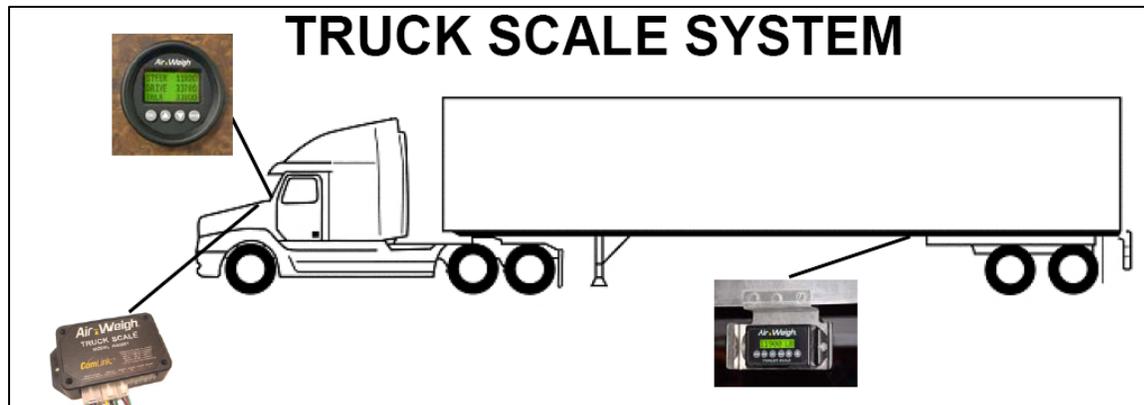


Figure 4.1: Air-Weigh System Components and Locations (Display, Truck Scale, and Trailer Scale)

4.2. Weather Station

The WXT510 weather station is mounted on the driver's side mirror. It collects weather data and sends it to the eDAQ using the RS-232 communication protocol.



Figure 4.2: Weather Station Location

4.3. VBOX

The VBOX II Lite is connected to a GPS antenna, which it uses to collect data

on vehicle motion and position. The GPS antenna is mounted on top of the tractor cab to obtain the best possible satellite reception. The VBOX is located in a protective container in the truck cab storage space, along with other equipment. It sends data to the eDAQ using the J1939 communication protocol.



Figure 4.3-1: VBOX and Truck Cab Storage Space

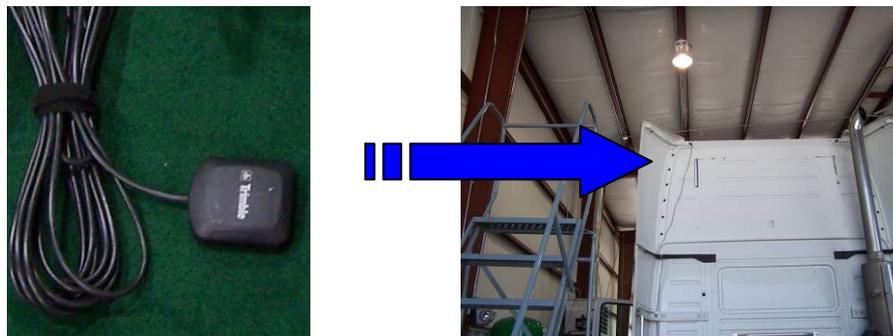


Figure 4.3-2: GPS Antenna and Tractor Top Location

4.4. Vehicle Data Bus

The J1939 vehicle data bus is present on most newer truck models and is accessible in the dashboard fuse panel. It provides information on fuel economy, current gear, engine speed, and many other vehicle parameters.



Figure 4.4: J1939 Vehicle Bus Connector in Dashboard Fuse Panel

4.5. EDAQ

The eDAQ Lite is connected to the Air-Weigh, weather station, VBOX, and vehicle data bus. It receives and stores data from all four sources at a rate of 5 Hz. The eDAQ uses a J1708 Vehicle Bus Module for communication with the Air-Weigh system and a J1939 Vehicle Bus Module for communication with both the truck data bus and the VBOX. The eDAQ and vehicle bus modules are located in the truck cab storage space.



Figure 4.5: EDAQ Lite with Two VBMs in Truck Cab Storage Space

5. WIRING DIAGRAMS

This section covers all wiring connections necessary on each truck. It contains wiring diagrams showing the connections between the eDAQ and each of the four sensors, as well as power, relay, and fan connections. Figure 5.0 gives an overview of all wiring, and details from Figure 5.0 are presented later in this section. The color abbreviations in Table 5.0 are used throughout this section.

Table 5.0: Color Abbreviations Key

Abbreviation	Color
BK	Black
BN	Brown
BL	Blue
GN	Green
OR	Orange
RD	Red
WT	White
YL	Yellow

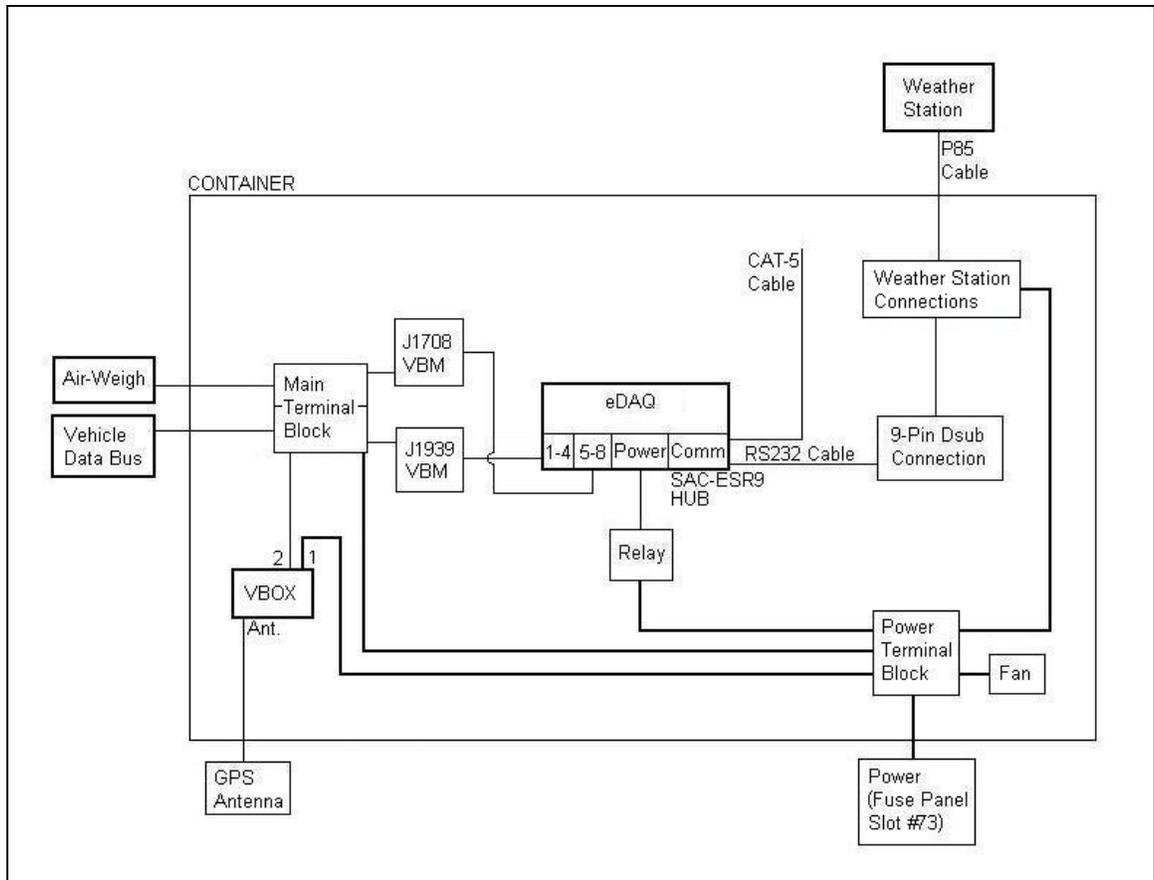


Figure 5.0: Wiring Overview

5.1. Power

Power comes into the eDAQ/VBOX container from the dashboard fuse panel. The red power connection is placed in series with a 5-amp fuse and then plugged into slot #73 in the Volvo fuse panel. This slot provides power that is switched on only when the ignition is switched on, preventing the eDAQ from draining the truck battery. The supply ground is connected to a fuse panel ground. Power and ground are then connected to a terminal block in the eDAQ container, where they branch off to the VBOX, the fan, the weather station, and to a time-delay relay. Ground is also connected to the main terminal block.

The relay, which can be set from 1 second to 1056 seconds, is set to supply power to the eDAQ 30 seconds after the ignition is switched on. This gives the VBOX time to acquire a satellite lock before the eDAQ starts recording data. The 30-second delay also prevents very short data sets from being recorded and avoids eDAQ battery problems due to a series of very short power-on and power-off cycles.

The fan keeps air flowing through the eDAQ/VBOX container, preventing that

the equipment inside from overheating. A filter is installed over the fan opening to keep dust out of the container.

5.2. Main Terminal Block

The terminal block shown in Figure 5.2 is installed in the eDAQ/VBOX container lid. On the left side, two Turck cables go to Vehicle Bus Modules (VBM), which are then connected directly to the eDAQ by a Turck cable. Each row of the terminal block is electrically connected, linking the J1708 VBM to the Air-Weigh, and the CAN J1939 VBM to the J1939 vehicle data bus and VBOX.

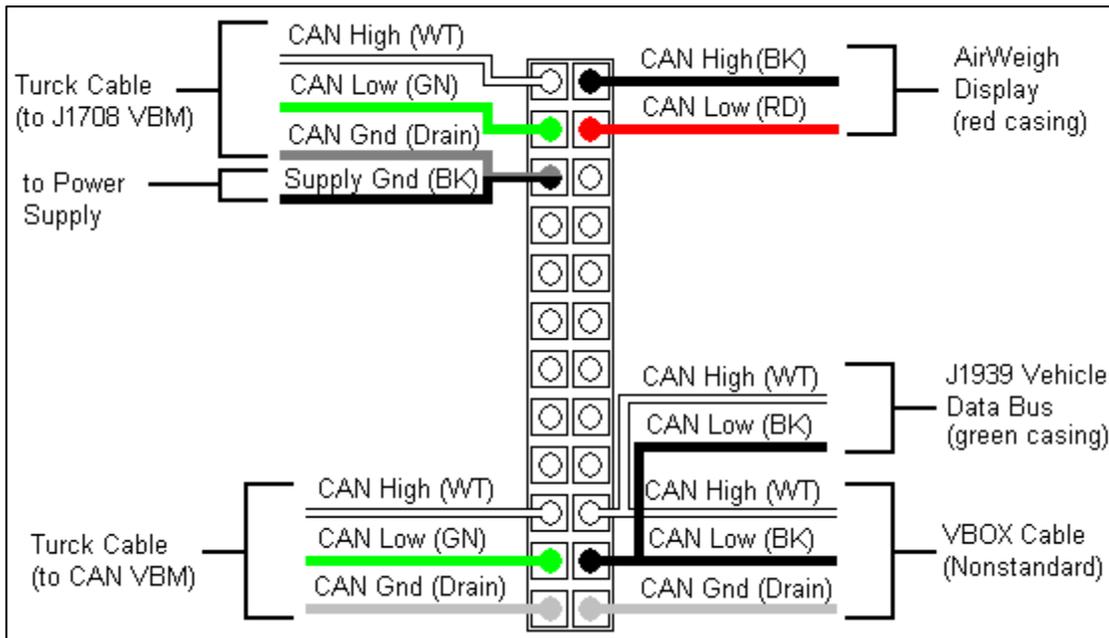


Figure 5.2: Main Terminal Block Wiring Diagram

5.3. Air-Weigh and J1939 Vehicle Data Bus

The Air-Weigh and J1939 vehicle data bus connections shown above are connected from the terminal block to the dashboard fuse panel with a single cable containing three twisted pairs with green, red, and blue casings. Figure 5.3 shows the connections made at the dashboard fuse panel end of this cable.

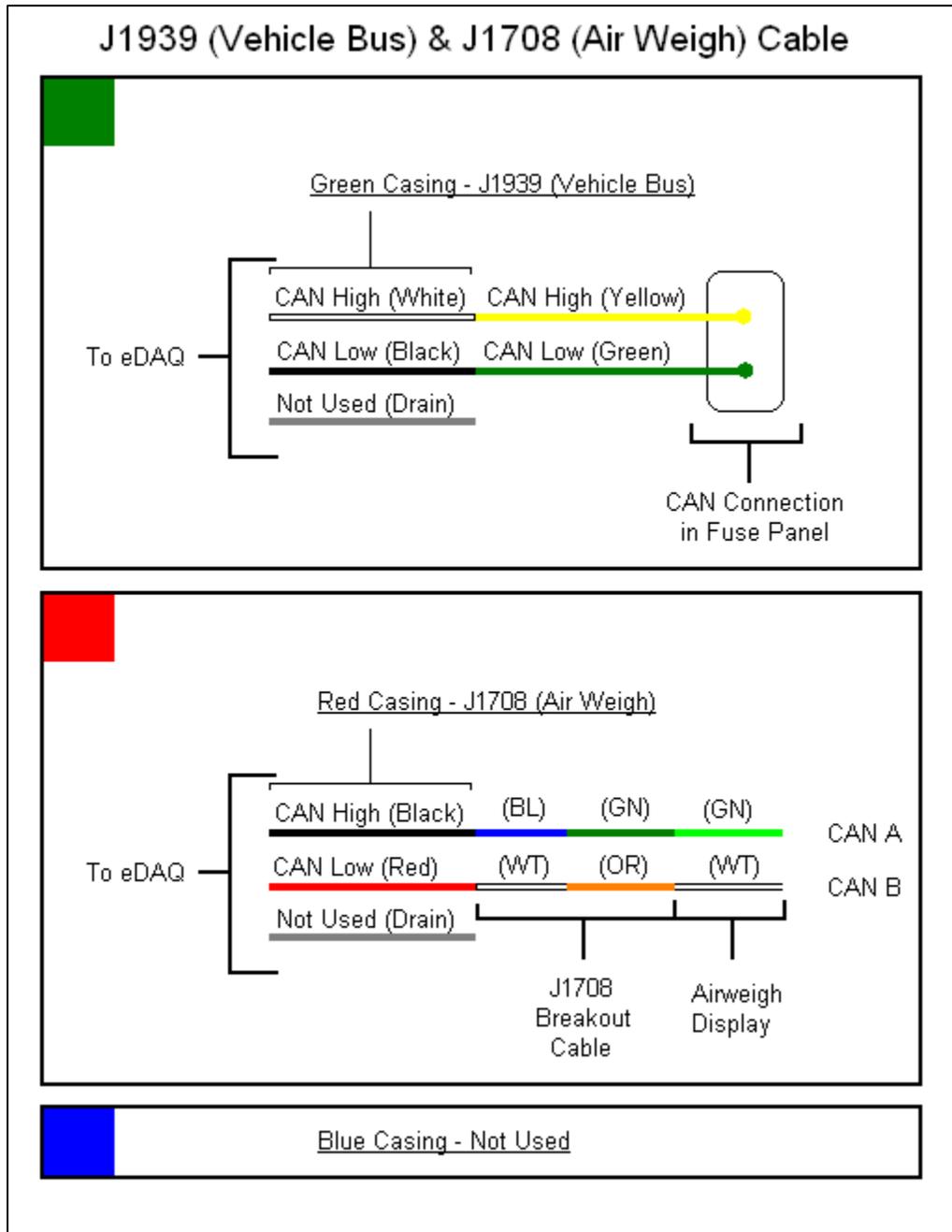


Figure 5.3: J1939 (Vehicle Bus) & J1708 (Air-Weigh) Cable

The J1939 connection requires a 120-ohm termination resistor to be in parallel with CAN High and CAN Low. This resistor is already present in the fuse panel connector, but a resistor would need to be added if this connector were removed.

Additional Air-Weigh wiring was completed by Air-Weigh personnel during product installation.

5.4. Weather Station Connections

Figure 5.3 presents the details of the weather station connections block from Figure 5.0. Each column in the diagram is electrically connected.

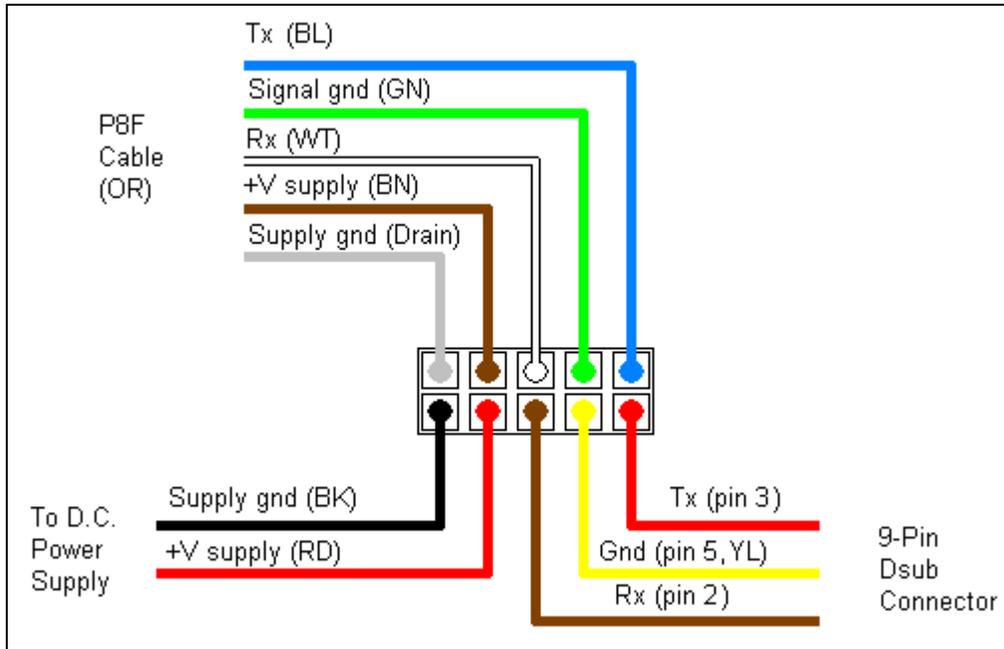


Figure 5.4: Weather Station Connections

5.5. Specific Cables

This section provides information regarding several of the specific types of cables used in the DAS.

5.5.1. EDAQ Turck Cable (Male)

The eDAQ Turck cable connects the main terminal block to the VBMs and the VBMs to the eDAQ.

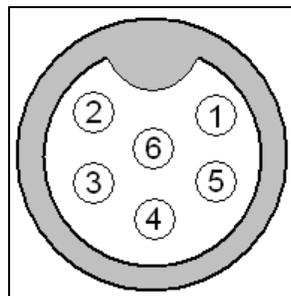


Figure 5.5.1: EDAQ Turck Cable (Male)

Table 5.5.1: EDAQ Turck Cable Pin-outs

Pin	Wire Color	CAN VBM	J1708 VBM
1	Brown	SWC [not used]	LIN_bus [not used]
2	White	CAN High	J1708_A
3	(bare wire)	AGnd	AGnd
4	Black	[not used]	[not used]
5	Red	+12V Ref [not used]	+12VRef [not used]
6	Green	CAN Low	J1708_B

5.5.2. P8F Cable (Weather Station)

The P8F Cable connects the weather station to the weather station connections block.

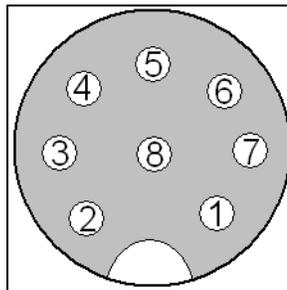


Figure 5.5.2: P8F Cable

Table 5.5.2: P8F Cable Pin-outs

Pin	Wire Color	Function
1	White	Data in (RxD)
2	Brown	Vin+ (operating)
3	Green	GND for data
4	Yellow	Vh+ (heating)
5	Gray	-
6	Pink	GND for Vh+
7	Blue	Data out (TxD)
8	Red/Clear ¹	GND for Vin+

1. Red in the internal wiring, clear in the cable (a non-insulated drain wire)

5.5.3. VBOX 5-Pin (to 6-Pin) Cable

The VBOX Cable connects the VBOX to the main terminal block.

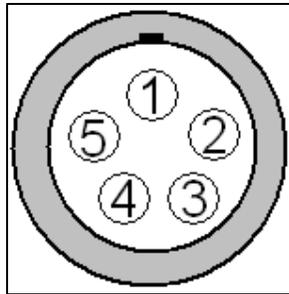


Figure 5.5.3: VBOX Cable

Table 5.5.3: VBOX Cable Pin-outs

Pin	Wire Color – NONSTANDARD	Wire Color – Standard	Function
1	[not used]	[not used]	[not used]
2	[not used]	[not used]	[not used]
3	White	White	CAN High
4	Black	Green	CAN Low
5	(bare wire)	(bare wire)	AGnd (Chassis)

6. SYSTEM INSTALLATION

This section describes the Data Acquisition System installation on a 2005 Volvo VNL tractor. It includes the placement of and the cable layout between the eDAQ, Air-Weigh, weather station, VBOX, and vehicle data bus. Specific wiring information is available in the Wiring Diagrams section, and most wiring within the eDAQ/VBOX container should be completed before in-truck installation.

6.1. Air-Weigh

Hire professional installation of the Air-Weigh system. Have the two wires for Air-Weigh data access (CAN High and Low) made accessible in the fuse panel on the dashboard. The Air-Weigh system must be calibrated at a certified scale after installation.



Figure 6.1: Fuse Panel in Volvo Dashboard

6.2. Storage Container

Place the eDAQ/VBOX container in the storage space on the left side of the truck as shown in Figure 6.2.



Figure 6.2: Truck Cab Storage Space

6.3. Weather Station

Clamp ANSI 3/4" tube to the driver's side mirror. Attach the weather station to the top of the tube, with North pointing forward. Cover the orange weather station cable with wire loom. Then run the cable down through the tube and under the body of the truck until it reaches the eDAQ. Use silicone and cable ties to hold the cable in place, taping over the silicone until it sets.



Figure 6.3: Weather Station Location

6.4. GPS Antenna

Use double sided tape to attach the VBOX GPS antenna to the top of the truck, on the left side. Cover the cable with wire loom. Then run the cable down the back of the truck to the VBOX, using silicone and cable ties to hold it in place, taping over the silicone until it sets.



Figure 6.4: GPS Antenna Location

6.5. Data Bus

Run a single cable containing at least two twisted pairs of wires from the eDAQ, under the floorboard on the driver's side, into the panel on the left of the driver's pedals, behind the steering wheel, and into the fuse panel on the dashboard on the center-right of the truck. A wire coat hanger can be used to pull the cable through tight spaces. Check that the cable follows a path that will not be pinched when the steering wheel is tilted. Use one twisted pair for the J1939 vehicle bus CAN High and Low connections, and another twisted pair for the Air-Weigh (J1708 CAN High and Low) connections.



Figure 6.5: Installation of Cables for J1939 and J1708 Connections

6.6 Power Supply

Use a second cable for ground and 12V power that is switched with the ignition. This cable should follow the same path as the J1939/J1708 cable to the dashboard fuse panel.

6.7 Additional Wiring

Make all connections described in the Wiring Diagrams section (Section 5). Use tap-splice connectors for connections in the dashboard fuse panel.

7. CONFIGURATION PROCEDURES

7.1. Setting up Instruments for the First Time

This section describes procedures for the first-time use of the eDAQ, VBOX, and weather station. These procedures are used to apply appropriate settings (which may or may not be the factory settings) to each of these instruments.

7.1.1. Initial EDAQ Setup

Hardware Setup

Note: This procedure starts with all equipment turned off and no connections made.

- 1) Turn on the computer and log in.

NOTE: If the TCE software has not been installed, do this now, following the instructions in the eDAQ manual (pp. 23-24 of 198 in eDAQManual_2005113.pdf).

- 2) Make the physical connections to the eDAQ.
 - a) To the computer
 - i) Connect the gray/black cable labeled **SAC-ESR9/HUB** to the **COMM** port of the eDAQ.
 - ii) Connect the black cable labeled **E-ETHERNET HUB** to the computer.
 - b) To the power supply
 - i) Verify that the power supply (12 Vdc) is off.
 - ii) Connect the power cable to the **POWER** port of the eDAQ.
 - iii) The attached cable labeled REMOTE POWER will not be used. Place the red and black leads of this cable in a position so that they will not touch.

NOTE: The purpose of this cable is equivalent to that of the power switch on the front of the eDAQ; shorting these wires will cause the eDAQ to turn off.

- iv) Connect the leads of the **POWER** cable to the power supply.
 - (1) The red lead is connected to the positive side of the power supply, and the black lead to the negative side.
 - (2) Position the connections away from each other so that there is no possibility of contact. (Shorting the leads of the power supply will damage the power supply.)
 - v) Check all connections, then turn on the power supply.
- 3) Turn on the eDAQ by pressing the power button to the left of the LEDs in the front of the eDAQ. All three lights should come on momentarily, and the green light will stay on, indicating a ready status.

Communication Setup

Note: This procedure is for an eDAQ which still has its factory-set IP address of 192.168.100.100. If using an eDAQ with a different IP address, substitute that IP address where the factory-set IP address is referenced; refer to Section 9.1.1. Changing IP Addresses for further information.

- 1) Verify that the computer's IP address is **192.168.100.xxx** (where xxx represents a number that is different from that of the eDAQ).
- 2) Verify that the computer recognizes the local connection.
 - a) Go to **Start > Run**.
 - b) In the Open field, type **cmd**.
 - c) Type **ipconfig**.

NOTE: This step may need to be repeated if the IP address does not immediately appear.

- d) When the computer's IP address appears in the window, close the command window and proceed to the next step.
- 3) Verify that the computer and eDAQ communication settings are correct.
- a) Open the TCE software (**Start > All Programs > SoMat TCE eDAQ V3.8.6d**).
 - b) From the menu, select **Preferences > Communications**.
 - c) Look under **IP Address or Host name**

NOTE: the connect timeout period and the socket buffer size

can also be changed from this window.

- i) If the appropriate IP appears (**192.168.100.100**), click on it and press **OK**.
 - ii) If the appropriate IP address is not in the list (because, for example, a new computer is being used or the IP address has been changed), click **Add**, type in the address (192.168.100.100), and click **OK**. Click on the correct address, and click **OK**.
- d) From the menu, select **File > New Setup**.
 - e) Select the **Hardware Setup** window and click **Query**.
 - f) If the software generates a list of hardware, then the setup has been successful.

Setting the Internal Clock

Refer to Section 9.1.5. Setting the FCS Time Zone and Clock.

7.1.2. Initial VBOX Setup

NOTE: This procedure begins with all equipment and power supplies turned off. The VBOX Tools software should be loaded, but not opened at this time. In order to use the USB-Serial connector to interface with the VBOX, the accompanying software must be loaded on the support computer; standard/default Windows configurations are inadequate.



Figure 7.1.2-1: VBOX II Lite and Accessories

- 1) Start the computer and log on, but do not open the VBOX Tools software yet.
- 2) Make the connections between the computer and the VBOX.
 - a) Connect the **USB/Serial** adapter to the computer.

Note: The USB/Serial adapter should already be configured. To verify that this is the case

 - i) Go to **Start > Control Panel > Performance and Maintenance > System**.
 - ii) Select the **Hardware** tab and click on the **Device Manager** button.
 - iii) Click on the **+** sign next to **Ports (COM & LPT)**. The device manager should list the USB/Serial adapter that is connected (for example, Belkin serial On USB Port (COM4)).
 - (1) If the connected adapter is shown without a warning symbol, then the adapter has been properly configured to the system; proceed to step 2)b).
 - (2) If the ports option is not listed or if the device is shown with a yellow warning symbol, the device will not be configured to the system until properly installed.
 - (a) If there is a yellow warning symbol next to the device, delete the device by double-clicking on the device and selecting Uninstall from the Driver screen.
 - (b) Close the open windows and return to the **Control Panel**. Select **Add Hardware** from the left column and follow the directions to configure the adapter. The configuration CD accompanying the adapter must be inserted at the prompt; the default Windows configuration will not be recognized by the VBOX Tools software.
 - (c) When the installation is complete, close other open programs and restart the computer.
 - b) Connect the **serial PC cable** (in the VBOX kit) to the VBOX, lining up the red dot on the cable with the red mark on the housing of **Socket 3**. The cable should snap into place.
 - c) Connect the **USB/Serial adapter** to the gray **serial PC cable**, screwing the sections together securely.
- 3) Connect the **lighter adapter** to a power supply and the other end of into the VBOX. Turn on the **power supply**.

NOTE: At this point, the red power LED on the VBOX should turn

on and the yellow light should begin to blink.

- 4) Finally, open the **VBOX Tools** software.

NOTE: The Source in the upper left corner of the window should be shown as the VBOX. If not, toggle by clicking on the icon in the upper-left corner of the window or pressing F11. Select the appropriate port (most likely COM4).

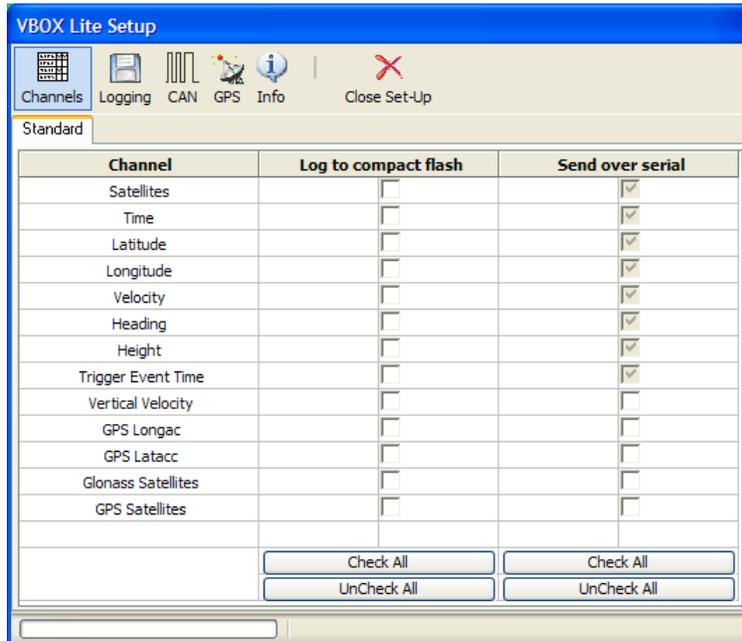


Figure 7.1.2-2: Setting up the VBOX

- 5) Click the **VBOX Set-up** icon and change the appropriate settings.

- a) If the setup file is available, use the following procedure.

- i) Go to **Config > Load**.
- ii) Locate **HTDC_Setup.rcf** and click **Open**.
- iii) In the Load Configuration Window, check **VBOX Settings** and click **Apply**.
- iv) Click on **OK** in the message window.

NOTE: Because the VBOX II Lite does not have analog and digital signal outputs, there is no Output Configure icon.

- v) Click the **Close Set-Up** icon.
- b) If a setup file is not available, click on the following icons in the setup window and make the changes specified.

- i) **Channels** (Standard) – **Deselect all** for both Compact Flash and Serial logging.
NOTE: Not all channels can be deselected in the serial logging column.
 - ii) **Logging** – Set the compact Flash Log Rate and the Serial Output to **20 Hz**; uncheck Log Only When Moving.
 - iii) **CAN** (Config) – Go to **Baud Rate > 250 Kbit**; set the CAN Bus Operation to **External**.
 - iv) **GPS** - Go to **DGPS > Enable WAAS**; click **OK** in the notification window.
 - v) Click the **Close Set-Up** icon.
 - c) Close VBOX Tools and turn off the VBOX (by cutting power).
- 6) Switch off internal RAM logging.

NOTE: When the internal memory of the VBOX is filled, the VBOX will begin to beep. In order to avoid distraction to the driver, it is important that the VBOX is prevented from logging to the RAM. This step provides a backup to step 5)b)ii) by ensuring that the VBOX will not log data to the internal memory.

- a) Locate **Socket 4** on the VBOX.
- b) Connect **Pin 1** to **Pin 2** using a short wire with the insulation stripped off the ends.
- c) Place a piece of electrical tape over Socket 4, securing the wire in place.

NOTE: Do not cover Socket 3 with electrical tape; Socket 3 must be accessible to make changes in the VBOX setup.

- 7) Cover the **Compact Flash** Card slot with a strip of electrical tape to keep out dust.

NOTE: Do not cover the LEDs; these LEDs can be used to determine the status of the VBOX.

7.1.3. Initial Weather Station Setup

- 1) Connect the serial adapter to the laptop and connect to the weather station service cable.
- 2) Connect the other end of the cable to the weather station (port is under the “Service” flap at the base of the weather station).
- 3) Make the power connections to a 9-V battery.



Figure 7.1.3-1: Weather Station and Service Cable

- 4) Open the **Vaisala Configuration Tool** Software (Start > Vaisala Configuration Tool > Vaisala Configuration Tool)

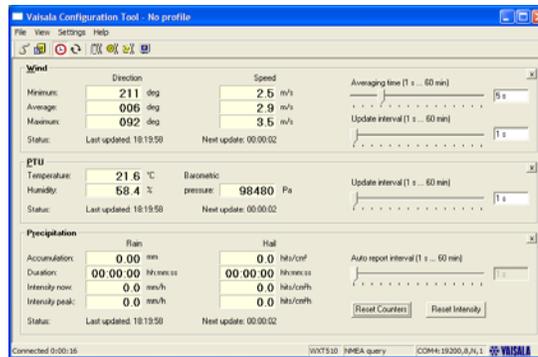


Figure 7.1.3-2: Vaisala Configuration Tool

NOTE: If a message appears regarding the unavailability of a com port, click OK, go to File > Connection Setup and select COM4 (or the appropriate port) in the Connect using field. Click OK.

For reference, the other Connection Setup settings are shown in Figure 7.1.3-3.

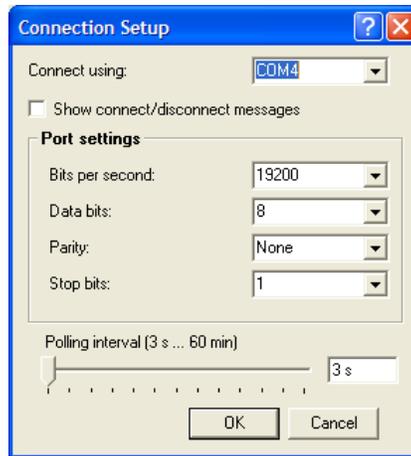


Figure 7.1.3-3: Connection Setup

- 5) Go to **Settings > Device** (or click the icon showing the weather station and a wrench).
- 6) Under Enhancements, check **Enable Heating** and **Error Messaging**.
- 7) Under Communication Protocol, select **NMEA v3.0** and check both **Query only** and **Use XDR for wind message**.

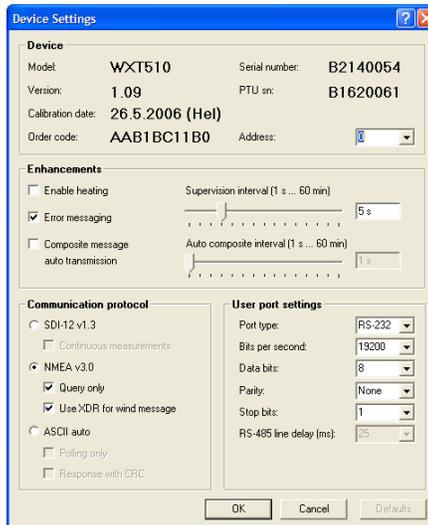


Figure 7.1.3-4: Device Settings

- 8) Click **OK**.
- 9) Go to **Settings > Sensor** (or click the icon showing the weather station and a clock) and make changes as necessary in the following sections.
 - a) Wind
Direction correction: **0**

- Speed unit: **m/s**
 Sampling frequency: **4 Hz**
 Averaging time: **1 s**
 Update interval: **1 s**
- b) PTU
 Temperature unit: **Celsius**
 Barom. pressure unit: **Pascal**
 Update interval: **1 s**
- c) Precipitation
 Rain unit: **Metric**
 Hail unit: **Metric**
 Counter reset: **Manual**
 Auto report based on: **Time**

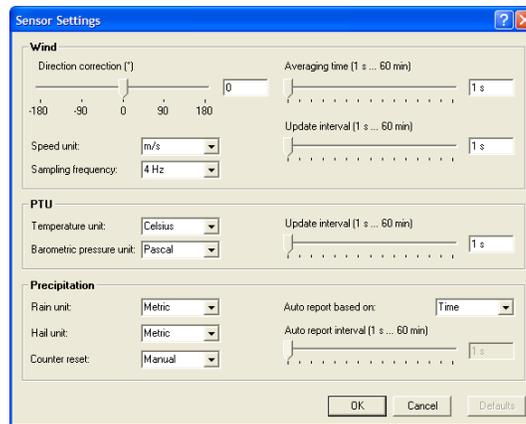


Figure 7.1.3-5: Sensor Settings

NOTE: To set up multiple weather stations, disconnect the battery, disconnect the weather station, connect the next weather station, and reconnect the battery. Within a few seconds, the Configuration Tool program will show readings for this weather station.

- 10) When finished, disconnect the battery from the weather station, close the configuration software, and disconnect the weather station.

NOTE: Be sure the service flap is fully closed after configuring the weather station.

7.2. Preparing the EDAQ to Collect Data

In order to collect the data required for the Project, certain databases must be loaded onto the eDAQ. In addition, the hardware must be configured and the transducer channels must be set up. From the transducer channels, calculated channels can be set up and the list of channels to be monitored by

the eDAQ can be finalized. This section details the procedures to prepare a test setup so the eDAQ may be used to collect data.

7.2.1. Loading EDAQ Databases

NOTE: This procedure requires that the eDAQ be on with all Vehicle Bus Modules connected as a minimum. If at all possible, all sensors should be connected as well. In order to configure the hardware, the appropriate database and/or firmware must be loaded.

- 1) Load all necessary databases onto the computer from the Databases, Setups, and Scripts CD.
 - a) Copy the AirWeigh database to the specified location:
C:\Program Files\SoMat\Tce_eDAQ_3.86d\Vbus_db\J1708\AirWeigh_Alone.txt
 - b) Copy the VBOX database to the specified location:
C:\Program Files\SoMat\Tce_eDAQ_3.86d\Vbus_db\CAN\VBOX_and_Volvo.txt
- 2) Copy the database files to the eDAQ.
 - a) Open the eDAQ web page (<http://192.168.100.100>).
 - b) Click on **Hardware** and select **Vehicle Bus Module (VBM_1)** from the list.
 - c) Add the database for the AirWeigh.
 - i) Click **Edit Parameter Databases** and click **J1708**.
 - ii) Click on **Copy New File to eDAQ**.
 - iii) Click on **Browse** to find and open
C:\Program Files\SoMat\Tce_eDAQ_3.86d\Vbus_db\J1708\AirWeigh_Alone.txt.
 - iv) Move the cursor to the end of the **Destination path on eDAQ** and type **AirWeigh_Alone.txt**.
 - v) Click on **Copy To eDAQ** and click **OK** at the confirmation message.
 - vi) Click the Up arrow to return to the Edit Parameter Database interface.
 - d) Add the database for the VBOX and Volvo.
 - i) From the Edit Parameter database screen (**Hardware > Vehicle Bus Module > Edit Parameter Database**), click on **CAN**.
 - ii) Click on **Copy New File to eDAQ**.

- iii) Click on **Browse** to find and open
C:\Program Files\SoMat\Tce_eDAQ_3.86d\Vbus_db\CAN\V
BOX_and_Volvo.txt.
- iv) Move the cursor to the end of the **Destination path on
eDAQ** and type **VBOX_and_Volvo.txt.**
- v) Click on **Copy To eDAQ** and click **OK** at the confirmation
message.
- e) Enable the custom module for the weather station.
 - i) Click in the eDAQ web page, click on **Custom > Install
new module.**
 - ii) **Browse** and open
C:\Program Files\Somat\TCE_eDAQ_3.86d\eDAQ_Plus\Vai
salaWXT.
 - iii) Click **Install Custom Module.** When informed of
installation, click **OK.**
 - iv) Click **Enable** and then **OK** on the following page.

The hardware may now be queried and configured for the appropriate databases. It is strongly recommended that this be done immediately and a few channels be monitored in order to verify that this step was done correctly (see following procedures)

7.2.2. Hardware Setup and Configuration

This procedure is for a new setup, beginning with all equipment connected to the eDAQ and turned on. While the instructions are specifically for the HTDC project (with an eDAQ IP address of 192.168.100.100), a very similar process is completed for other applications.

- 1) Open TCE (Start > All Programs > SoMat TCE eDAQ V3.8.6d > **TCE eDAQ V3.8.6d**)
- 2) Begin a new setup by clicking **File > New Setup** (or press Ctrl+N)
- 3) In the **Hardware Setup** window (F1), click **Query.**
 - a) After several seconds, a list of the hardware will appear
 - b) Follow the steps below if the following TCE message is displayed: "The RAM Disk card file is not properly defined for card (_____). This is the normal situation whenever the eDAQ card set is changed. Use the FCS Setup menu option [Format FCS RAM Disk] to eliminate this conflict!"

- i) Click **OK**.
- ii) Click **FCS Setup > Format FCS RAM Disk**.
- iii) A TCE Message as follows should appear:
 “Formatting the FCS RAM disk will destroy all test data, test setup, and system files! Are you sure you want to proceed?”
- iv) If all necessary data has been saved already (or if the unit is new and has not been used for any data storage yet), click **Yes**.
- v) After several minutes, a TCE Message will be displayed similar to the following:
 “The eDAQ has been reset. Please wait for the eDAQ to complete the boot cycle and then you can continue TCE interface operations.”
- vi) Click **OK** and wait for the eDAQ to complete its boot cycle. When the yellow light has turned off (the red and green lights may be continuously lit), close all open windows in the TCE software. (It is not necessary to close and reopen TCE.)
- vii) Click **File > New Setup** as before. A message will appear regarding the reset memory of the eDAQ. Click **OK**, and the red light should turn off, leaving only the green light on.
- viii) Select the **Hardware Setup** window and click on **Query**. A list of the hardware associated with the eDAQ will be generated in this window.

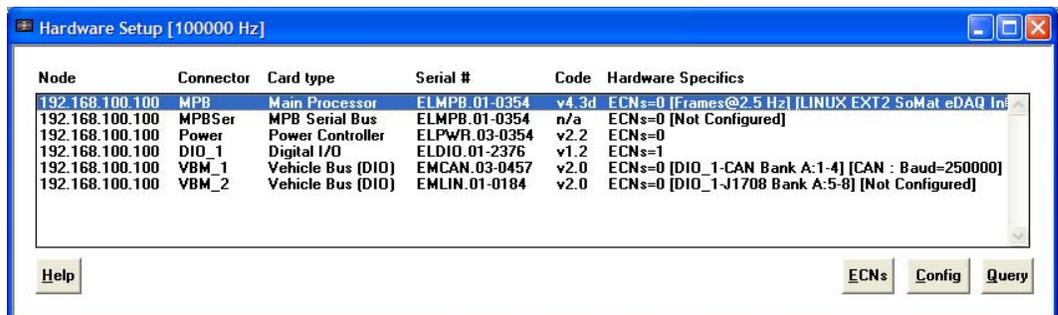


Figure 7.2.2-1: Hardware Setup Window

- 4) The following list of hardware will appear. Select each as indicated below and click **Config**.
 - a) Main Processor (MPB) – no configuration necessary
 - b) MPB Serial Bus (MPBSer) – Select the **VaisalaWXT** database and click **OK**

- c) Power Controller (Power) – no configuration necessary
- d) Digital I/O (DIO_1) – Select **Bank A** and click **OK** in the dialog boxes which follow.

NOTE: A dialog box will indicate that the power supply must be at least 14 Vdc. This is just to prevent the user from attempting to use a 12-Vdc source; 13.8 V is sufficient.

- e) Vehicle Bus (DIO) (VBM_1) – Select the **VBOX_and_Volvo** database. Under Active Querying Master Control options, **uncheck Disable Active Querying**, and set the Max Rate to **10 Hz**. Click the **Hardware Interface Specifics** button and set the baud rate to **250000 (OK)**. Click **OK**.
- f) Vehicle Bus (DIO) (VBM_2) – Select the **AirWeigh_Alone** database. Under Active Querying Master Control options, **uncheck Disable Active Querying**, set the Max Rate to **5 Hz**, and click **OK**.
- g) High Level SS (HLSS_1) – no configuration necessary

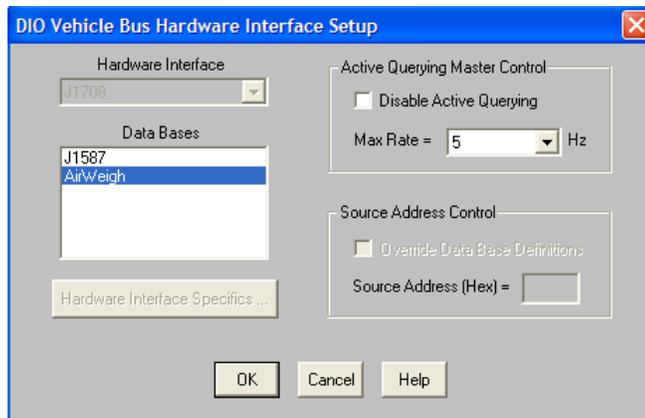


Figure 7.2.2-2: DIO Vehicle Bus Configuration

- 5) When the Hardware Setup window lists all the connections and their configurations, the Hardware Setup is complete; continue to Transducer and Message Channel Setup.

NOTE: The setup may be saved at this point (**File > Save As...**). The file name should be of the form "HTDC0a.tce", where "0" represents the DAS number.

7.2.3. Test ID Setup

NOTE: This procedure begins with a TCE setup file open. While this procedure may be performed at any point during test setup, it is highly recommended that the Test ID be set up immediately following the

Hardware Setup and Configuration. For all channel IDs, the “0” (as in “xxxx_0”) represents the DAS number.

- 1) Select the **Test ID / Network Setup** window and click **Edit ID**.
- 2) In the **Title** field, type the TCE setup file name.
- 3) Fill in the name of the **Operator**.
- 4) The **Date** field will automatically show the current date.

NOTE: Whenever the Edit ID button is clicked, the date field will be updated to the current date. If necessary, this date may be changed by typing in the desired date.

- 5) In the **Comments** field, type in a brief description of the test including the purpose of the test specific hardware/sensors used, and any other notes which may be helpful to future operators.

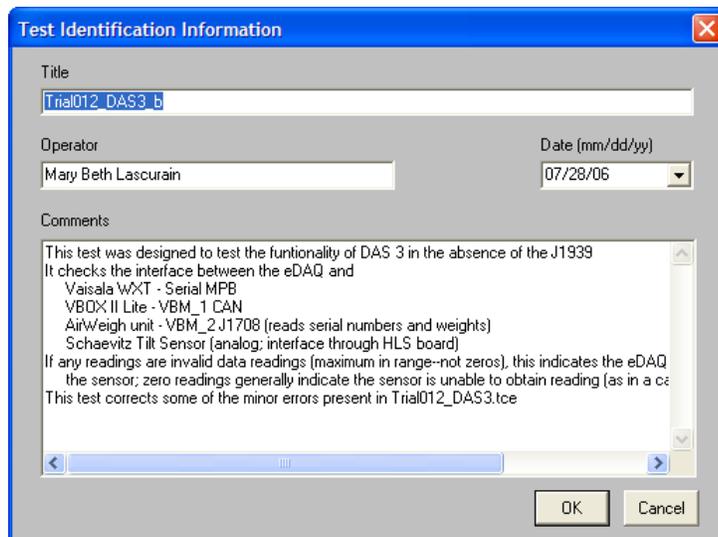


Figure 7.2.3: Editing the Test ID

- 6) When finished, click **OK** and save the test setup file (**Ctrl+S**).

NOTE: Changes to the Test ID may be made at any time during the test setup. When finished with test setup, check/update the Test ID to verify the information it contains is still relevant to the test.

7.2.4. Transducer Channel Setup

Note: This procedure is performed following Hardware Setup and Configuration. While the eDAQ does not need to be connected to the computer for this step, the TCE software should be running and the appropriate setup file (with hardware already set up) should be open (File > Open).

- 1) Select the **Transducer and Message Channel Setup** window (F2).
- 2) Setting up the VBOX and J1939 channels
 - a) Click **Add**.
 - b) Select **Vehicle Bus (DIO)** from the list and click **OK**.
 - c) Select **VBM_1 : CAN : VBOX_and_Volvo** and click **OK**.
 - d) Select the following 41 channel IDs (holding down Ctrl) and click **OK**.

Lateral_acce	Altitude	Latitude
Longitudinal	Heading	Time
DGPS	Velocity	Sats
Vertical_Vel	Longitude	InsFuEcon
IGr	ActEgPctTq	ActGrRatio
DrvDmEgPctTq	EgSp	EgOilTmp
FuTmp	FAxSp	AvFuEcon
FuRate	OutShaftSp	SelectedGr
TotIdHr	TotPTOHr	HResTotVehDt
AccPdlPos	MaxVehSpLm	TotFuUsed
TotIdFuUsed	PctLoadISp	BrkSw
ClSw	CruAccSw	CruActive
CruCoastSw	CruEnSw	CruResSw
CruSetSw	BattVolt	

- e) With the VBOX/J1939 channels selected, click **Edit**.
- f) Select the **Query and Sample Rates** option and click **OK**.
- g) Change the output sample rate to **5 Hz** and click **OK**.
- h) With the following 14 J1939 channels selected, click **Edit**, select the **Query and Sample Rates** option and click **OK**.

InsFuEcon	IGr	ActEgPctTq
EgOilTmp	FAxSp	BrkSw
TotIdHr	TotPTOHr	HResTotVehDt
AccPdlPos	MaxVehSpLm	TotFuUsed
OutShaftSp	BattVolt	

- i) Check the **Enable Active Querying** option and set the rate to **5 Hz**.

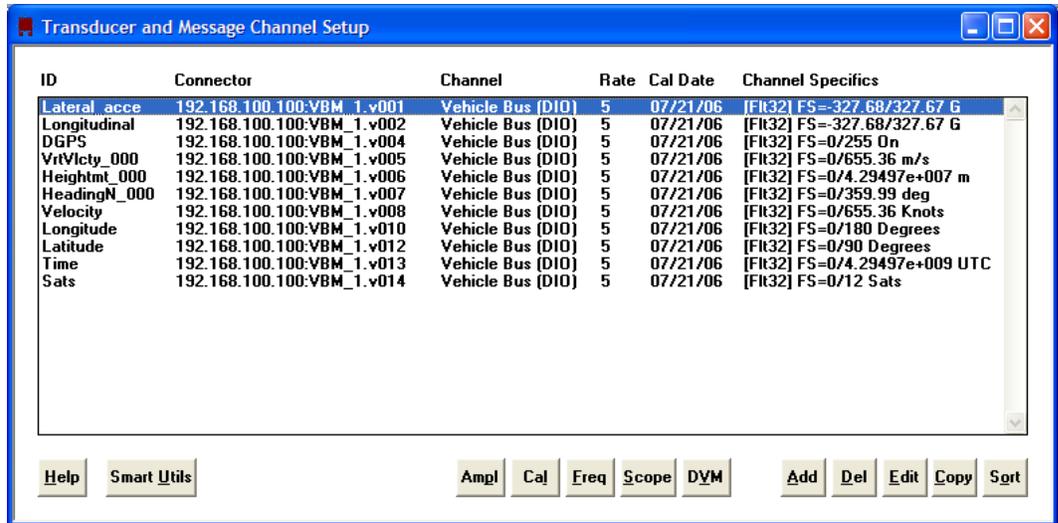


Figure 7.2.4-1: Transducer and Message Channel Setup Window

- 3) Set up the AirWeigh channels
 - a) Select the blank line at the bottom of the transducer channel list and click **Add**.
 - b) Select **Vehicle Bus (DIO)** from the list and click **OK**.
 - c) Select **VBM_1 : J1708 : AirWeigh_Alone** and click **OK**.
 - d) Select the following channel IDs and click **OK**.
 - SterAWID
 - TrlrAWID
 - SterAxWt
 - DrivAxWt
 - TrailrWt
 - e) With the AirWeigh channels selected, click **Edit**.
 - f) Select the **Query and Sample Rates** option and click **OK**.
 - g) Change the output sample rate to **5 Hz** and click **OK**.
 - h) Select just **SterAWID** and **TrlrAWID**, click **Edit**, select the **Query and Sample Rates** option and click **OK**.
 - i) Check the **Enable Active Querying** option and set the rate to **1 Hz**.

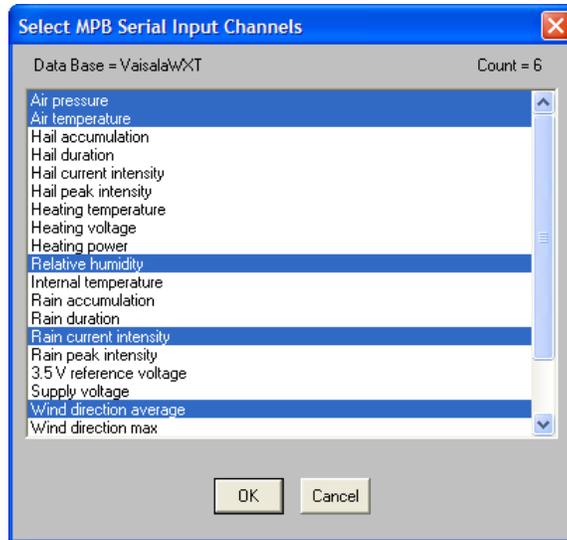


Figure 7.2.4-2: Adding Transducer Channels

- 4) Set up the weather station channels
 - a) Select the blank line at the bottom of the transducer channel list and click **Add**.
 - b) Select **Serial Bus (MPB)** from the list and click **OK**.
 - c) From the list, select the following channels and click **OK**.

Air pressure	Rain current intensity
Air temperature	Wind direction average
Relative humidity	Wind speed average
 - d) With the serial channels selected, click **Edit**.
 - e) Select the **Query and Sample Rates** option and click **OK**.
 - f) Change the output sample rate to **5 Hz** and click **OK**.
- 5) Change the ID and/or units of directly-recorded channels.
 - a) To edit a channel, click on the ID and click **Edit**.
 - b) Make the changes in the ID, units (to standard abbreviations), and invalid data values shown below in the Table 7.2.4 and click **OK**.

Note: Only changes from the default settings are shown below. Make the modifications shown and leave the other fields default.

Table 7.2.4: Changes to Transducer Channel Settings

Interface	Original ID	New ID	Units (U) or Invalid Data Output (IDO)
VBM_1	Vertical_Vel	VrtVlcty_0	U: m/s

Interface	Original ID	New ID	Units (U) or Invalid Data Output (IDO)
	Altitude	Altitude_0	U: m
	Heading	HeadingN_0	U: deg
	Longitude		IDO: 18000
	Latitude		IDO: 9000
	InsFuEcon	InFuEcon_0	
	IGr	CrntGear_0	
	SelectedGr	SelctdGr_0	
	ActEgPctTq	ActEngTq_0	
	ActGrRatio	ActGrRto_0	
	DrvDmEgPctTq	DvDmEgTq_0	
	EgSp	EngSpeed_0	
	EgOilTmp	EgOilTmp_0	U: deg C
	FuTmp	FuelTemp_0	U: deg C
	FAxSp	FAxleSpd_0	
	AvFuEcon	AvFuEcon_0	
	FuRate	FuelRate_0	
	OutShaftSp	OShaftSp_0	
	BrkSw	BrakingS_0	
	ClSw	ClutchSw_0	
	CruAccSw	CCAccelS_0	
	CruActive	CCActive_0	
	CruCoastSw	CCCoastS_0	
	CruEnSw	CCEnable_0	
	CruResSw	CCResume_0	
	CruSetSw	CCSetSwt_0	
	TotIdHr	TotIdleH_0	
	TotPTOHr	TotPTOHr_0	
	HResTotVehDt	TotVDist_0	
	MaxVehSpLm	MaxVSpLm_0	
	TotFuUsed	TotFuUsd_0	
	TotIdFuUsed	TotIdFud_0	
	PctLoadISp	PctLdISp_0	
	AccPdlPos	AcPdlPos_0	IDO: 120%
	BattVolt	BattVolt_0	
VBM_2	SterAWID	TractrID_0	
	TrlrAWID	TrailrID_0	
	SterAxWt	SterAxWt_0	
	DrivAxWt	DrivAxWt_0	
	TrailrWt	TrailrWt_0	
MPBSer	humid_rel	RelHumid_0	U: %
	rain_int	RainInts_0	
	wind_dir_avg	WindDirc_0	U: deg

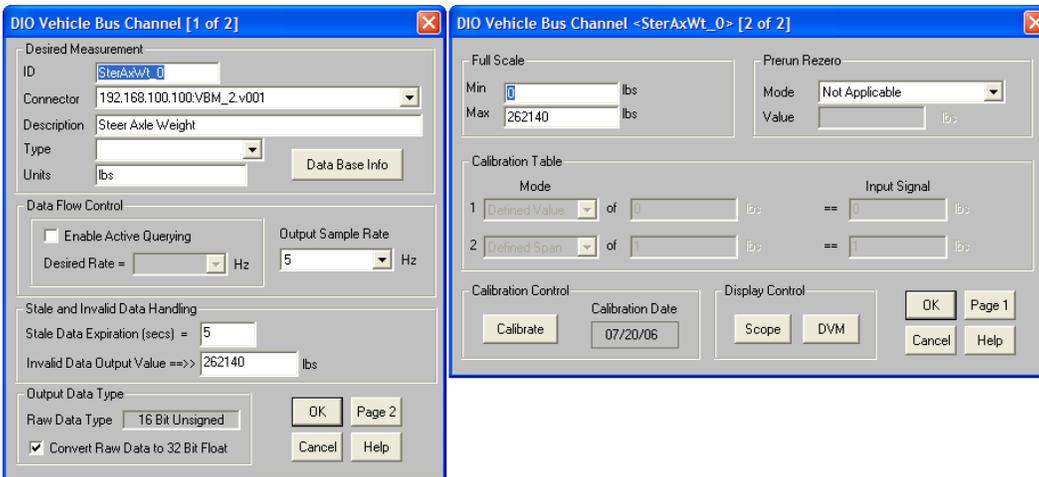


Figure 7.2.4-3: Editing DIO Vehicle Bus Channels

- 6) Verify that transducers channels are working properly
 - a) Select a few channels from each transducer.
 - b) Click the **DVM** button.
 - c) Readings should be typical for the setting; if any readings are invalid data values (the highest possible for the channel), there is a communication error between that sensor and the eDAQ due to either instrument or transducer setup.

NOTE: If the VBOX is unable to get a satellite lock but is connected properly to the DAQ, the VBOX transducer channel readings will be zero (with the exception of the incrementing time channel).

Transducer and Message Channel Setup is complete. Save the setup file by pressing **Ctrl+S** or File > Save As.

7.2.5. Computed Channel Setup

This procedure is written to follow the transducer and message channel setup. While the eDAQ does not need to be connected to the computer for this step, the TCE software should be running and the appropriate setup file (with hardware and transducer channels already set up) should be open (File > Open).

- 1) Select the **Computed Channel Setup** window (F3).
- 2) Add the appropriate types of channels as shown in the following list by selecting a blank line, clicking **Add**, selecting the appropriate channel type, and clicking **OK**.

NOTE: It is recommended that the channels be created in the order

shown within each section to avoid error messages in the initialization sequence.

- a) For Desk Calculator channels, fill in the information as listed (leaving other fields blank or default) and click **OK**.
- b) For State Mapper channels, use the following procedure with the inputs shown in following list.
 - i) To the right of the State Mapper ASCII File field, click **Browse**.
 - ii) Open the **Work** folder (C:\Program Files\Somat\Tce_eDAQ_3.86c\Work)
 - iii) An ASCII file will need to be created as specified (if not created in a previous test)
 - (1) Right click on the file > **Open**
 - (2) Type in the text specified, press **Ctrl+S**, and close the Notepad window.
 - iv) In the Select State Mapper File window, choose the file and click **Open**.
 - v) In the channel setup window, click **Check File** to verify the file format.
- c) For Valid Data Gate, Down Sample, and time Base Shift channels, fill in the fields with the values listed.

NOTE: For all channel IDs, the “0” (as in “xxxx_0”) represents the DAS number.

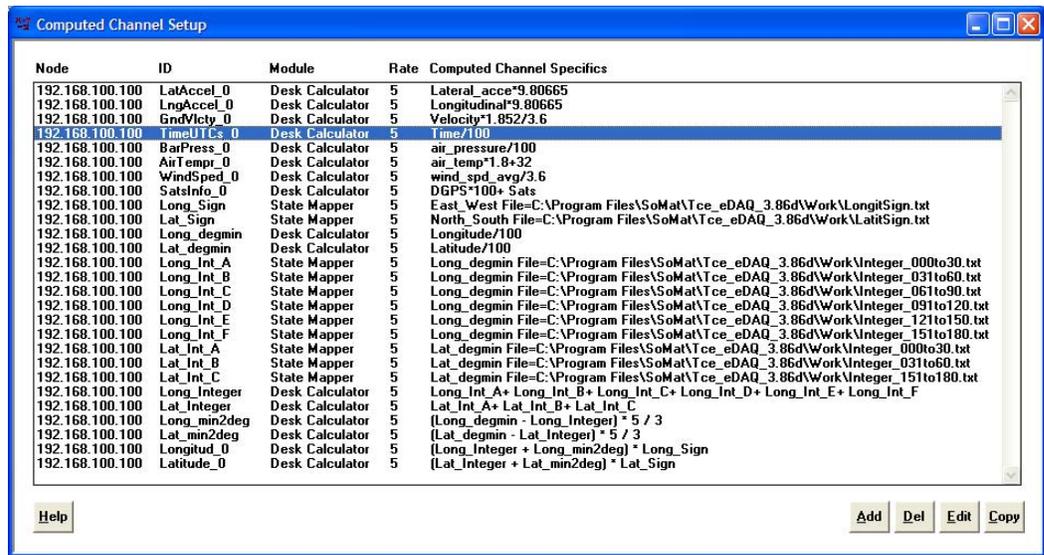


Figure 7.2.5-1: Computed Channel Setup Window

A. Changing Units – Converting transmitted units into desired units

1. Channel Type: Desk Calculator
ID: **LatAccel_0**
Description: Lateral Acceleration in the chosen units (from g to m/s²)
Type: Acceleration
Units: m/s²
Full Scale Estimate - Min: -3214 Max: 3214
Desk Calculator Expression: Lateral_acce * 9.80665
2. Channel Type: Desk Calculator
ID: **LngAccel_0**
Description: Longitudinal Acceleration in the chosen units (from g to m/s²)
Type: Acceleration
Units: m/s²
Full Scale Estimate - Min: -3214 Max: 3214
Desk Calculator Expression: Longitudinal* 9.80665
3. Channel Type: Desk Calculator
ID: **GndVlcty_0**
Description: Ground Velocity in the chosen units (from knots to m/s)
Type: Velocity
Units: m/s
Full Scale Estimate - Min: 0 Max: 338
Desk Calculator Expression: Velocity*1.852/3.6
4. Channel Type: Desk Calculator
ID: **TimeUTCs_0**
Description: Time in s since midnight UTC
Type: Time
Units: s (UTC)
Full Scale Estimate - Min: 0 Max: 86400
Desk Calculator Expression: Time/100
5. Channel Type: Desk Calculator
ID: **BarPress_0**
Description: Air Pressure in chosen units (from Pa to hPa)
Type: Pressure
Units: hPa
Full Scale Estimate - Min: 0 Max: 2000
Desk Calculator Expression: air_pressure / 100
6. Channel Type: Desk Calculator

ID: **AirTempr_0**
 Description: Air Temperature in chosen units (from deg C to deg F)
 Type: Temperature
 Units: deg F
 Full Scale Estimate - Min: -148 Max: 212
 Desk Calculator Expression: $\text{air_temp} * 1.8 + 32$

7. Channel Type: Desk Calculator
 ID: **WindSped_0**
 Description: Wind speed in chosen units (from km/h to m/s)
 Type: Velocity
 Units: m/s
 Full Scale Estimate - Min: 0 Max: 278
 Desk Calculator Expression: $\text{wind_spd_avg} / 3.6$

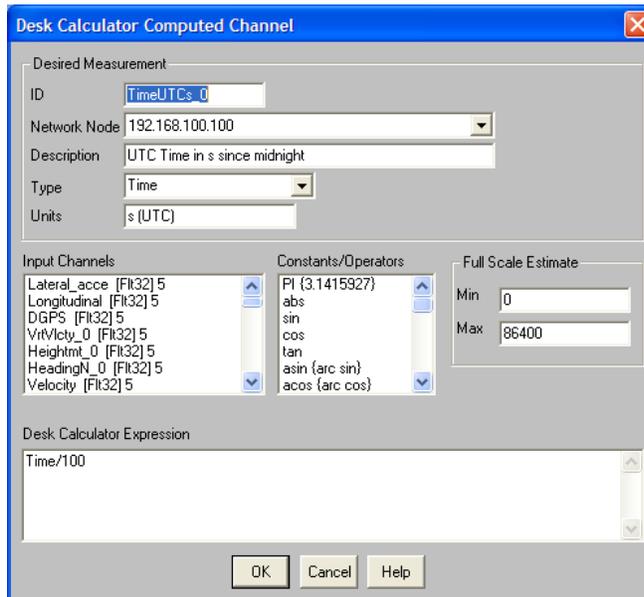


Figure 7.2.5-2: Desk Calculator Setup Window

B. Satellites – Assembles satellite data into one value

NOTE: This channel adds 100 to the number of satellites when DGPS is available

Channel Type: Desk Calculator
 ID: **SatsInfo_0**
 Description: Satellite count (plus 100 when DGPS available)
 Type: [none]
 Units: [none]
 Full Scale Estimate - Min: 0 Max: 120
 Desk Calculator Expression: $\text{DGPS} * 100 + \text{Sats}$

C. Coordinates – Assign correct sign to latitude and longitude and convert degrees and minutes to degrees.

1. Channel Type: Desk Calculator
ID: **Long_degmin**
Description: Longitude in degrees and minutes (unsigned)
Type: Coordinate [type in]
Units: deg.min
Full Scale Estimate - Min: 0 Max: 180
Desk Calculator Expression: Longitude / 100

2. Channel Type: Desk Calculator
ID: **Lat_degmin**
Description: Latitude in degrees and minutes (unsigned)
Type: Coordinate [type in]
Units: deg.min
Full Scale Estimate - Min: 0 Max: 90
Desk Calculator Expression: Latitude / 100

3. Channel Type: Desk Calculator
ID: **Lat_Integer**
Description: Integer value for the Latitude
Full Scale Estimate - Min: 0 Max: 90
Desk Calculator Expression: floor(Lat_degmin)

4. Channel Type: Desk Calculator
ID: **Long_Integer**
Description: Integer value for the Longitude
Full Scale Estimate - Min: 0 Max: 180
Desk Calculator Expression: floor(Long_degmin)

5. Channel Type: Desk Calculator
ID: **Long_min2deg**
Description: Extracts minute portion of Longitude and converts to deg
Full Scale Estimate - Min: 0 Max: 1
Desk Calculator Expression: (Long_degmin – Long_Integer) * 5 / 3

6. Channel Type: Desk Calculator
ID: **Lat_min2deg**
Description: Extracts minute portion of Latitude and converts to deg
Full Scale Estimate - Min: 0 Max: 1
Desk Calculator Expression: (Lat_degmin – Lat_Integer) *

7. Channel Type: Desk Calculator
ID: **Longitud_0**
Description: Longitude with correct sign and units
Type: Coordinate [type in]
Units: deg
Full Scale Estimate - Min: -180 Max: 180
Desk Calculator Expression: (Long_Integer + Long_min2deg) * (-1)

8. Channel Type: Desk Calculator
ID: **Latitude_0**
Description: Latitude with correct sign and units
Type: Coordinate [type in]
Units: deg
Full Scale Estimate - Min: -90 Max: 90
Desk Calculator Expression: (Lat_Integer + Lat_min2deg)

D. Tire Code Lookup and Information Flag – Relate the tire type to the AirWeigh ID.

1. Channel Type: State Mapper
ID: **Tractor_Tire**
Description: Checks the tractor tire type based on AirWeigh ID
Type: [none]
Units: [none]
Input channel ID with Sample Rate: TractrID_0 [Flt32] 5
Full Scale Estimate - Min: 0 Max: 90
State Mapper ASCII File: TireType.txt
Uncheck Use Default output Value
Default Out (Initial): 90
Latch Period (secs): 0

2. Channel Type: State Mapper
ID: **Trailer_Tire**
Description: Checks the trailer tire type based on AirWeigh ID
Type: [none]
Units: [none]
Input channel ID with Sample Rate: TrailrID_0 [Flt32] 5
Full Scale Estimate - Min: 0 Max: 9
State Mapper ASCII File: TireType.txt
Check Use Default output Value
Default Out (Always): 9 (non-instrumented trailer code is default)
Latch Period (secs): 3 (3 s of same value to

switch)

Table 7.2.5: Contents of TireType.txt

42956	42956.6	20
43173	43173.6	10
43174	43174.6	30
43175	43175.6	10
43176	43176.6	20
43177	43177.6	10
49272	49272.5	1
49890	49890.5	2
49891	49891.5	1
49892	49892.5	3
49893	49893.5	1
49894	49894.5	3
49895	49895.5	1
49896	49896.5	3
49897	49897.5	1
49898	49898.5	2

NOTES

- TireType.txt must be checked regularly and updated as needed to reflect the proper tire code associated with the Air-Weigh unit (by ID). The following code should be used:

- 10 Tractor, Michelin Singles
- 20 Tractor, Michelin Duals
- 30 Tractor, Generic Duals
- 1 Trailer, Michelin Singles
- 2 Trailer, Michelin Duals
- 3 Instrumented Trailer, Generic Duals

- Because there are two possible methods of identification for each trailer (depending on how the vehicle data bus is interfaced) two entries should be made to TireType.txt for each trailer in order to have a complete reference file.

- A value of 90 for Tractor_Tire indicates that the tractor Air-Weigh was unavailable or that a non-instrumented tractor is being used. A value of 9 for Trailer_Tire indicates that a non-instrumented trailer is being used (or that the trailer Air-Weigh is not functioning).

E. Marriage Status – Determine whether instrumented trailer is connected by verifying valid weight data from Air-Weigh and set up a trigger to identify trailer 5 minutes into each run

1. Channel Type: Valid Data Gate
ID: **TractrAWokay**

Description: Tractor Air-Weigh functioning
 Type: Logical
 Units: [none]
 Input Channel: SterAxWt_0 [Flt52] 5
 DrivAxWt_0 [Flt52] 5

NOTE: The value given indicates one of the following conditions:

- 0 Tractor Air-Weigh unit is not functioning properly (giving invalid data)
- 1 Tractor Air-Weigh unit appears to be functioning properly

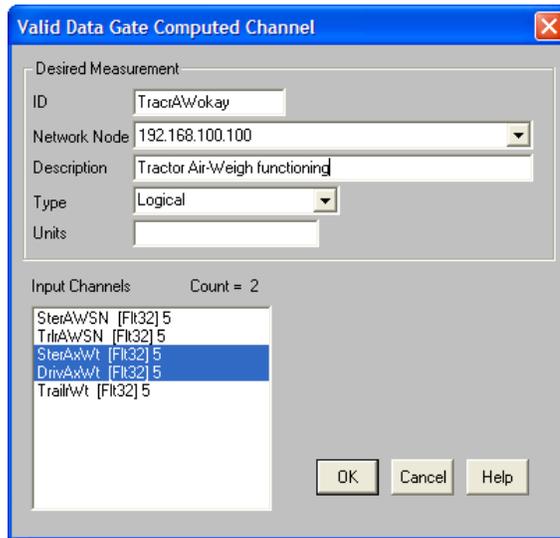


Figure 7.2.5-3: Valid Data Gate Setup Window

2. Channel Type: Valid Data Gate

ID: **Marriage_0**
 Description: Instrumented trailer connected
 Type: Logical
 Units: [none]
 Input Channel: TrailrWt_0 [Flt52] 5

NOTE: The value given indicates one of the following conditions

- 0 Not married with instrumented trailer (invalid trailer weight)
- 1 Married with instrumented trailer

3. Channel Type:

Timed Trigger

ID: **MarriageTrig**
 Description: Trigger for Marriage data mode
 Type: Logical
 Units: [none]
 Input Channel ID: TractrAWokay [Uns8] 5

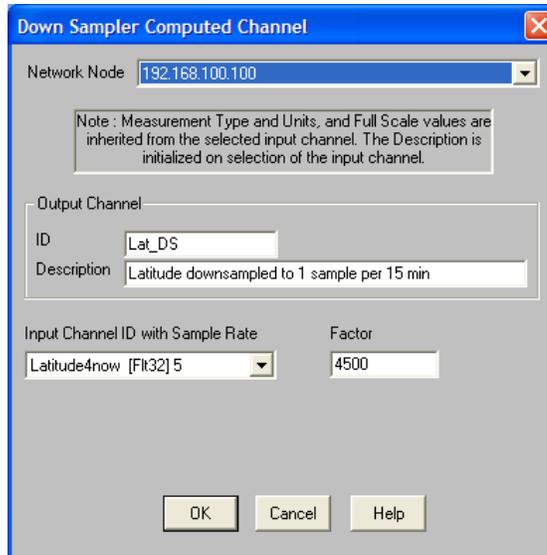


Figure 7.2.5-5: Down Sampler Setup Window

2. Channel Type: Down Sampler
 ID: **Longt_DS_0**
 Description: Longitude downsampled to 1 sample per 15 min
 Input Channel: Longitud_0
 Factor: 4500

3. Channel Type: Time Base Shifter
 ID: **Lat_DS_lead**
 Description: Downsampled latitude shifted 8 samples (2 hrs)
 Input channel: Latit_DS_0
 Shift Direct.: Lead
 Shift Count: 8

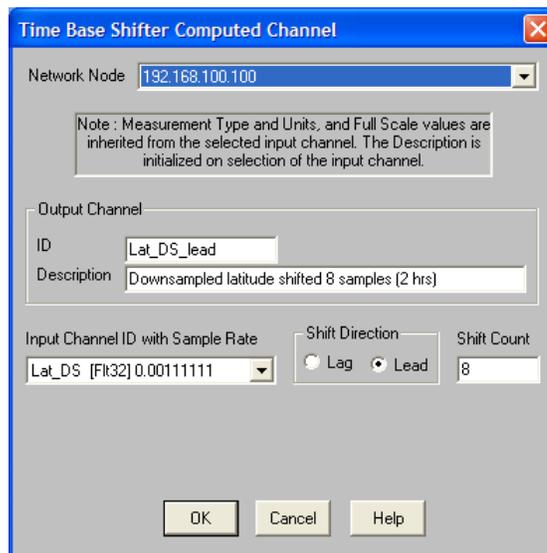


Figure 7.2.5-6: Time Base Shifter Setup Window

4. Channel Type: Time Base Shifter
ID: **Long_DS_lead**
Description: Downsampled longitude shifted 8 samples (2 hrs)
Input channel: Longt_DS_0
Shift Direct.: Lead
Shift Count: 8

5. Channel Type: Desk Calculator
ID: **Lat_Differ**
Description: Latitude difference over 2 hours
Type: [none]
Units: deg
Full Scale Estimate - Min: 0 Max: 90
Desk Calculator Expression: $\text{abs}(\text{Latit_DS_0} - \text{Lat_DS_lead})$

6. Channel Type: Desk Calculator
ID: **Long_Differ**
Description: Longitude difference over 2 hours
Type: [none]
Units: deg
Full Scale Estimate - Min: 0 Max: 180
Desk Calculator Expression: $\text{abs}(\text{Longt_DS_0} - \text{Long_DS_lead})$

7. Channel Type: Desk Calculator
ID: **Station_Ext**
Description: Stationary for extended time period (2 hrs)
Type: Logical
Units: [none]
Full Scale Estimate - Min: 0 Max: 1
Desk Calculator Expression: $(\text{Lat_Differ} \leq 0.002) \ \&\& \ (\text{Long_Differ} \leq 0.002)$

G. Road Grade

This channel calculates the approximate road grade based on the vertical and ground velocities for ground velocities greater than or equal to 4.44 m/s.

Channel Type: Desk Calculator
ID: **RoadGrad_0**
Description: Slope of Road from horizontal from VBOX velocities

Type: Angle
 Units: deg
 Full Scale Estimate - Min: -45 Max: 45
 Desk Calculator Expression: $\text{float}(\text{GndVlcty}_0 \geq 4.44) * \text{asin}(\text{VrtVlcty}_0/\text{GndVlcty}_0) * 180/\text{PI} + \text{float}(\text{GndVlcty}_0 < 4.44) * 45$

H. Placeholders – To avoid difficulties with data analysis software, the total number of output channels will be kept at a constant 60, without any change in channel names throughout the field test. If new channels need to be added, their data may be output under a Placeholder channel name. All fields may be changed except for the Channel ID field.

1. Channel Type: Desk Calculator
 ID: **PicehdrB_0**
 Description: Unused channel B. Delete this if adding a new channel.
 Type:
 Units:
 Full Scale Estimate - Min: 0 Max: 0
 Desk Calculator Expression: $0 * \text{EngSpeed}_0$
2. Channel Type: Desk Calculator
 ID: **PicehdrC_0**
 Description: Unused channel C. Delete this if adding a new channel.
 Type:
 Units:
 Full Scale Estimate - Min: 0 Max: 0
 Desk Calculator Expression: $0 * \text{EngSpeed}_0$
3. Channel Type: Desk Calculator
 ID: **PicehdrD_0**
 Description: Unused channel D. Delete this if adding a new channel.
 Type:
 Units:
 Full Scale Estimate - Min: 0 Max: 0
 Desk Calculator Expression: $0 * \text{EngSpeed}_0$
4. Channel Type: Desk Calculator
 ID: **PicehdrE_0**
 Description: Unused channel E. Delete this if adding a new channel.
 Type:

Units:
 Full Scale Estimate - Min: 0 Max: 0
 Desk Calculator Expression: 0*EngSpeed_0

7.2.6. Data Mode Setup

This procedure is to be used after all hardware, transducer channels, and computed channels have been set up (see previous procedures). This is the final step in making a setup file.

- 1) Set up the Time History Data Mode (for generic data collection).
 - a) In the **Data Mode Setup** window (F4), click **Add**.
 - b) Select **Time History** and click **OK**.
 - c) Select the following 57 input channels. (These are the standard 5-Hz signals which will be recorded; their channel names all end in “_0,” where “0” represents the DAS number.)

VrtVlcty_0	SatsInfo_0	EgOilTmp_0
Altitude_0	Longitud_0	FuelTemp_0
HeadingN_0	Latitude_0	FAxleSpd_0
GndVlcty_0	TireFlag_0	AvFuEcon_0
RelHumid_0	TimeUTCs_0	FuelRate_0
RainInts_0	BarPress_0	OShaftSp_0
WindDirC_0	AirTempR_0	SelctdGr_0
TractrID_0	WindSped_0	TotIdleH_0
TrailrID_0	InFuEcon_0	TotPTOHr_0
SterAxWt_0	CrntGear_0	TotVDist_0
DrivAxWt_0	ActEngTq_0	MaxVSpLm_0
TrailrWt_0	ActGrRto_0	TotFuUsd_0
LatAccel_0	DvDmEgTq_0	TotIdFUd_0
LngAccel_0	EngSpeed_0	BattVolt_0
PlcehdrB_0	PlcehdrC_0	PlcehdrD_0
RoadGrad_0	PctLdISp_0	AcPdlPos_0
BrakingS_0	ClutchSw_0	CCAccelS_0
CCActive_0	CCCoastS_0	CCEnable_0
CCResume_0	CCSetWt_0	PlcehdrE_0

- d) In the Data Mode ID, type in **BasicData**.
- e) Set the Triggering Option to **Always On**
- f) Set the Floats --> Data Type field to **Flt 32 --> Flt 32**.
- g) Verify that the Time Input Channel is **(None)** and the Data Storage/File System is set to **PC Card**.
- h) When finished, click **OK**.

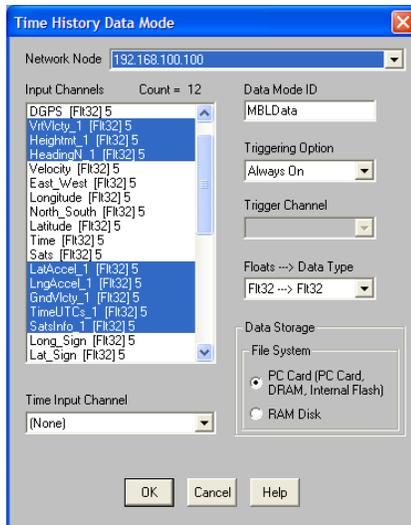


Figure 7.2.6-1: Time History Data Mode Setup

- 2) Set up a Burst History Data Mode to track tractor/trailer marriage.
 - a) Click **Add** and select **Burst History**.
 - b) Select **Marriage_0** as the input channel.
 - c) In the Data Mode ID field, type **Married**.
 - d) Set the Triggering Option to **On False-True Edge**.
 - e) Select **MarriageTrig** as the Trigger Channel.
 - f) Adjust the following settings as necessary.
 - Number of Bursts: **1**
 - Pre Trigger Time: **0**
 - Post Trigger Time: **0**
 - g) Set **PC Card** as the Data Storage option and check **DRAM Buffering**.

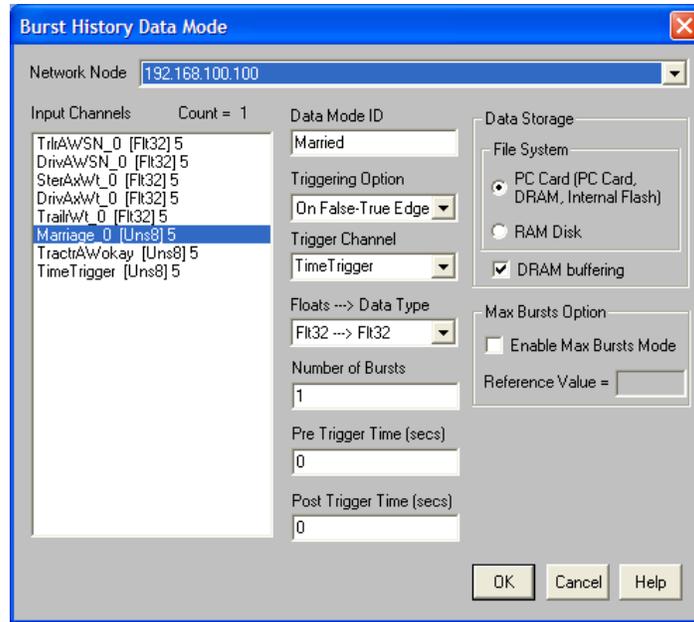


Figure 7.2.6-2: Burst History Data Mode Setup

- 3) Set up a second Burst History Data Mode to flag a stationary truck.
 - a) Click **Add** and select **Burst History**.
 - b) Select the following input channels:

Latit_DS_0	Longt_DS_0
-------------------	-------------------
 - c) In the Data Mode ID field, type **Stationary**.
 - d) Set the Triggering Option to **On False-True Edge**.
 - e) Select **Station_Ext** as the Trigger Channel.
 - f) Adjust the following settings as necessary.

Number of Bursts:	20
Pre Trigger Time:	0
Post Trigger Time:	0
 - g) Set **PC Card** as the Data Storage option and check **DRAM Buffering**.

The setup file is now complete; save changes to this file (**Ctrl+S**) and make a backup copy immediately.

NOTE: All channels included in individual data modes must have the same sampling rate. For different rates and/or trigger events, different types of data modes will be required. For more information about these types, use the Help menu in the individual data mode setup screens (Add > [Selected Data Mode] > OK, Help).

8. OPERATIONAL PROCEDURES

8.1. Generic EDAQ Procedures

This section provides general information on how to run a test and upload data.

8.1.1. Running Tests

NOTE: These procedures make use of completed test setups (.tce files). Refer to the previous sections for instructions on setting up these files. This procedure begins with all power and sensor connections made. The computer should be on and connected to the eDAQ with TCE V3.86d running.

Initializing a test

- 1) Open a completed setup file.
 - a) Press **Ctrl+O** (or go to File > Open)
 - b) Choose the appropriate setup file and click **Open**.
 - c) Activate the Test ID / Network Setup window and read/update the Test ID as necessary.
- 2) Press **Ctrl+2** to initialize the test. The eDAQ's yellow LED will begin blinking slowly.
- 3) The first run may be started at this point, or the eDAQ may be turned off.

Viewing Live Data – anytime after starting a run

- 1) Press **Ctrl+0** to open the Test Control Panel
- 2) Click **RT Display**.
 - a) Click **Setup**.
 - b) Select up to 16 transducer channels (at a time).
 - c) Choose **Digital Readout** as the Display Mode (usually recommended).
 - d) Click **OK**.
- 3) When finished, click **Quit** or close the window.

Starting a run

Press **Ctrl+3** (or click Run in the Test Control Panel).

Note: Each Test is composed of one or more Runs.

Ending a run

Press **Ctrl+6** (or click Stop in the Test Control Panel).

NOTE: A new run may also be started by power cycling the eDAQ. The eDAQ will end the current run when it is turned off and immediately begin a new run when it is turned on again.

Ending a test

Press **Ctrl+E** (or click End in the Test Control Panel).

NOTE: See the Uploading Data section for more information on ending a test.

8.1.2. Uploading Data

Note: Data may be uploaded with or without ending a test. However, the current run must be ended before data is uploaded, as described in the procedures which follow.

After Ending a Test

- 1) Verify that the eDAQ is ON (Green light on).
- 2) Turn on the computer (if it is not on already) and connect the computer to the eDAQ.
- 3) Open **TCE** (Start > All Programs > SoMat TCE eDAQ V3.8.6d > SoMat TCE eDAQ V3.8.6d)
- 4) Press **Ctrl+6** to end the run.
- 5) Press **Ctrl+E** to end the test.
- 6) Press **Ctrl+7** to upload the data, saving in the desired location.
- 7) Repeat step 6, uploading a backup copy directly from the eDAQ in another location.
- 8) At this time, another test may be initialized (see procedure). When finished, close TCE, remove the Ethernet cable from the computer, and turn off the computer.

Without Ending the Test

NOTE: This option allows data from all the runs up to the present to be uploaded from the eDAQ without ending the test. This option is useful to verify that the sensors are functioning properly without interrupting a

test of the memory card capacity. The runs uploaded are not removed from the memory card, and will therefore appear on subsequent data upload screens until the memory card is purged.

- 1) Verify that the eDAQ is ON (Green light on, yellow light flashing rapidly).
- 2) Turn on the computer (if it is not on already) and connect the computer to the eDAQ.
- 3) Open **TCE** (Start > All Programs > SoMat TCE eDAQ V3.8.6d > SoMat TCE eDAQ V3.8.6d)
- 4) Press **Ctrl+6** to end the run
- 5) Press **Ctrl+7** to upload the data, saving in the desired location.

NOTE: Make note of the last run number appearing in the list. This run and the run immediately following should be treated similar to the first and last runs of the test in the data analysis.

- 6) Press **Ctrl+3** to resume the test by starting the next run. The yellow light will resume rapid flashing.
- 7) When finished, close TCE, remove the Ethernet cable from the computer, and turn off the computer.

8.2. Procedures for Heavy Truck Duty Cycle Project

The following set of procedures expands those presented in the Generic EDAQ Procedures section (Section 8.1) for application in the Heavy Truck Duty Cycle Project.

8.2.1. HTDC Routine Data Upload

NOTE: This procedure is specifically designed for periodic data collection during the HTDC field operational test. This procedure is primarily for reference purposes; the checklist **DataUpload.xls** (Figure 8.2.1) should be used when uploading data. This checklist appears in **Appendix D: Checklists and Forms**.

This procedure begins with the ignition turned ON and the computer turned ON.

- 1) Verify that the eDAQ is ON (Green LED on, yellow light blinking).
NOTE: if the eDAQ does not turn on, follow the procedure in Section 9.1.2 to recover the SIC files.
- 2) Connect the computer to the eDAQ.
- 3) Open TCE (Start > All Programs > SoMat TCE V3.8.6d > **SoMat TCE eDAQ V3.8.6d**)
- 4) Monitor the channels to identify potential problems (**Ctrl+0 > RT Display**).
- 5) Press **Ctrl+6** to end the run.
- 6) Press **Ctrl+E** to end the test.
- 7) Press **Ctrl+7** to upload the data, saving in the file path shown:
C:\Documents and Settings\gcp\Desktop\yyyyymmdd\HTDC_0_yyyymmdd where
 - a) 0 = DAS #
 - b) yyyy = year
 - c) mm = month
 - d) dd = day
- 8) While the data is being uploaded, check the physical condition of the sensors.
- 9) When the data upload is completed, press Ctrl+7 again and save to F:\yyyyymmdd\HTDC_0_yyyymmdd
- 10) In TCE, select FCS Setup > Set FCS Clock.

- d) Turn on the ignition.
 - e) Turn on the eDAQ (power switch).
 - 12) In TCE, Press **Ctrl+O** to open the appropriate setup file, based on the truck number.
 - 13) Press **Ctrl+2** to initialize the test. Several checks of the setup file and hardware configuration will automatically be run. (The yellow LED will begin blinking slowly.)
 - 14) Press **Ctrl+3** to start a new run. (The yellow light will begin blinking more rapidly.)
 - 15) Close the TCE software.
 - 16) Unplug the cable from the computer and return to the DAS box.
- The ignition may be turned off at this time. The computer may be turned off as well.

8.2.2. HTDC Data Storage

This procedure is to be completed immediately after data is uploaded from the DAS (Routine Data Upload procedure). Two copies have been saved: one on the laptop and one on the orange portable USB drive. This procedure is specifically designed for periodic storage of data collected during the HTDC field operational test.

- 1) Upload the sif files (folder yyyyymmdd, where yyyy=year, mm=month, and dd=day of the latest data upload) from the laptop (C:\Documents and Settings\gcp\Desktop\yyyyymmdd) to the 250MB drive in L118 (F:\yyyyymmdd).
- 2) Copy the sif files from the orange portable drive (G:\yyyyymmdd) to the remote computer at ORNL. (\\Cappsgj-htdc\HTDC SIF A\yyyyymmdd)
- 3) Delete the yyyyymmdd folder from the laptop and from the orange portable USB drive when finished working with them.
- 4) Type the notes from the weekend into Upload Notes.xls on the ORNL computer (\\Cappsgj-htdc\HTDC SIF A\Upload Notes.xls). Make a backup copy on the laptop.
- 5) Sync the laptop clock with the UTC time zone from <http://www.time.gov>. It should be five hours ahead of Eastern Standard Time, or four hours ahead of Eastern Daylight Time (before Oct. 29, 2006 or after March 11, 2007).
- 6) At this point, there should be two copies of each sif file:
 - 250MB drive in L118

- remote computer at ORNL

The data may now be deleted from the orange portable drive and the laptop.

- 7) Download the yyyyymmdd folder to the data analysis computer from the ORNL computer.
- 8) Translate the sif files into ASCII and store them on the data analysis computer.

At this time the data is pre-processed and separated into files that cover just a day worth of data for each truck. General statistics (min, max, averages, standard deviations and other statistics) where appropriate are also generated. A summary of errors (i.e. sensor failures, out-of range values) as well as valid data is also generated.

- 8) Make a backup copy of the ASCII files on a local 250MB drive.
- 9) When an Excel file of route, weight, and fuel information is received by email, store it in the data analysis computer, and back it up in the ORNL computer. (\\Cappsgj-htdc\HTDC SIF A\yyyyymmdd)

9. APPENDICES

This section provides additional procedures, explanations, notes, and checklists.

9.1. Appendix A: Additional Procedures

9.1.1. Changing IP Addresses

Changing the Computer's IP Address

NOTE: In order for a communication link to exist, the last number of the computer's IP is to be different from the last number of the eDAQ's IP. For example, if the eDAQ's IP is 192.168.100.100, then set the computer's IP to something close to 192.168.100.90 (a difference of 10 is usually good).

- 1) Go to **Start > My Computer > My Network Places > View network connections.**
- 2) Right click on **Local Area Connection** and select **Properties.**
- 3) Under the **General** tab, scroll down and select **Internet Protocol (TCP/IP).** Click on **Properties.**

- 4) Change the IP address field to the desired IP (see note above). Generally, the Subnet mask should remain **255.255.255.0** (the same for the eDAQ), and the other fields should be blank.
- 5) Click **OK, OK**. Minimize (or close) Network Connections.

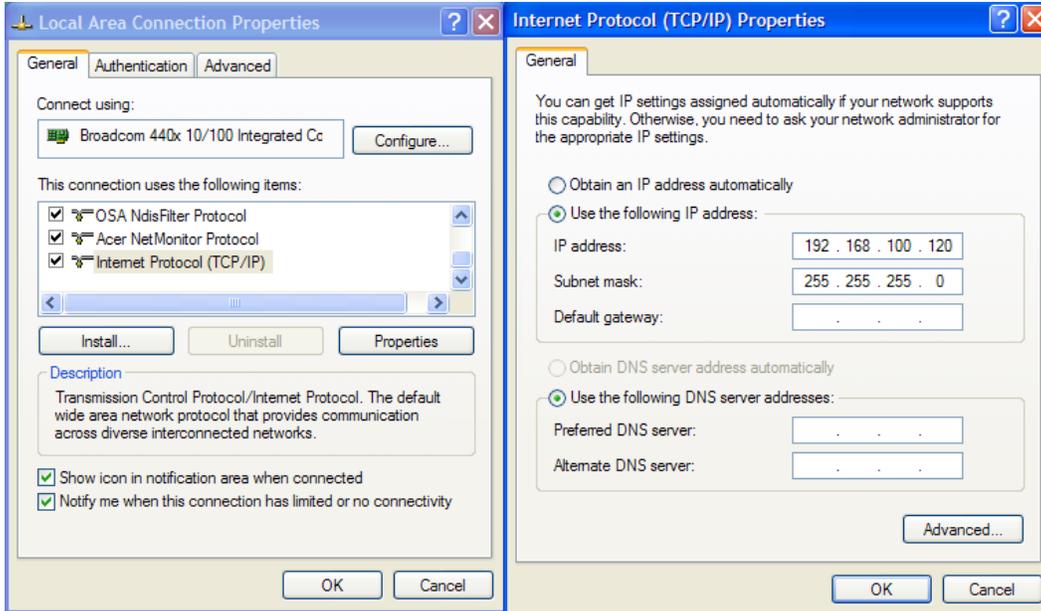


Figure 9.1.1-1: Changing the Computer's IP Address

Changing the eDAQ's IP address

NOTE: This procedure is to be performed with the eDAQ on and connected to the support computer. After changing the IP address of the eDAQ, the computer's IP address may need to be changed in order to reestablish communication. For example, after the eDAQ's IP is changed to 192.168.0.50, change the computer's IP to a value close to 192.168.0.60 using the previous procedure.

- 1) Establish communication with the eDAQ.
 - a) Open **Microsoft Internet Explorer**.
 - b) In the address field, type the current IP address of the eDAQ (in the format `http://192.168.100.100`) and press Enter or click **Go**.
NOTE: if the factory-set IP of the eDAQ differs from what is given here, substitute that IP.
 - c) After a few moments, the eDAQ page should come up.

NOTE: If the page does not appear, verify the IP address of the eDAQ (on a yellow card on the eDAQ). Also verify that the first three numbers of the computer's IP are exactly the same as the first three numbers of the eDAQ's IP. (In some cases, it may be

necessary to restart the computer after changing the IP address.)

- 2) Change the IP address of the eDAQ.
 - a) Click **System > Network Setup**.
 - b) Type in the new IP number in this field. Leave other fields the same.

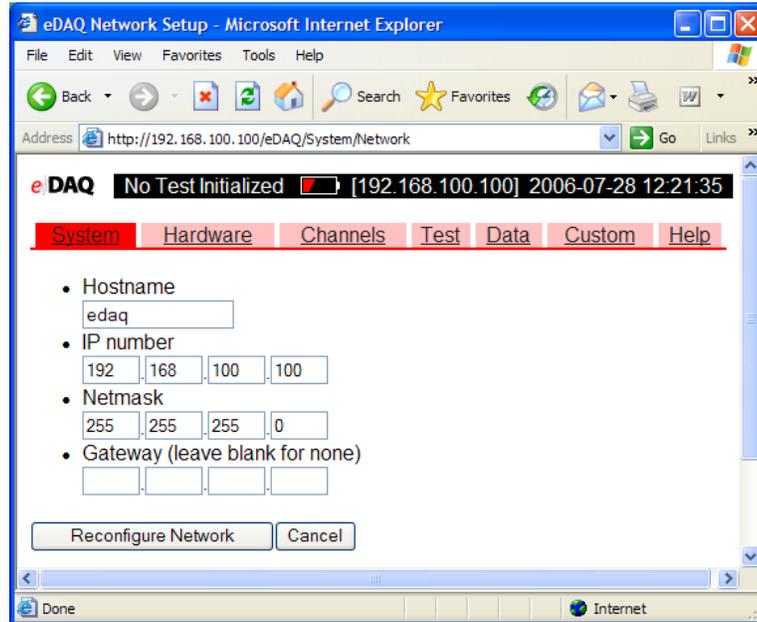


Figure 9.1.1-2: Changing the EDAQ's IP

- c) Remove the yellow card from the slip cover in the eDAQ and record the new information on the reverse side of the card (if the eDAQ is being changed from factory settings). Date and initial the new information to avoid future confusion.
 - d) Verify that the IP address matches that on the yellow card, and return the card to the slip cover on the eDAQ.
 - e) Click **OK** and close Internet Explorer.
 - 3) Reboot the eDAQ.
 - a) The green light should still be lit on the front of the eDAQ.
 - b) Press the power button on the front of the eDAQ and the eDAQ should turn off.
 - c) After a few seconds, press the power button again and the eDAQ will go through its power-up cycle.
 - 4) Change the computer's IP address so that it can communicate with the eDAQ. (Refer to the previous procedure for help.)

- 5) Check to see that the computer can communicate with the eDAQ by opening Microsoft Internet Explorer and typing in the new IP address of the eDAQ as before.

NOTE: It is highly recommended that the Favorites folder be updated to reflect the current address of the eDAQ.

9.1.2. Shutdown Procedure

NOTE: This procedure begins with all equipment on and all connections made.

- 1) Verify that the yellow indicator light on the LED is off (or blinking, if in the middle of a test or run).
- 2) Close the TCE software. (This step is not required.)
- 3) Press the **power button** on the front of the eDAQ and wait for the eDAQ to complete its shut-down cycle. When all LEDs have turned off, proceed to the next step.
- 4) Turn off the **power supply**.
- 5) All connections may be unplugged at this time.



Figure 9.2.1: Power Button on Front of eDAQ Lite

NOTE: The eDAQ may be turned off by cycling power. However, if this is done repeatedly without giving the battery sufficient time to recharge, the eDAQ may become inoperable without recharging and re-initialization. In case of this situation, refer to Section 9.1.3: SIC File Recovery.

9.1.3. SIC File Recovery Procedure

NOTE: This procedure is to be used when the eDAQ fails to start up due to a power failure with insufficiently charged backup battery.

- 1) Re-establish communication with the eDAQ
 - a) Verify that the power is supplied to the eDAQ
 - b) Turn off the power switch on the front of the eDAQ.
 - c) Allow the eDAQ to sit for a few minutes connected to the power supply.
 - d) Turn on the power switch on the front of the eDAQ.
 - e) Open the eDAQ web page.
- 2) Create a folder on the desktop to upload the recovered files to (e.g., SicRecover)
- 3) Upload SIC files
 - a) In the eDAQ web page, click **System**.
 - b) Under System Maintenance, click **Explore eDAQ Files**.
 - c) Open **hd > eDAQ**.
 - d) For each of the individual SIC files (beginning with sif00000.sic and ending with the last sic file listed), follow the procedure listed below.
 - i) Across from the sic file, click **Get from eDAQ**.
 - ii) Click **Save** in the File Download window.
 - iii) Save the file in the folder created in step 2) above.
 - iv) Click **Close** in the Download complete window and repeat for the next file.

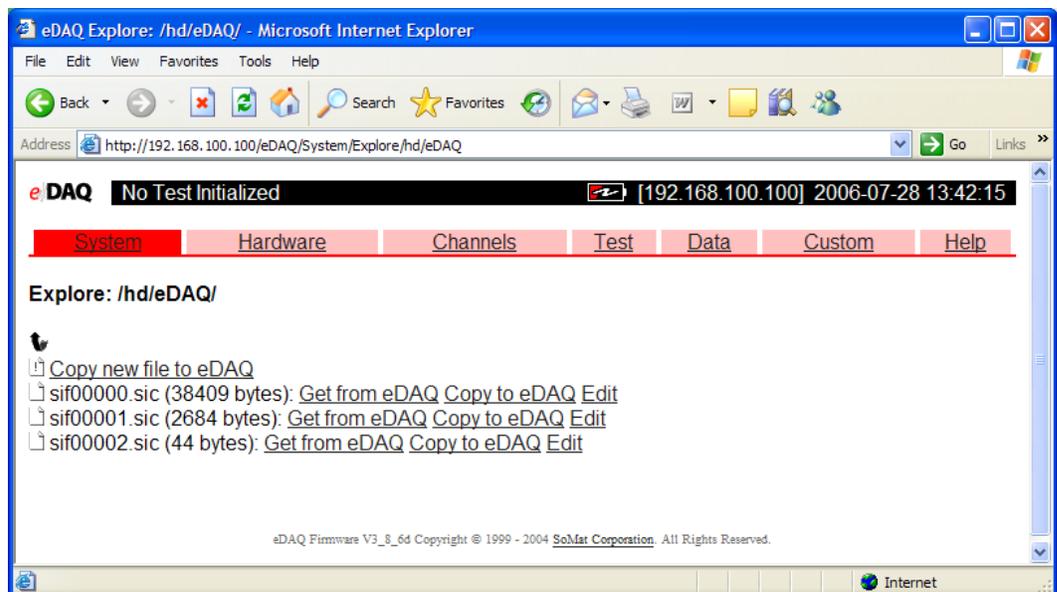


Figure 9.1.3: Locating the SIC Files

- e) When all SIC files have been saved to the specified folder, close the eDAQ web page.
- 4) Convert to SIF files
 - a) Open TCE.
 - b) Go to **File > Consolidate SIC Files**.

NOTE: Pay close attention to all message windows and the log file—these will give information regarding what runs have been lost and how the missing data has been handled (in the case of a power failure with insufficiently charged backup battery). More information can be found in the TCE help screens for SIF File Consolidation Issues and eDAQ-Plus and eDAQ-Lite Power Supply and Backup Battery Considerations.
 - c) Locate the recovery folder containing the SIC files, select **sif00000.sic**, and click **Open**.
 - d) Name the SIF file and save it in the desired location(s).
- 5) To continue to use the eDAQ, the test must be reinitialized before starting a new run.

9.1.4. Setting the FCS Time Zone and Clock

These procedures begin with the eDAQ on and connected to the support computer. To avoid confusion, it is strongly recommended that the support computer and the eDAQ both be set for UTC (GMT).

Setting the FCS Time Zone

- 1) Open the eDAQ web page (<http://192.168.100.100>).
- 2) Click on **System**.
- 3) Under System Setup, click **Timezone Setup**.
- 4) Scroll to select **Etc/Universal -> Etc/UTC** and click **Set timezone**.

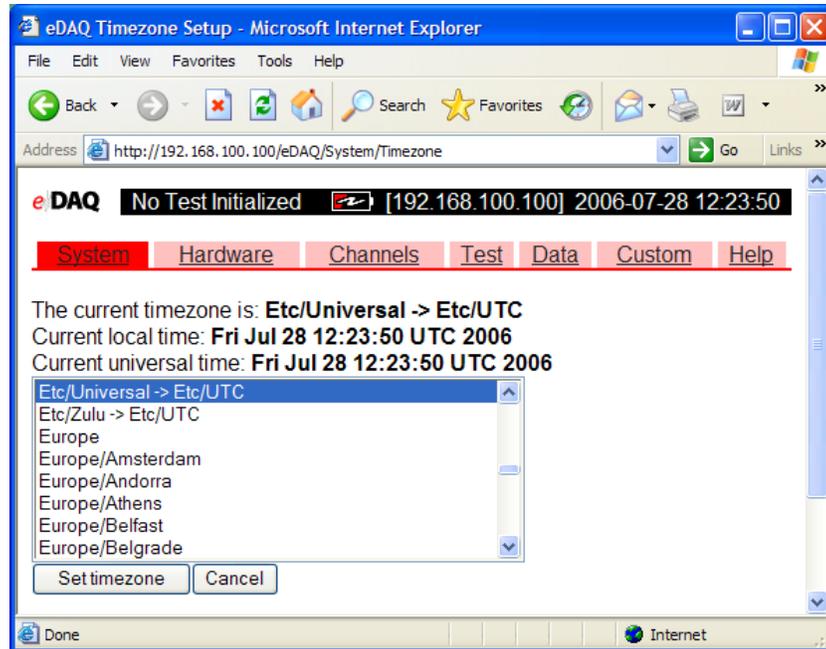


Figure 9.1.4-1: Setting the Field Computer System Time Zone

- 5) Click **OK** at the confirmation message.
- 6) When only the solid green LED is on, press the power button on the front of the eDAQ.
- 7) Once the eDAQ has completely shut down (all LEDs off), press the power button to turn on again, completing the time zone set.

Setting the FCS Clock

- 1) Open the **TCE V3.8.6d** software.
- 2) Click **FCS Setup > Set FCS Clock**.
- 3) A dialog box will appear, showing the computer's clock and the eDAQ's FCS clock. They should be within a few minutes of each other. Click **Yes** to confirm.

NOTE: If the two times are an hour or more apart, the eDAQ's time zone most likely differs from that of the computer. See the previous procedure to correct this problem.

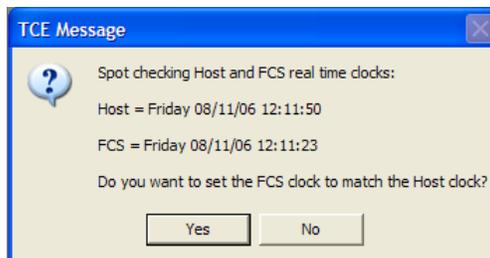


Figure 9.1.4-2: FCS Clock Confirmation Dialog Box

- 4) To verify the time setting, go to **FCS Setup > Set FCS Clock**. The Host and FCS clocks should show a matching date and time. Click **No** to cancel the second clock reset.

Note: To verify the timezone and FCS clock settings, return to the eDAQ web page and click **System > Timezone Setup**. Current local time and Current universal time should be identical UTC times. Click **Cancel** and close the window.

9.1.5. Importing and Constructing Databases

Importing dbc files

Note: “Dbc files” are standard database files with a “.dbc” extension, which can be interpreted by the eDAQ to set up a Vehicle Bus Module.

- 1) Open the eDAQ web page (<http://192.168.100.100> or appropriate IP)
- 2) Click on **Hardware > Vehicle Bus Module > Import Vector CANdb Database**.
- 3) **Browse** and open the database file (e.g., Sensor.dbc).
- 4) In the name for the converted eDAQ database field, type the desired database name with a “.txt” extension (e.g., Sensor.txt).
- 5) Click on **Import File** and the **OK** in the confirmation screen.
- 6) When finished, close the web browser. The database will be listed as a configuration option the next time the hardware is queried.

Constructing VBM databases

NOTE: Databases are most easily created by modifying existing databases.

- 1) Make a copy of an existing database
 - a) Open
C:\Program Files\SoMat\Tce_eDAQ_3.86d\Vbus_db\J1708
 - b) Highlight an existing, working file such as **J1587.txt** and press **Ctrl+C** to copy.
 - c) Press **Ctrl+V** to paste the copy in the J1708 folder.

NOTE: This procedure details the making of a J1708 database; the procedure for a CAN database differs only in the folder in which the copy is made (CAN rather than J1708).
 - d) Click on the file name and change it to the desired file name (e.g., **Trial0.txt**)
- 2) Copy the database to the eDAQ.
 - a) Open the eDAQ web page (**http://192.168.100.100**)
 - b) Click **Hardware > Vehicle Bus Module > Edit Parameter Databases > J1708**.
 - c) Click **Copy new file to eDAQ**.
 - d) **Browse** and open
C:\Program Files\SoMat\Tce_eDAQ_3.86d\Vbus_db\J1708\Trial0.txt.
 - e) Move the cursor to the end of the Destination path on eDAQ and type **Trial0.txt**.
 - f) Click OK on the confirmation screen.
- 3) Edit the new database
 - a) Across from Trial0.txt, click **Edit**.
 - b) Delete the last several lines (ID through request) to make the file smaller.

NOTE: To increase the file size, copy a few lines (ID through request) and paste at the end. Do not add blank lines or formatting—only copying, cutting, and pasting should be done in this screen.
 - c) Click **Save File** at the bottom of the screen.
 - d) Across from Trial0.txt, click **Spreadsheet**.

e) Alter the id, mask, value, etc. as necessary. Descriptions of these values follow.

NOTE: The length of the mask must be the same as the length of the value or the eDAQ will crash.

4) When finished click **Save File** and close the web browser. The database will be listed as a configuration option the next time the hardware is queried.

General Explanation of Database Setup

id – the eDAQ’s 12-character identification; may include a-z, A-Z, 0-9, and _, but must start with a letter

interface – should be the appropriate connection depending on what is used; for example:

VBOX	CAN
AirWeigh	J1708

mask – often 0x87FF; keep previous values if adding a row; if starting “from scratch” (as with AirWeigh), the use of 0xFFFF is recommended; **this value must be the same length as the value**

value – identifies which “row” in the data stream (view data in text file) is being used for the data; first four hexadecimal characters (e.g., 0x0301 for some VBOX parameters, 0xE1FE for some AirWeigh parameters, etc.)

description – a brief description assigned to the channel, up to 64 characters

bitpos – the starting bit for the data

bitlength – the number of bits assigned to that data

units – the units that will be displayed for the value

offset – the offset value for the data; often 0

scale – the number the data sent must be multiplied by in order to get the value that the data represents

min – the minimum value that data will represent

max – the maximum value that data will represent

dataformat – options: signed most significant byte (MSB), unsigned most significant byte (UMSB), signed least significant byte (SLSB), unsigned least significant byte (ULSB)

request – the message sent by the eDAQ to request specified information from the instrument, usually in the format 0xAC____;

AirWeigh_Alone.txt J1708 Database File

id	interface	mask	value	description	bitpos
	bitlength	units	offset	scale	min
	max	dataformat	request		
SterAWID	J1708		0xFFFFFFFF	0xE1EA1138	
	Steer AirWeigh	Serial Number	- 16 LS bits		
	128	16	NA	0	1
				0	100000000
					ULSB
					0xF580EAE1
DrivAWID	J1708		0xFFFFFFFF	0xE2EA1138	
	Drive Air Weigh	Serial Number	128	24	NA
	1	0	100000000	ULSB	0xF580EAE2
TrlrAWID	J1708		0xFFFFFFFF	0xE3C009F3	
	Trailer AirWeigh	Serial Number	- 16 LS bits		64
	16	NA	0	1	0
					100000000
					ULSB
					0xF580F3E3
SterAxWt	J1708		0xFFFFFFFF	0xE1FF99	Steer Axle
	Weight	24	16	lbs	0
				4	0
					300000
					ULSB
					0xAC001F
DrivAxWt	J1708		0xFFFFFFFF	0xE2FF99	Drive Axle
	Weight	24	16	lbs	0
				4	0
					300000
					ULSB
					0xAC001F
TrailrWt	J1708		0xFFFFFFFF	0xE3FF99	Trailer Axle
	Weight	24	16	lbs	0
				4	0
					300000
					ULSB
					0xAC001F

NOTES

- 1) For the request fields for the serial numbers, the eDAQ is obtaining the information from the AirWeigh unit by mimicking the display.
- 2) The request fields for the weights are irrelevant, serving only as placeholders; weight data is automatically sent to the display.
- 3) The AirWeigh manual cautions that values should not be queried at rates greater than 10 Hz.

VBOX_and_Volvo.txt J1939 Database File

id	interface	mask	value	description	bitpos
	bitlength	units	offset	scale	min
	max	dataformat	receivers	packetname	
	bytecount	transmitter			
Lateral_acce	CAN		0x87FF	0x0304	
	Lateral_acceleration			64	16
				G	0
	0.01	-327.68	327.67	SMSB	VBOX_II
					VBOX_4
	8	VBOX_II			

```

Longitudinal CAN 0x87FF 0x0304
  Longitudinal_acceleration 48 16 G 0
  0.01 -327.68 327.67 SMSB VBOX_II VBOX_4
  8 VBOX_II

DGPS CAN 0x87FF 0x0303 DGPS 74 1 On 0
  1 UMSB VBOX_II VBOX_3 8
  VBOX_II

Vertical_Vel CAN 0x87FF 0x0303
  Vertical_Velocity 40 16 m/s 0 0.01 0
  655.36 SMSB VBOX_II VBOX_3 8 VBOX_II

Altitude CAN 0x87FF 0x0303 Altitude 16 24
  metres 0 0.01 0 42949700 SMSB VBOX_II
  VBOX_3 8 VBOX_II

Heading CAN 0x87FF 0x0302 Heading 64 16
  Degrees 0 0.01 0 359.99 UMSB VBOX_II
  VBOX_2 8 VBOX_II

Velocity CAN 0x87FF 0x0302 Velocity 48 16
  Knots 0 0.01 0 655.36 UMSB VBOX_II
  VBOX_2 8 VBOX_II

East_West CAN 0x87FF 0x0302 East_West 16 1
  East 0 1 UMSB VBOX_II VBOX_2
  8 VBOX_II

Longitude CAN 0x87FF 0x0302 Longitude 17 31
  Degrees 0 1e-05 0 180 UMSB VBOX_II
  VBOX_2 8 VBOX_II

North_South CAN 0x87FF 0x0301 North_South
  48 1 South 0 1 UMSB
  VBOX_II VBOX_1 8 VBOX_II

Latitude CAN 0x87FF 0x0301 Latitude 49 31
  Degrees 0 1e-05 0 90 UMSB VBOX_II
  VBOX_1 8 VBOX_II

Time CAN 0x87FF 0x0301 Time 24 24 UTC 0
  1 UMSB VBOX_II VBOX_1 8
  VBOX_II

Sats CAN 0x87FF 0x0301 Sats 16 8 Sats 0
  1 0 12 UMSB VBOX_II VBOX_1 8
  VBOX_II

InsFuEcon CAN 0x83FFFF 0x80FEF2 Instantaneous
  Fuel Economy 48 16 Fuel Economy km/L 0
  0.001953125 0 125.5 ULSB
  0x98EAFFFFBF2FE00

IGr CAN 0x83FFFF 0x80F005 Current Gear 56 8
  Gear -125 1 -125 125 ULSB
  0x98EAFFFFB05F000

```

ActEgPctTq CAN 0x83FFFF 0x80F004 Actual
Engine - Percent Torque 48 8 Ratio %
-125 1 -125 125 ULSB 0x98EAFFFFB04F000

ActGrRatio CAN 0x83FFFF 0x80F005 Actual Gear
Ratio 40 16 Ratio 0 0.001 0
64.255 ULSB 0x98EAFFFFB05F000

DrvDmEgPctTq CAN 0x83FFFF 0x80F004 Driver's
Demand Engine - Percent Torque 40 8 Ratio
% -125 1 -125 125 ULSB 0x98EAFFFFB04F000

EgSp CAN 0x83FFFF 0x80F004 Engine Speed 56 16
Rotational Velocity rpm 0 0.125 0
8031.875 ULSB 0x98EAFFFFB04F000

EgOilTmp CAN 0x83FFFF 0x80FEEE Engine Oil
Temperature 48 16 Temperature Degrees C -
273 0.03125 -273 1735 ULSB 0x98EAFFFFBEEFE00

FuTmp CAN 0x83FFFF 0x80FEEE Fuel Temperature
40 8 Temperature Degrees C -40 1 -
40 210 ULSB 0x98EAFFFFBEEFE00

FAxSp CAN 0x83FFFF 0x80FEBF Front Axle Speed
32 16 Velocity km/h 0 0.00390625 0
251 ULSB 0x98EAFFFFBBFFE00

AvFuEcon CAN 0x83FFFF 0x80FEF2 Average Fuel
Economy 64 16 Fuel Economy km/L 0
0.001953125 0 125.5 ULSB
0x98EAFFFFBF2FE00

FuRate CAN 0x83FFFF 0x80FEF2 Fuel Rate 32 16
Flow L/h 0 0.05 0 3212.75 ULSB
0x98EAFFFFBF2FE00

OutShaftSp CAN 0x83FFFF 0x80F002 Output Shaft
Speed 40 16 Rotational Velocity rpm 0
0.125 0 8031.875 ULSB 0x98EAFFFFB02F000

CrusInfo CAN 0x83FFFF 0x80FEF1 "Brake, Clutch,
and Cruise Control Info (8 signals)" 56 16
Status 0 1 0 131071 UMSB
0x98EAFFFFBF1FE00

TotIdHr CAN 0x83FFFF 0x80FEDC Total Idle Hours
64 32 Time h 0 0.05 0 210554060.8
ULSB 0x98EAFFFFBDCFE00

TotPTOHr CAN 0x83FFFF 0x80FEE7 Total Power
Takeoff Hours 64 32 Time h 0 0.05 0
210554060.8 ULSB 0x98EAFFFFBE7FE00

HResTotVehDt CAN 0x83FFFF 0x80FEC1 High
Resolution Total Vehicle Distance 32 32
Distance m 0 5 0 21055406000

ULSB 0x98EAFFFFBC1FE00

```
MaxVehSpLm      CAN  0x83FFFF  0x80FEED  Maximum
Vehicle Speed Limit 32  8    Velocity km/h 0
1    0    250  ULSB 0x98EAFFFFBEDFE00

TotFuUsed CAN  0x83FFFF  0x80FEE9  Total Fuel Used
64  32  Volume  L    0    0.5  0
2105540608      ULSB 0x98EAFFFFBE9FE00

TotIdFuUsed     CAN  0x83FFFF  0x80FEDC  Total Idle
Fuel Used      32  32  Volume  L    0    0.5  0
2105540608      ULSB 0x98EAFFFFBDCFE00

FuelLevl_000    CAN  0x83FFFF  0x80FEFC  Fuel Level
40  8    Ratio  %    0    0.4  0    120
ULSB 0x98EAFFFFBFCFE00

AccPdlPos CAN  0x83FFFF  0x80F003  Accelerator Pedal
Position      40  8    Ratio  %    0    0.4  0
100  ULSB 0x98EAFFFFB03F000

PctLoadISp     CAN  0x83FFFF  0x80F003  Percent Load
at Current Speed 48  8    Ratio  %    0    1
0    125  ULSB 0x98EAFFFFB03F000
```

NOTE: This file differs slightly from that generated by directly converting the dbc file. The dbc file contains some values that are not actually available from the VBOX II Lite (such as a break trigger). It also contains more vehicle bus signals.

9.1.6. VBOX ColdStart Procedure

NOTE: This procedure is to be used to reset the VBOX when it performs erratically. For example, this procedure is to be used when the VBOX is unable to maintain a satellite lock. In this situation, a graph of the satellite count may look similar to the image below.

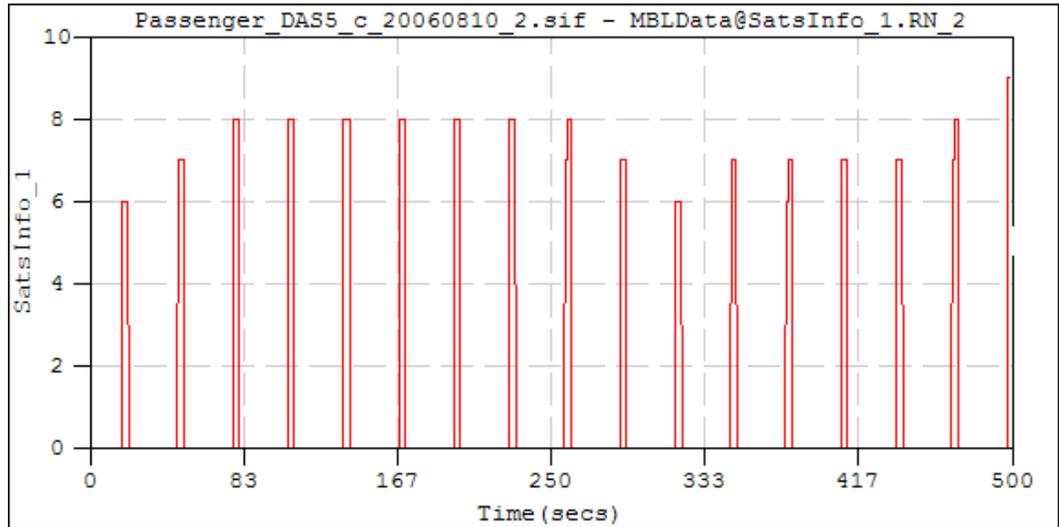


Figure 9.1.6-1: Example of Satellite Information Indicating the Need for a Cold Start.

NOTE: This procedure begins with the VBOX turned on and the support computer running. While the VBOX may remain connected to the eDAQ during this procedure, the eDAQ should not be in the middle of a run; if the eDAQ is on, only the solid green LED should be on.

- 1) Connect the gray **VBOX serial cable** to socket 3 in the back of the VBOX.
- 2) Connect the **USB/Serial adapter** to the support computer.
- 3) Connect the gray VBOX cable to the serial adapter.
- 4) Open the **VBOXTools** software.
- 5) Perform a Cold Start of the VBOX.
 - a) Verify that the VBOX icon appears in the top left corner of the window. If not, press **F11** to toggle from the file option.

NOTE: The text beside this icon should read "Serial data okay."
If this is not the case, verify that the correct serial port is selected (**Options > COM Port**). It will be necessary to reopen the VBOXTools software after making any changes to the connections.

- b) Click the **Tools** icon and then click **ColdStart**.

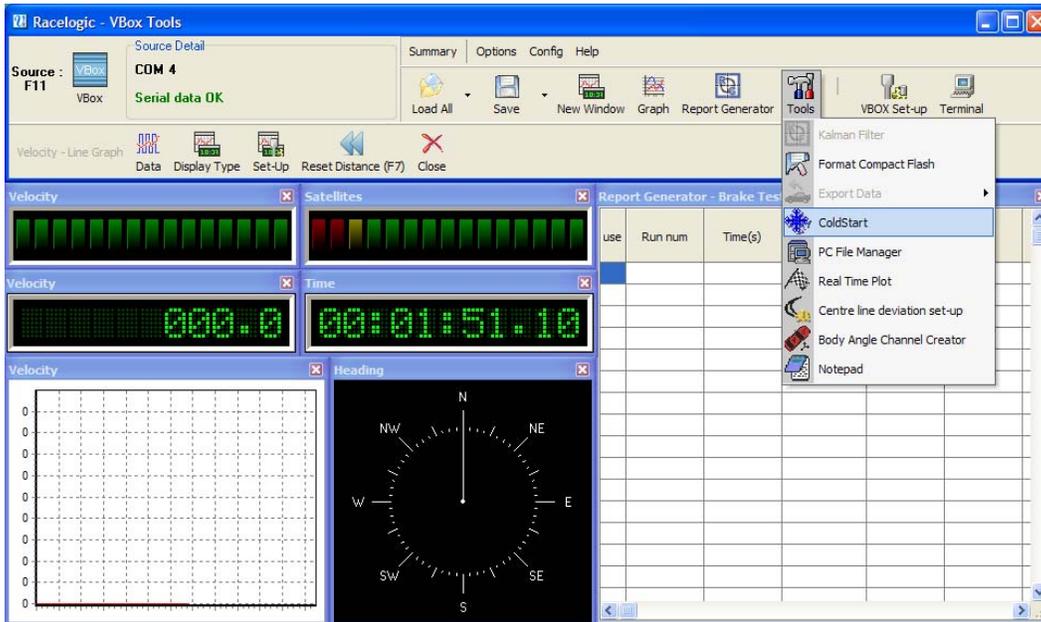


Figure 9.1.6-2: Performing a ColdStart

6) Reload the setup file. Refer to Initial VBOX Setup, step 5.

NOTE: VBOX setup must be repeated; if the VBOX is not configured properly, it will be unable to communicate with the eDAQ.

9.2. Appendix B: Additional Information Regarding Data Collected

9.2.1. Data Comments

Prematurely ending a run

- If a vehicle bus module loses its connection with the eDAQ, the run will be ended.
- If the connections between the vehicle bus module(s) and the eDAQ are remade, the eDAQ will record data as usual beginning with the next run.

Invalid data

- The invalid data value (generally the highest possible value for a channel) indicates that the eDAQ is unable to receive information from the sensor. The connection between the sensor and its associated vehicle bus module (or COMM port, depending on the sensor) is at fault.
- The invalid data value for computed channels is derived from the associated transducer channels rather than the “maximum” specified in the channel setup.

VBOX

- In case of a loss of satellite lock, the VBOX will transmit zeros for all channels except its Time channel; the Time channel will transmit an incrementing value (like a counter).
- When satellite lock is obtained, all VBOX values will be corrected.

AirWeigh

- When AirWeigh_Append is used, it will take up to 2 seconds from the beginning of a run to identify which trailer unit is connected
- A change in trailer status will take up to 45 seconds to be properly reflected in all channels (weight, ID, tire flag, marriage indicator).
- When the Air-Weigh display is unplugged, values recorded are invalid data values.
- When the tractor unit is disconnected, values recorded are invalid data values.

9.2.2. ID Explanations

The following Tables contain information regarding each channel of data collected.

Table 9.2.2-1: Descriptions and Units of Channels

Channel ID	Description	Units
InFuEcon_0	Instantaneous Fuel Economy	km/L
AvFuEcon_0	Average Fuel Economy	km/L
FuelRate_0	Fuel Rate	L/h
TotFuUsd_0	Total Fuel Used	L
TotIdFUd_0	Total Idle Fuel Used	L
CrntGear_0	Current Gear	none
SelctdGr_0	Selected Gear	none
OShaftSp_0	Output Shaft Speed	rpm
ActEngTq_0	Actual Engine - Percent Torque	%
ActGrRto_0	Actual Gear Ratio	none
DvDmEgTq_0	Driver's Demand Engine - Percent Torque	%
PctLdISp_0	Percent Load at Current Speed	%
EngSpeed_0	Engine Speed	rpm
EgOilTmp_0	Engine Oil Temperature	deg C
FuelTemp_0	Fuel Temperature	deg C
FAxleSpd_0	Front Axle Speed	km/h
TotVDist_0	High Resolution Total Vehicle Distance	m
AcPdlPos_0	Accelerator Pedal Position	%
TotIdleH_0	Total Idle Hours	h
MaxVSpLm_0	Maximum Vehicle Speed Limit	km/h
TotPTOhr_0	Total Power Takeoff Hours	h
ClutchSw_0	Clutch Switch	none
BrakingS_0	Brake Switch	none
CCEnable_0	Cruise Control Enable Switch	none
CCActive_0	Cruise Control Active	none
CCAccelS_0	Cruise Control Accelerate Switch	none
CCResume_0	Cruise Control Resume Switch	none
CCCoastS_0	Cruise Control Coast Switch	none
CCSetSwt_0	Cruise Control Set Switch	none
BattVolt_0	Battery Electrical Potential (Voltage)	V
DrivAxWt_0	Tractor Drive Axles Weight	lbs
SterAxWt_0	Tractor Steer Axle Weight	lbs
TrailrWt_0	Trailer Weight	lbs
TractrID_0	Tractor Serial Number	none
TrailrID_0	Trailer Serial Number	none
Latitude_0	Latitude	deg
Longitud_0	Longitude	deg
Altitude_0	Altitude	m
VrtVlcty_0	Vertical velocity	m/s
GndVlcty_0	Velocity over ground	m/s
LngAccel_0	Longitudinal acceleration	m/s ²
LatAccel_0	Lateral acceleration	m/s ²
HeadingN_0	Heading	deg
SatsInfo_0	Satellites	none

Channel ID	Description	Units
TimeUTCs_0	Time UTC	s (UTC)
WindSped_0	Wind Speed	m/s
WindDirC_0	Wind Direction	deg
RainInts_0	Rain Intensity	mm/h
BarPress_0	Barometric Pressure	hPa
AirTempr_0	Air Temperature	deg F
RelHumid_0	Relative Humidity	%
TireFlag_0	Tire Flag	none
RoadGrad_0	Road Grade	deg
PlcdhdrB_0	Placeholder B	none
PlcdhdrC_0	Placeholder C	none
PlcdhdrD_0	Placeholder D	none
PlcdhdrE_0	Placeholder E	none
Latit_DS_0	Stationary Latitude	deg
Longt_DS_0	Stationary Longitude	deg
Marriage_0	Tractor-Trailer Marriage	none

Table 9.2.2-2: Sources, Format, and Location

Channel ID	Sensor	Format	Integer?	PGN	SPN
InFuEcon_0	Vehicle Data Bus	5Hz, Flt32	N	FEF2	184
AvFuEcon_0	Vehicle Data Bus	5Hz, Flt32	N	FEF2	185
FuelRate_0	Vehicle Data Bus	5Hz, Flt32	N	FEF2	183
TotFuUsd_0	Vehicle Data Bus	5Hz, Flt32	N	FEE9	250
TotIdFud_0	Vehicle Data Bus	5Hz, Flt32	N	FEDC	236
CrntGear_0	Vehicle Data Bus	5Hz, Flt32	YES	F005	523
SelctdGr_0	Vehicle Data Bus	5Hz, Flt32	YES	F005	524
OShaftSp_0	Vehicle Data Bus	5Hz, Flt32	N	F002	191
ActEngTq_0	Vehicle Data Bus	5Hz, Flt32	YES	F004	513
ActGrRto_0	Vehicle Data Bus	5Hz, Flt32	N	F005	526
DvDmEgTq_0	Vehicle Data Bus	5Hz, Flt32	YES	F004	512
PctLdISp_0	Vehicle Data Bus	5Hz, Flt32	YES	F003	92
EngSpeed_0	Vehicle Data Bus	5Hz, Flt32	N	F004	190
EgOilTmp_0	Vehicle Data Bus	5Hz, Flt32	N	FEFE	175
FuelTemp_0	Vehicle Data Bus	5Hz, Flt32	YES	FEFE	174
FAxleSpd_0	Vehicle Data Bus	5Hz, Flt32	N	FEBF	904
TotVDist_0	Vehicle Data Bus	5Hz, Flt32	YES	FEC1	917
AcPdlPos_0	Vehicle Data Bus	5Hz, Flt32	N	F003	91
TotIdleH_0	Vehicle Data Bus	5Hz, Flt32	N	FEDC	235
MaxVSpLm_0	Vehicle Data Bus	5Hz, Flt32	YES	FEED	74
TotPTOHr_0	Vehicle Data Bus	5Hz, Flt32	N	FEE7	248
ClutchSw_0	Vehicle Data Bus	5Hz, Flt32	YES	FEF1	598
BrakingS_0	Vehicle Data Bus	5Hz, Flt32	YES	FEF1	597
CCEnable_0	Vehicle Data Bus	5Hz, Flt32	YES	FEF1	596
CCActive_0	Vehicle Data Bus	5Hz, Flt32	YES	FEF1	595

Channel ID	Sensor	Format	Integer?	PGN	SPN
CCAccelS_0	Vehicle Data Bus	5Hz, Flt32	YES	FEF1	602
CCResume_0	Vehicle Data Bus	5Hz, Flt32	YES	FEF1	601
CCCoastS_0	Vehicle Data Bus	5Hz, Flt32	YES	FEF1	600
CCSetSwt_0	Vehicle Data Bus	5Hz, Flt32	YES	FEF1	599
BattVolt_0	Vehicle Data Bus	5Hz, Flt32	N	FEF7	168
DrivAxWt_0	Air-Weigh	5Hz, Flt32	YES		
SterAxWt_0	Air-Weigh	5Hz, Flt32	YES		
TrailrWt_0	Air-Weigh	5Hz, Flt32	YES		
TractrID_0	Air-Weigh	5Hz, Flt32	YES		
TrailrID_0	Air-Weigh	5Hz, Flt32	YES		
Latitude_0	VBOX	5Hz, Flt32	N		
Longitud_0	VBOX	5Hz, Flt32	N		
Altitude_0	VBOX	5Hz, Flt32	N		
VrtVlcty_0	VBOX	5Hz, Flt32	N		
GndVlcty_0	VBOX	5Hz, Flt32	N		
LngAccel_0	VBOX	5Hz, Flt32	N		
LatAccel_0	VBOX	5Hz, Flt32	N		
HeadingN_0	VBOX	5Hz, Flt32	N		
SatsInfo_0	VBOX	5Hz, Flt32	YES		
TimeUTCs_0	VBOX	5Hz, Flt32	N		
WindSped_0	Weather Station	5Hz, Flt32	N		
WindDirC_0	Weather Station	5Hz, Flt32	YES		
RainInts_0	Weather Station	5Hz, Flt32	YES		
BarPress_0	Weather Station	5Hz, Flt32	N		
AirTempr_0	Weather Station	5Hz, Flt32	N		
RelHumid_0	Weather Station	5Hz, Flt32	YES		
TireFlag_0	Air-Weigh-calc	5Hz, Flt32	YES		
RoadGrad_0	VBOX-calc	5Hz, Flt32	N		
PlcdhdrB_0	none	5Hz, Flt32			
PlcdhdrC_0	none	5Hz, Flt32			
PlcdhdrD_0	none	5Hz, Flt32			
PlcdhdrE_0	none	5Hz, Flt32			
Latit_DS_0	VBOX-calc	Burst, Flt32	N		
Longt_DS_0	VBOX-calc	Burst, Flt32	N		
Marriage_0	Air-Weigh-calc	Burst, Uns8	YES		

Note regarding Table 9.2.2-2:

Vehicle Data Bus PGN and SPN can be looked up in SAE J1939-71 for more information

Table 9.2.2-3: Invalid Data Values

Channel ID	eDAQ Invalid Data Value	Sensor Invalid Data Value	Other Invalid Data Value
InFuEcon_0	125.5	127.998	
AvFuEcon_0	125.5	127.998	
FuelRate_0	3212.75	3276.75	
TotFuUsd_0	2105540000	2147480000	
TotIdFUd_0	2105540000	2147480000	
CrntGear_0	125	130	
SelctdGr_0	125	130	
OShaftSp_0	8031.88	8191.88	
ActEngTq_0	125	130	
ActGrRto_0	64.255	65.535	
DvDmEgTq_0	125	130	
PctLdISp_0	125	255	
EngSpeed_0	8031.88	8191.88	
EgOilTmp_0	1735	1774.97	
FuelTemp_0	210	215	
FAxleSpd_0	251	255.996	
TotVDist_0	21055400000	21474800000	
AcPdlPos_0	120	102	
TotIdleH_0	210554000	214748000	
MaxVSpLm_0	250	255	
TotPTOHr_0	210554000	214748000	
ClutchSw_0	4	3	
BrakingS_0	4	3	
CCEnable_0	4	3	
CCActive_0	4	3	
CCAccelS_0	4	3	
CCResume_0	4	3	
CCCoastS_0	4	3	
CCSetSw_0	4	3	
BattVolt_0	3212.75	3276.75	
DrivAxWt_0	300000		
SterAxWt_0	300000		
TrailrWt_0	300000		
TractrID_0	100000000		
TrailrID_0	100000000		
Latitude_0	90		-58.5 OR random for first week (20061021)
Longitud_0	-180		117OR random for first week. (20061021)
Altitude_0	42949700		
VrtVlcty_0	655.36		

Channel ID	eDAQ Invalid Data Value	Sensor Invalid Data Value	Other Invalid Data Value
GndVlcty_0	337.146		
LngAccel_0	3213.35		
LatAccel_0	3213.35		
HeadingN_0	359.99		
SatsInfo_0	25512		25500 when dgps error, + 12 when sats error
TimeUTCs_0	42949700		
WindSped_0	277.778		
WindDirc_0	1000		Stays constant when wind speed < 0.05 m/s
RainInts_0	1000		
BarPress_0	2000		
AirTempr_0	212		
RelHumid_0	200		
TireFlag_0	99		9*
RoadGrad_0	90		45, 0
PlcdhdrB_0	none		
PlcdhdrC_0	none		
PlcdhdrD_0	none		
PlcdhdrE_0	none		
Latit_DS_0	90		
Longt_DS_0	-180		
Marriage_0	none		

Notes regarding Table 9.2.2-3:

"eDAQ Invalid Data Value" is returned when the eDAQ does not receive the data

"Sensor Invalid Data Value" is returned when the sensor does not collect the data

Table 9.2.2-4: Resolution, Accuracy, and Other Notes

Channel ID	Resolution	Accuracy	Notes
InFuEcon_0	1/512 km/L		Not accurate unless calibrated with actual fuel receipts
AvFuEcon_0	1/512 km/L		Not accurate unless calibrated with actual fuel receipts
FuelRate_0	0.05 L/h		Not accurate unless calibrated with actual fuel receipts
TotFuUsd_0	0.5 L		Not accurate unless calibrated with actual fuel receipts
TotIdFUd_0	0.5 L		Not accurate unless calibrated with actual fuel receipts
CrntGear_0	1 gear value		+=forward, -=reverse, 0=neutral, 126=park

Channel ID	Resolution	Accuracy	Notes
SelctdGr_0	1 gear value		+ =forward, - =reverse, 0 =neutral, 126 =park
OShaftSp_0	0.125 rpm		
ActEngTq_0	1%		also see pp. 635-636 in SAE J1939-71
ActGrRto_0	0.001		
DvDmEgTq_0	1%		also see pp. 635-636 in SAE J1939-71
PctLdISp_0	1%		
EngSpeed_0	0.125 rpm		
EgOilTmp_0	0.03125 °C		
FuelTemp_0	1 °C		
FAxleSpd_0	1/256 km/h		not as accurate as VBOX (GndVlcty)
TotVDist_0	5 m		
AcPdlPos_0	0.40%		
TotIdleH_0	0.05 h		
MaxVSpLm_0	1 km/h		
TotPTOHr_0	0.05 h		
ClutchSw_0	4 states/2 bit		0 =clutch pedal released, 1 =clutch pedal pressed, 2 =error, 3 =not available
BrakingS_0	4 states/2 bit		0 =brake pedal released, 1 =brake pedal pressed, 2 =error, 3 =not available
CCEnable_0	4 states/2 bit		0 =off, 1 =on, 2 =error, 3 =not available
CCActive_0	4 states/2 bit		0 =off, 1 =on, 2 =error, 3 =not available
CCAccelS_0	4 states/2 bit		0 =off, 1 =on, 2 =error, 3 =not available
CCResume_0	4 states/2 bit		0 =off, 1 =on, 2 =error, 3 =not available
CCCoastS_0	4 states/2 bit		0 =off, 1 =on, 2 =error, 3 =not available
CCSetSwt_0	4 states/2 bit		0 =off, 1 =on, 2 =error, 3 =not available
BattVolt_0	0.05 V		
DrivAxWt_0		+/-300 lbs	units will not change regardless of changing the units in the display
SterAxWt_0		+/-300 lbs	units will not change regardless of changing the units in the display

Channel ID	Resolution	Accuracy	Notes
TrailrWt_0		+/-300 lbs	units will not change regardless of changing the units in the display
TractrID_0			16 least significant bits of tractor comlink serial number
TrailrID_0			16 least significant bits of trailer comlink serial number
Latitude_0		3m 95% CEP, 1.8m with DGPS	check SatsInfo for accuracy of data
Longitud_0		3m 95% CEP, 1.8m with DGPS	check SatsInfo for accuracy of data
Altitude_0	0.01m		check SatsInfo for accuracy of data
VrtVlcty_0	0.01m	0.2 km/h	check SatsInfo for accuracy of data
GndVlcty_0	0.00514m	0.2 km/h	check SatsInfo for accuracy of data
LngAccel_0	0.098m/s ²	1%	check SatsInfo for accuracy of data
LatAccel_0	0.098m/s ²	1%	check SatsInfo for accuracy of data
HeadingN_0	0.01deg	0.2deg	check SatsInfo for accuracy of data
SatsInfo_0	1		total number of satellites, plus 100 if DGPS available/enabled
TimeUTCs_0	0.01 s	0.05 s	check SatsInfo for accuracy of data
WindSped_0	1/3.6 m/s	+/-0.3m/s or +/- 2% whichever is greater	
WindDir_0	1 deg	+/-2 deg	Relative wind direction based on "north" as front of vehicle, gives direction wind is coming from
RainInts_0	1 mm/h		running 1 min avg in 10 sec steps, mist 0.1, light drizzle 0.2, drizzle 0.5, light rain 1, medium rain 4, heavy rain 15, thundershower 100

Channel ID	Resolution	Accuracy	Notes
BarPress_0	0.01 hPa	+/- 0.5 hPa at 0-30 deg C	
AirTempr_0	1.8 deg F	+/- 0.3 deg C at 20 deg C	
RelHumid_0	1%	+/- 3% at 0-90% RH, +/- 5% at 90-100% RH	
TireFlag_0	1		tens place is tractor tires, ones place for trailer tires. 1=Michelin single, 2=Michelin dual, 3=generic dual (retread), 9=none or error
RoadGrad_0		+/- 1 deg for <15 deg	45 output means GndVlcty was under 16 km/h and slope would not be accurate to within 1 degree, 0 output when both VrtVlcty and GndVlcty are 0
PlcdhdrB_0			
PlcdhdrC_0			
PlcdhdrD_0			
PlcdhdrE_0			
Latit_DS_0		3m 95% CEP, 1.8m with DGPS	
Longt_DS_0		3m 95% CEP, 1.8m with DGPS	
Marriage_0	1		1 = instrumented trailer is connected, checked 300 sec into each run

Note regarding Table 9.2.2-4:

Rain intensities from http://www.terrestris.de/hp/en/con_prozesse.php

9.3. Appendix C: Additional DAS Notes

This section provides additional information the data acquisition system as a whole, individual instruments, and some issues encountered in this Project.

9.3.1. General Notes

Upgrades

Changes in the default settings and software of each instrument can affect the data collection and communication settings. While improvements of this sort may benefit future projects, the instruments were configured for this Project using the latest software and firmware available at the beginning of the field operational test. Therefore, do not make any software or firmware upgrades for the duration of the HTDC project. If a new computer must be used, be sure to use the software which was initially used in setup (even if a newer version is available).

Laptop computer online issue

It was decided that the benefits of keeping the project support computer off the ORNL network outweighed the minor benefits of network access with the laptop. First, putting the laptop online would mean that the users would no longer be able to use a project password to log on. Only the computer administrator would be able to load software. This would serve to complicate problems that could normally be solved simply by reinstalling software. With multiple users to the project computer, data, settings, and even setup files would be under different user names; this means that up-to-date project information could be unavailable to some users. Another advantage to keeping the computer offline is that it makes undesirable mid-project firmware upgrades more difficult. (However, the VBOXTools software is available on the desktop for pre- and post-project upgrades.) For these reasons, it was decided that the support computer not be put on the ORNL network.

CAUTION: The following section of information is provided for reference purposes only; see note above.

The eDAQ's IP address is static (i.e., once it is set, it will keep that IP until it is changed). Therefore, in order to communicate with the eDAQ, the laptop's IP address must remain a certain value in relation to the eDAQ's IP (as described in Section 9.1.1. Changing IP Addresses); this means that the laptop's IP address must be static as well. However, in order to access the ORNL internet, the IT department must be able to change the IP address as it chooses. Therefore, if the IP address is set (static) and internet login is successful, the connection will only last a few seconds. This issue can be resolved by setting the primary IP as dynamic and

the secondary as the static IP necessary for communication with the eDAQ, as outlined below.

- 1) Go to Start > My Computer > My Network Places > View Network Connections
- 2) Double-click on Local Area Connection.
- 3) Under the General Tab, scroll down, select Internet Protocol (TCP/IP), and click Properties.
- 4) Under the General tab, select Obtain an IP address automatically
- 5) Under the Alternate Configuration tab, select User configured IP address: 192.168.100.xxx (or required IP)
Subnet mask: 255.255.255.0 (or required Subnet mask)
- 6) Click OK, Close, and close Network Connections.

Note: Because the static IP address is the alternate, the computer will usually take a few minutes to recognize the eDAQ.

Timing Issue

The time stamping done by the eDAQ is based on the internal starting time and the frequency with which samples are being taken. Therefore, over a test period of several days, the clock will usually drift. To resolve the time issue, the following precautions were taken.

- 1) The VBOX will record UTC (in seconds) as a regular data point; this time will be used to check the time stamp. UTC is basically Greenwich Mean Time; this time will have to be adjusted to the time zone in which the data is taken (including Daylight Savings Time) in order to determine time of day (rush hour, night, etc.)
- 2) Every time data is uploaded from the eDAQ, the eDAQ time (used for time stamping) will be readjusted to the computer time.
- 3) In order to avoid confusion, the eDAQ internal clock needs to be kept in one time zone and not changed for Daylight Savings Time. For simplicity (and since the time will need to be adjusted anyway based on season and zone), the computer is set to GMT and the eDAQ will be synchronized with that (eDAQ on UTC also).

Procedures for setting the appropriate time zones appear in Section 9.1.4.

Antennas and GPS coordinates

When the VBOX takes data in stand-alone data acquisition, it saves the coordinates in degrees. When the VBOX sends CAN data to the eDAQ, it sends the coordinates in degrees and minutes; a series of computed channels have been set up to convert the coordinates from the VBOX into degrees (Section 7.2.5.C.) The GPS coordinate data taken directly by the eDAQ's antenna are in degrees. However, when the eDAQ's GPS antenna is used, the data is updated at 1 Hz. Therefore, if the sampling rate of the eDAQ is set to 5 Hz, the data will

be replicated and saved as five identical data points in a row. Because the use of the eDAQ antenna would increase post-processing requirements and decrease precision, it was determined that the VBOX would be the source for the GPS coordinates.

Data File numbering issue (DAS # vs. external truck #)

The one-digit DAS number is used to identify the truck in the TCE files and channel names. This method was chosen because of the advantages it afforded. A comparison of the advantages and disadvantages of this method and the external truck ID method is briefly outlined in Table 9.3.1.

Table 9.3.1: Naming Convention Comparison

Scenario	If use DAS #	If use truck # (external ID)
need to switch out DAS	probable data confusion issue	no data confusion
choosing test file	simple—right on box	outside marking used inside—unless some kind of sticker or other marking is on the box too
switch out instrument in DAS	easy—linked to DAS already	changed in DAS in database, not truck
interpreting data	requires another database to associate files	truck already identified by channel names
truck ID longer than 3 digits (likelihood depending on fleet size)	Not an issue – DAS # is one digit long	Must use only a portion of the Truck ID or Forced to use only a portion of the
In case of any confusion	Identification for truck is available as a channel in the data produced	

J1939 Requests

In the Transducer Channel Setup, only 14 vehicle bus channels have requests enabled. Actually, all 30 channels that are collected from the vehicle bus are being requested; but some share the same PGN with other vehicle data bus channels. These channels are transmitted together in the same message, and only one channel per message needs to be requested. The 14 PGNs requested are as follows:

F002	F005	FEDC	FEED
	FEF2		
F003	FEBF	FEE7	FEEE
	FEF7		

9.3.2. EDAQ Notes

Indicator LEDs

GREEN: EDAQ is on and ready for use.

YELLOW

Steady: The processor busy (for example, during boot-up cycle or changing settings).

Flashing: A test is in process.

RED

Error, There is an internal fault, or a reset has just taken place.

(For details, check the Logbook, [http://\[eDAQ IP\]](http://[eDAQ IP]) > **Test** > **View eDAQ Logbook**)



Figure 9.3.2: Indicator LEDs on Front of EDAQ Lite

Specific LED cycles

Startup – All LEDs are on, then the RED turns off, followed by the YELLOW (after several seconds); Only the GREEN LED remains on.

Armed (initialized, ready to begin run) – The GREEN is on (steady) and the YELLOW is blinking slowly. At this point it is acceptable to power off; when powered on again, the eDAQ will resume this status.

Performing Run (in the middle of a run) – The GREEN LED is on (steady) and the YELLOW is blinking rapidly. At this point, it is acceptable to power off; when powered on again, the eDAQ will begin a new run (in the same test).

Resetting Complete – Both the GREEN and RED LEDs are on (steady). A notification dialog box will appear upon continued work in TCE, after which the RED will go off.

Verifying VBOX's connection to the eDAQ

1) Go to **Start** > **Run**

- 2) Type in "**cmd**"
- 3) Type "**ipconfig**"
When the computer returns value of **ping 192.168.100.100**, communication has been established.
NOTE: may take a few attempts to establish communication (ipconfig) when using the laptop's secondary IP with eDAQ.
- 4) Open Microsoft **Internet Explorer**.
- 5) Open the eDAQ web page (set as home page, or type in <http://192.168.100.100>)
- 6) Click on **Hardware > VBM_1**. Make sure **250 kbps** is chosen to match other J1939 communications (the VBOX must already be set at this baudrate)
- 7) Click the **Log VBM_1 Messages** button, and prepare to hit the stop (cancel) button.
If data is displayed after a few seconds, quickly hit the stop button (in Internet Explorer).
If after about half a minute nothing shows up, contact has not been established (recheck connections, switch out with working cable, etc.).
This procedure may be repeated for VBM_2 to verify the J1708 (Air-Weigh) connection.

Loading the dcb file for the VBOX II Lite

[Open Microsoft Internet Explorer, go to eDAQ page]

- 1) Click on **Hardware** and select **VBM_1**.
- 2) For VBM_1, click on **Import Vector CANdb Database**
- 3) Click on Browse and locate the data base (most likely titled VBOX_II_V2.dbc); call it VBOX_2_Lite and click OK
- 4) Click on Edit parameter db >CAN
- 5) Under VBOX_2_Lite.txt, click on Spreadsheet. A spreadsheet version of the .dbc file should appear.

Note: Changes in units and IDs should be made through TCE rather than the spreadsheet to minimize the possibility of introducing errors into the database.

When the hardware is re-queried, a new database message will be shown. This new file will now appear as a database option.

NOTE: The mask length must be the same as the value length or the eDAQ will crash!

For an illustration of matching the mask length with the value length, view an existing data file.

Checking Data Storage Capabilities

- 1) Open the Sensor Tools (General) software (No, do not update license).
- 2) Click on Calibration Tools. At the bottom of this window is the Memory Capacity Calculator. Enter the values listed below
Bit Res – 32
Channels – Select the total number of channels being recorded
SRate Hz – 5
Store (MB) – 1024 (highest can input; actually half of capability of system using)
Time Base – Days
- 3) Multiply the number generated in the Availability field by 2, because the actual storage capacity is 2 GB rather than 1 GB.
- 4) The result is the estimated number of days of continuous data collection possible at the current settings.
NOTE: When Sensor Tools is closed, it is likely that an error message will appear. Do not send error report to Microsoft.

If using another computer (i.e., rather than the original HTDC laptop)

The following files must be copied to

C:\Program Files\SoMat\Tce_eDAQ_3.86d

Setup files (.tce)

Files referenced by State Mapper computed channels (.txt)

Database files (.txt)

NOTE: it is recommended that the entire contents of the Work and Vbus folders from the original computer be copied to these folders of the new computer. Also check the eDAQ_Plus folder.

Computed Channel Notes

- 1) Computed Channels use transducer channels which already appear in the Transducer and Message Channel Setup window or the Computed Channel Setup window.
- 2) In order to perform calculations with these channels, the type must be 32-bit float. Converting to 32-bit float for calculations is possible within the computed channel setup window.
- 3) Computed channels which give a Boolean output are in 8-bit format. In order to use these outputs in the Desk Calculator, use the float() function to convert to 32-bit float.
- 4) When inputting channels or functions by clicking in the given lists, these inputs will appear at the end of the expression, regardless of the cursor position.
- 5) Detailed help for each type of computed channel is available by clicking Add, selecting the channel type, and clicking Help in the resulting dialog box.

Producing multiple setup files

- 1) Get one setup file (with IDs ending in _0) completed and working exactly as required. Save this setup file.
- 2) Locate the “_0” setup file and make a copy. Name this setup file like the original, changing the ending to “_x” (where _x identifies the DAS and/or truck).
- 3) Change the extension of the “_x” file to “.txt” and confirm the change if prompted.
- 4) Open the “_x.txt” file with notepad.
- 5) Click Edit > Replace (or press Ctrl+H). In the Find what field, type _0. In the Replace with field, type, _x.
- 6) Click Find Next and check each occurrence before replacing.
- 7) Save changes (Ctrl+S) and close the text file.
- 8) Locate the “_x.txt” file and change the extension to “.tce.”
- 9) Open the “_x” file in TCE with the appropriate DAS connected to the computer.
- 10) Run a hardware query. Click Yes to use the current hardware setup.
- 11) Save changes to the setup file. Repeat the process until six “copies” of the original (_0) setup file exist, one for each DAS.

Other Comments

- Keep Automatically Convert to 32-bit Float checked (in channel edit) so the data is available for use in calculated channels.
- Choose the eDAQ Plus option when there is no eDAQ Lite option (the two are basically the same).
- For explanations of the available buttons in any channel setup window, click on Help in the window.

9.3.3. VBOX Notes

VBOX card slot

As a precaution, tape over the card slot so dust does not get in.

9.3.4. Air-Weigh Notes

AirWeigh and resetting on power cycle

Upon power up, a calibrated Air-Weigh will immediately give weights and permit querying. According to AirWeigh 5800 Install Guidelines, “Do not connect the Truck ComLink to constant 12V from the battery, as this will drain your battery.”

Potential J1708 Issues

The J1708 data bus has a nominal 45 messages/second rate (9600 baud, 10 bits/character for J1708 networks, standard message length of 21 characters). Querying 10 parameters at 5 Hz is equivalent to 50 messages/second—this does not count the message responses, AirWeigh messages, or the normal functions of the J1708. As this will exceed the capacity of the J1708 network, it is recommended that the following steps be taken in the event a J1708 vehicle databus will be used.

- 1) Set the sample rate for the eDAQ at 5 Hz for uniformity
- 2) Set the query rate to a lower value, such as 1 Hz. (Make note of this value, as this will essentially be the “data refresh” rate.)
- 3) Set the invalid data timeout to a value substantially lower than the sampling rate (for example, 5 seconds). Otherwise, invalid data values will be recorded between samples.

9.3.5. Weather Station Notes

- The weather station should be set up to update every 1 s because it is the smallest available interval.
- Set averaging interval to 1 s (smallest available interval), because “average” values (rather than max, min, or peak) will be recorded.

9.4. Appendix D: Checklists and Forms

9.4.1. HTDC Data Upload Checklist

This form is to be used for the biweekly upload of data for the Project. A form is to be filled out for each truck each time data is uploaded.

9.4.2. Tools and Supplies for Data Upload

This checklist outlines the equipment which should be taken to upload the data.

9.4.3. Weather Station Test Sheet

This table is designed to help diagnose problems which may arise with the weather station.

Tools and Supplies for Data Upload

Necessary:

- Laptop with Power Cord
- Portable Hard Drive
- Pen and Paper
- Data Upload Checklist
- Seals
- Wire Cutters

May Be Needed:

- CAT-5 Cable Extension
- Battery Pack with Attached Inverter
- USB to Serial Adapter, Weather Station Service Cable, 9V Battery
- VBOX RS232 to Serial Cable (May Be Stored with VBOX)
- Spare VBOX Antenna
- Multimeter
- Extension Cord
- Extra Cables, Wires, Alligator Clips, Wire Connectors
- Wire Termination Kit
- Wire Coat Hanger
- Cable Ties
- Silicone, Isopropyl Alcohol, and Paper Towels or Cloth
- Double Sided tape, Electrical Tape, Duct Tape
- Screwdrivers, Allen & Torx Wrenches, Adjustable Wrenches, Wire Strippers, Pliers
- Weather Station Clamps
- Spare 5 Amp Fuses, No-Skid, Wire Loom, Air Filter for Fan Covering
- Flashlight

Weather Station Test Sheet

ID	Description	TTG 201	TTG 202	TTG 203	TTG 204	TTG 205	TTG 206
air_pressure	Air Pressure						
air_temp	Air temperature						
hail_acm	Hail accumulation						
hail_dur	Hail duration						
hail_int	Hail current intensity						
hail_pk_int	Hail peak intensity						
heat_temp	Heating temperature						
heat_v	Heating voltage						
heat_pwr	Heating power						
humid_rel	Relative Humidity						
int_temp	Internal Temperature						
rain_acm	Rain accumulation						
rain_dur	Rain duration						
rain_int	Rain current intensity						
rain_pk_int	Rain peak intensity						
ref_v	Reference voltage						
supply_v	Supply voltage						
wind_dir_avg	Wind direction average						
wind_dir_max	Wind direction max						
wind_dir_min	Wind direction min						
wind_spd_avg	Wind speed average						
wind_spd_max	Wind speed max						
wind_spd_min	Wind speed min						

- √ - Readings appear reasonable
- 0 - Reads "0"; unable to test further in lab
- X - Invalid data reading

Comments:

Tested by: _____

Date: _____

9.5. Appendix E: References and Websites for Additional Information

SoMat

eDAQ-Lite

<http://www.ncode.com/page.asp?section=00010001000100010002>

InField Download

<http://www.somat.com/downloads/infield.htm>

Download Center

<http://www.ncode.com/page.asp?section=0001000100030013>

VBOX

Racelogic – VBOX

<http://www.racelogic.co.uk/?show=VBOX>

VBOX USA

<http://www.vboxusa.com/>

Weather Station

Vaisala WXT 510

<http://www.vaisala.com/businessareas/instruments/products/weathermulti-sensor>

Appendix E
DYNAMOMETER TESTING FINAL REPORT

Characterization of NO_x Emissions from Late Model Year Heavy-Duty Vehicles

FINAL REPORT

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March 25, 2008

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1 Introduction

The objective of the proposed study is to evaluate the torque and exhaust emissions from one 2005 Volvo tractor on the WVU Transportable Heavy-duty Vehicle Emissions Laboratory. The test vehicle was exercised over three cycles provided by Oak Ridge National Laboratory (ORNL). Measurement of torque and distance-specific values fuel usage rate, total particulate matter, oxides of nitrogen, total hydrocarbons, carbon monoxide, and carbon dioxide were made.

2 Test Vehicle and Engine

WVU conducted emissions evaluation on a heavy-duty vehicle powered by MY 2004 Cummins ISM engine tested over two three cycles (as discussed below).

Test Cycle

The vehicle was exercised over the three test cycles under two test weight configurations of 23,300 lbs and 41,248 lbs.

The setpoints for the cycle one represented as the Gear Change Matrix is shown in Table 1. The cycle was broken down into two parts due to limitations on the length of a single test cycle.

Table 1 Setpoints for Cycle 1 (Gear Change Matrix)

mph	gear#									
	0	1	2	3	4	5	6	7	8	9
600	0.0	X	X	X	X	X	X	X	X	X
900	X	1.4	X	X	X	X	X	X	X	X
1100	X	2.8	3.9	5.3	7.4	10.0	13.9	19.0	26.1	36.1
1300	X	3.4	4.6	6.3	8.7	11.8	16.5	22.4	30.9	42.6
1550	X	4.0	5.5	7.5	10.4	14.0	19.6	26.8	36.8	50.8
1800	X	4.7	6.4	8.7	12.0	16.3	22.8	31.1	42.8	59.0
1900	X	X	X	X	X	X	X	X	X	X
2000	X	X	X	X	X	X	X	X	X	X
	140	700	560	560	560	560	560	560	560	560

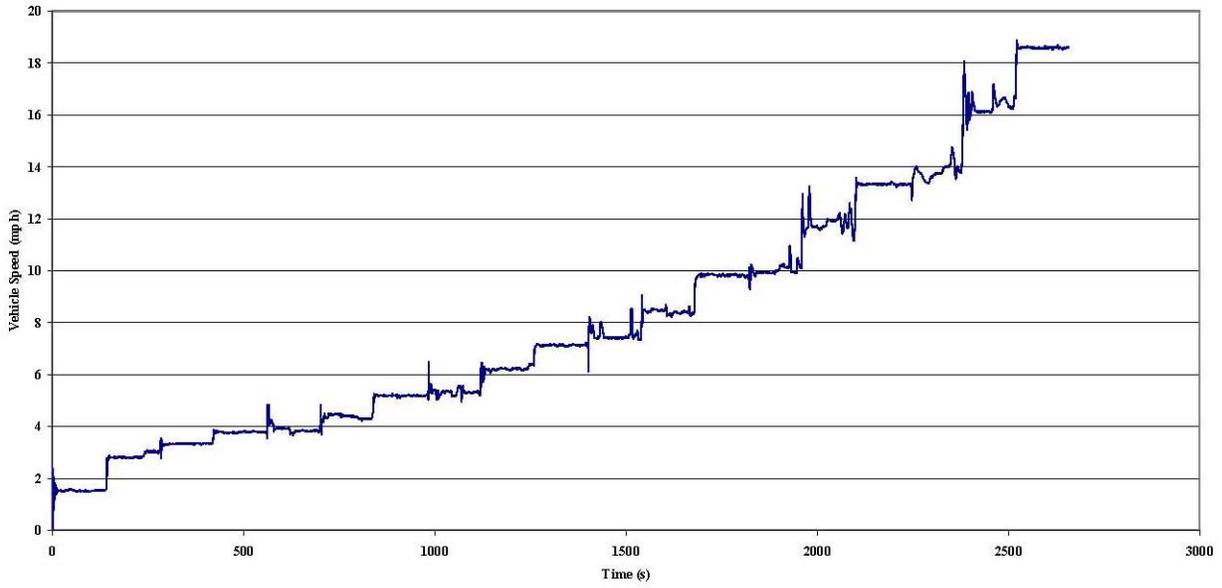


Figure 2-1 Scheduled vehicle speed trace for the Gear Change Matrix-Part 1

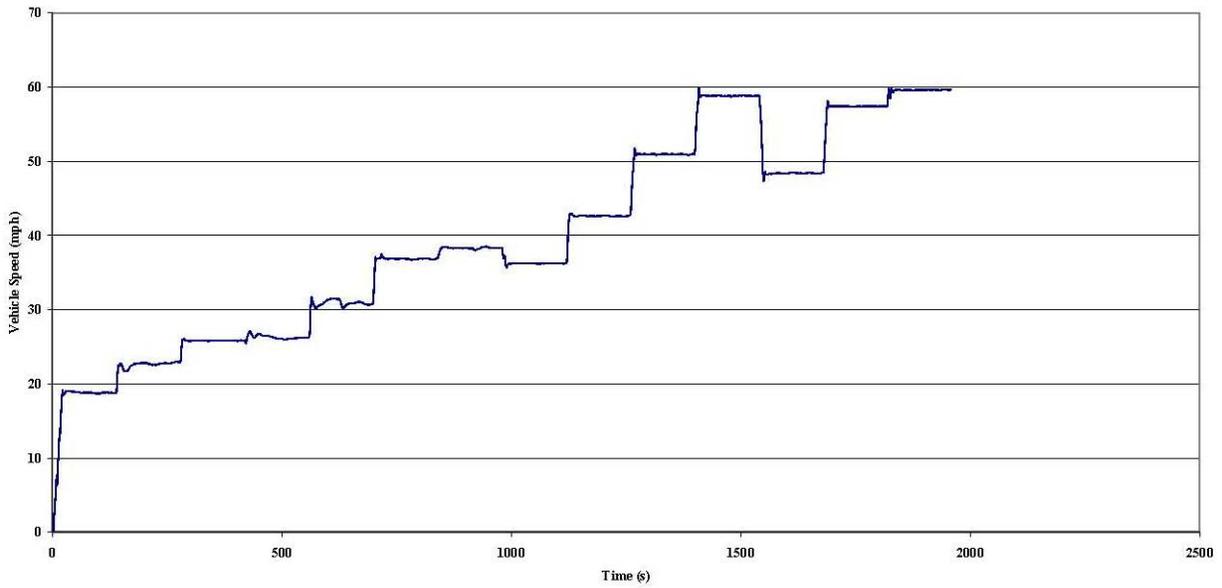


Figure 2-2 Scheduled vehicle speed trace for the Gear Change Matrix-Part 2

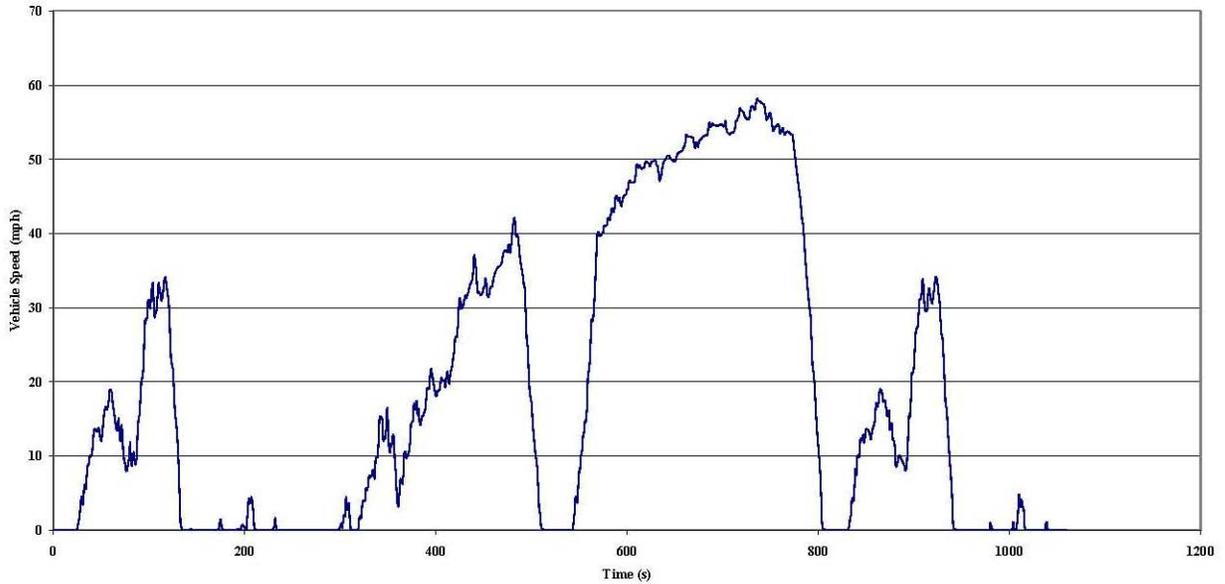


Figure 2-3 Scheduled vehicle speed trace for the UDDS cycle

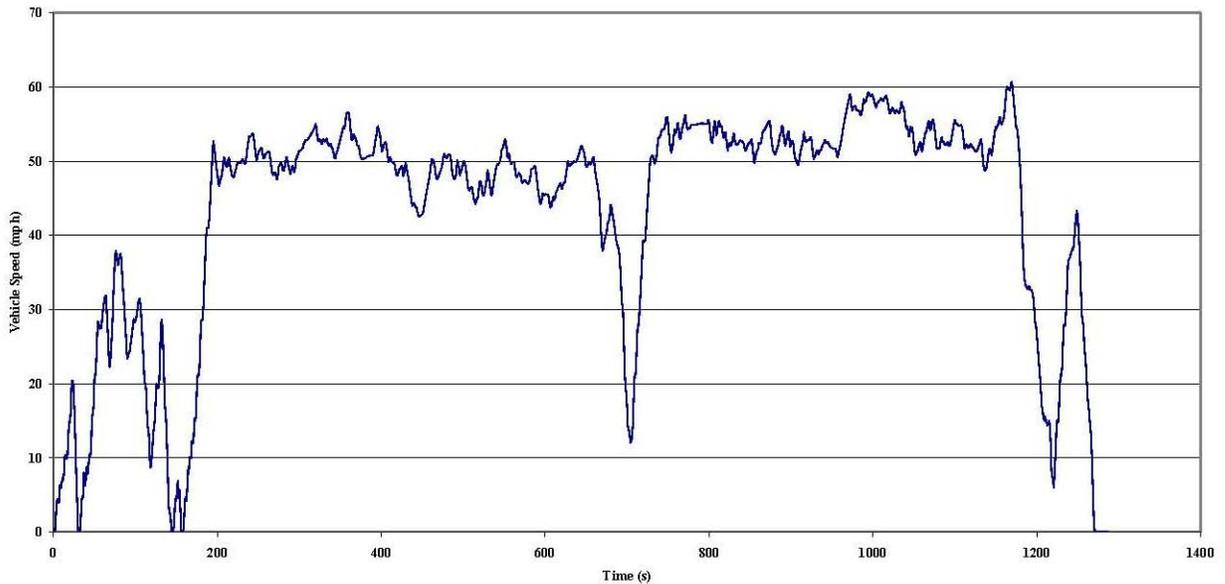


Figure 2-4 Scheduled vehicle speed trace for the In-Use cycle.

Coast-down Tests

Coast-down tests were performed under different configurations. Before the actual tests were conducted, the vehicle operated in order to raise the temperature at the differentials to about 88°F. The configurations are listed below:

- On the Chassis dynamometer
 - With the hub adapter
 - Without the hub adapter

When the coast-down tests were performed under this configuration the outer drive wheels were removed, with the brake drum still intact.

- With the vehicle mounted on the crib and wheels suspended in air
 - All eight wheels were removed with the brake drum intact.
 - Four wheels were removed with the brake drum intact
 - All eight wheels were intact.

The data files from these tests have been provided to the sponsor.

3 Experimental Setup

This section discusses the experimental setup and procedure used for measuring emissions from the test vehicle. Testing was conducted on WVU's Transportable chassis dynamometer Laboratory, stationed at Westover, WV. WVU's Transportable Heavy Duty Vehicle Emissions Testing Laboratory has been operational since 1993, traveling coast to coast with innumerable successful emissions tests to its credit. This mobile laboratory consists of chassis dynamometer, which is used for driving the test vehicle on desired duty cycles, and an instrumentation trailer that serves as the analytical component of the system. Laboratory quality instrumentation, including a full flow primary dilution tunnel, secondary tunnel for particulate sampling, regulated and unregulated gas emissions sampling trains, data acquisition, and control systems, are operated according to procedures and recommendations of 40CFR, Part 86, Subpart N. A detailed description of the laboratory equipment, test vehicle, and test cycle is discussed in the following sections.

Chassis Dynamometer

The chassis dynamometer test bed consists of rollers, flywheel assembly, eddy current power absorbers, differentials, hub adapter, torque and speed transducer built onto a tandem axle semi trailer. The hydraulic jack on the chassis dynamometer test bed is functional in setting the test bed on the ground and onto the trailer. The various components of the chassis dynamometer are discussed in detail below.

Rollers: The chassis dynamometer consists of a set of two paired rollers in the front which supports the single or forward drive axle and a set of single roller at the back in order to support the rear axle of tandem axle vehicles. The rear pair of rollers can be placed in three different positions to accommodate tandem spacing of 4 to 5 ft (1.22 – 1.52m) and each roller is 12.6 in (32 cm) in diameter with their axis along the length of the test bed. Each pair of rollers is linked by a flexible coupling to have uniform rotational speed on either side of the vehicle and the coupling was designed to accept 20% of the wheel torque in case of any imbalance due to uneven surface at the test location.

- Hub Adapters: The hub adapters are used to couple the engine drive axle with the flywheel assembly and eddy current power absorber via torque and speed transducer. The adapter is made of a 0.5 in (13 mm) thick aluminum plate of diameter 1.8 ft (0.55 m).
- Load Simulation System: The load simulation system consists of a flywheel assembly, an eddy current power absorber, a speed and torque transducer, double differentials and universal couplings on either side of the vehicle to be tested as shown in the figure below. The power from the vehicle's drive axle is transmitted to the flywheel assembly and power absorbers by a hub adapter which is connected to a 24 in (61 mm) long spline shaft running into a pillow block. The spline shaft is connected to the speed and torque transducer by a universal coupling which can withstand torque up to 16,415 lb-ft (222,256 N-m) on either side. The speed and torque transducer is capable of providing the data logging computer with time varying output torque at a rate of 10 Hz. The torque transducer drives a second shaft via companion flange. This shaft transfers power to a right-angle speed increasing drive, a double reduction differential with a ratio of 1:3.65 which drives the flywheel assembly and a second differential. The second differential with a ratio of 1:5.73 drives the eddy current power absorbers and a 20hp ac motor.
- Flywheel Assembly: The flywheel assembly is designed to simulate vehicle gross weights of 40,000 to 66,000 lb. With the maximum being 40,000 lb (18,144 kg) at a wheel diameter of 4 ft (1.22 m) and 66,000 lb (30,000) at a wheel diameter of 3.25 ft (1 m). The flywheel assembly consists of a drive shaft with four drive rotors running in two pillow blocks. Each drive shaft supports eight flywheels of different sizes with bearings resting on the shaft. By selectively engaging the flywheels to the drive rotors, vehicle mass can be simulated in 250 lb (113 kg) increments.
- Eddy Current Power Absorbers: A Mustang model CC300 air cooled eddy current dynamometer mounted on two bearings is used as power absorbers. The power absorbers are used to simulate load due to rolling friction of the tires and the aerodynamic drag resistance. The eddy current dynamometer has the capability of absorbing 300 hp (224 kW) continuously and 1000 hp (745.7 kW) intermittently during peak operation. Dynamometer load at any speed is controlled by the direct current supplied to the coils and the power absorbed is measured by the torque arm force transducer (load cell).

- AC Drive Motors: Two 20 hp variable speed motors, one on each side of the vehicle, provide limited motoring effort and help overcome frictional losses in the dynamometer drive train.

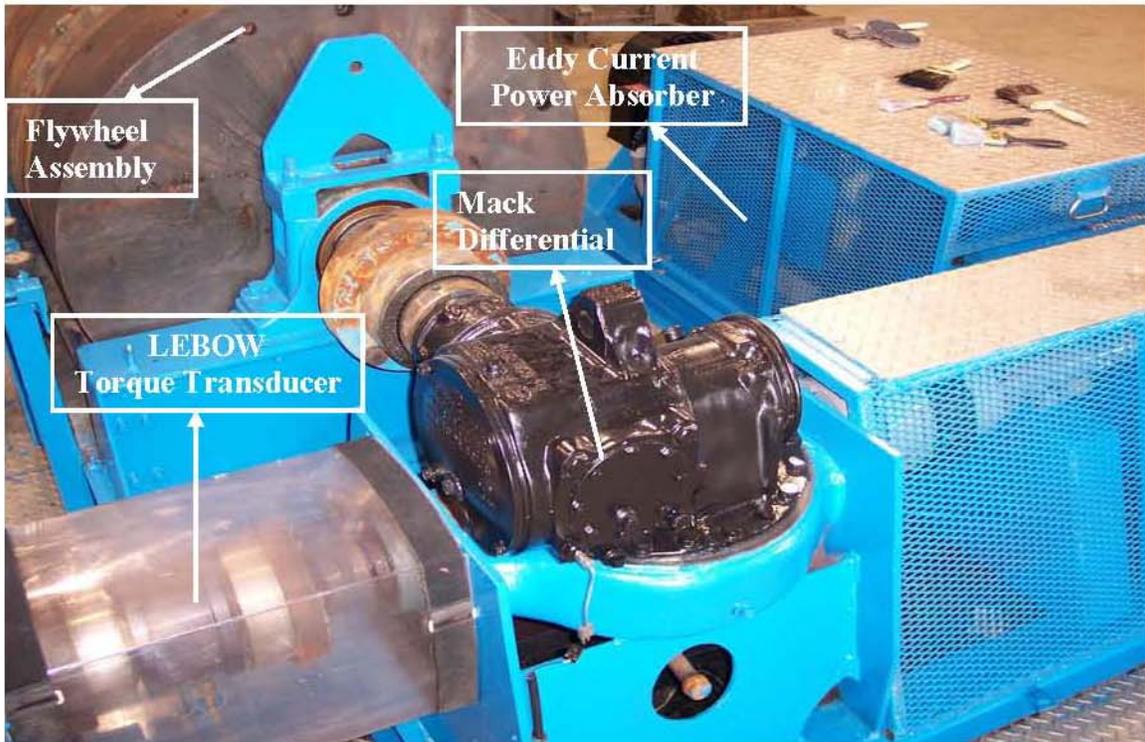


Figure 3-1 Components of a Chasis Dynamometer

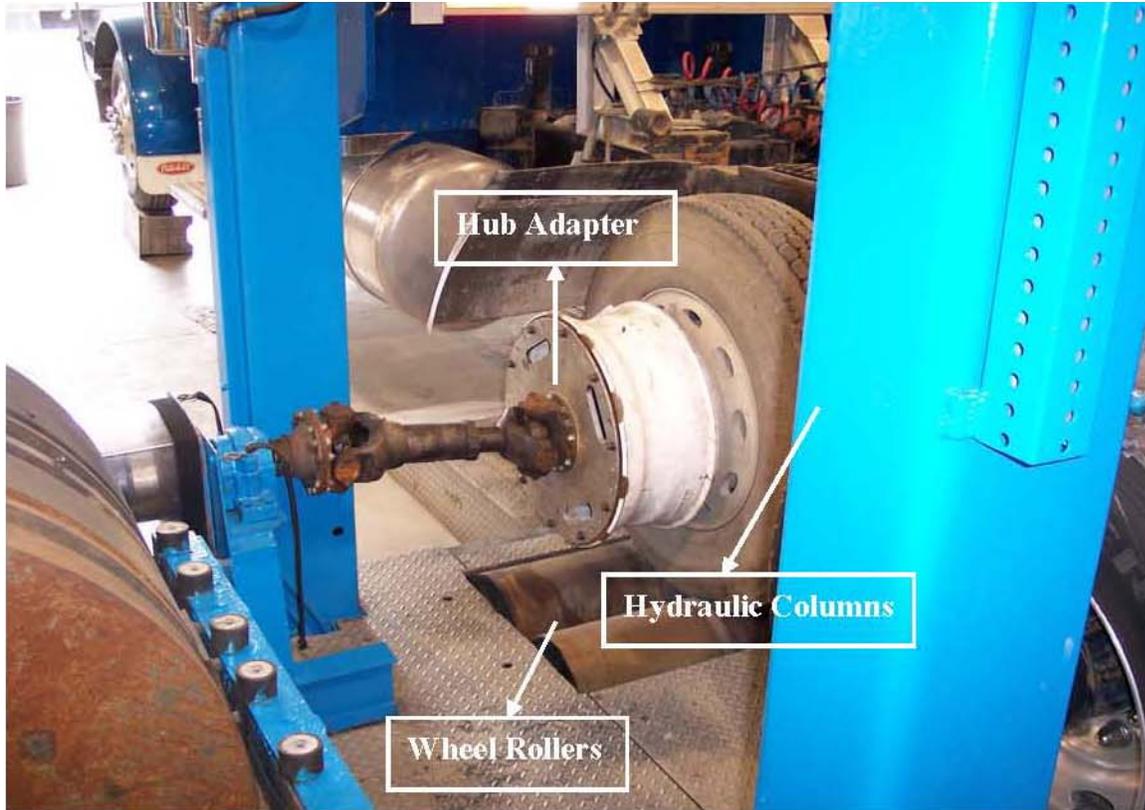


Figure 3-2 Connection and Support Structure of Chassis Dynamometer

According to the regulations published in CFR 40, Part 86, Subpart N the speed and load of a dynamometer must be controlled simultaneously. While the driver is responsible for the control of the speed, the transient torque must be controlled by an automated system. The load supplied by the flywheels simulates the static weight on the engine and is controlled by their rotational speed, while the load due to rolling friction and wind drag is simulated by the eddy current dynamometer. The eddy current dynamometer is controlled by a Dyn-Loc IV control system provided by Dyne-Systems. The Dyn-Loc IV control system operated by a PID control loop where “P” stands for proportional control in which the controller calculates error between the actual and the desired output resulting in a restoration signal linearly proportional to the error. “I” stands for integral control in which the controller calculates the average error over a time and provides a restoring signal which is the product of the error and the time the error persisted. It is used to restore the original set point. D stands for differential control in which the controller calculates the rate at which the set point is changed and produces a corrective signal to reach the set point quickly. Hence, PID controller provides a fast and smooth response in controlling the transient set points. During the test, the power absorbers receive the torque set point from the

dyne-loc controller. The set point is equal to the road load power and it is calculated using the following equation

$$P_r = (C_r M g + \frac{1}{2} \rho_a C_D A V^2) V \quad \text{Equation 3.1}$$

Where

P_r = Road load power

C_r = Coefficient of rolling resistance

M = Vehicle gravitational mass

ρ_a = Air density

A = Frontal area of vehicle

C_D = Coefficient of drag

V = Vehicle speed

The set point is updated every 100 milliseconds. The speed and torque values are logged at a frequency of 10 Hz to ensure the test has been performed to the specification.

Full Flow Clean Dilution Tunnel

In 2003, the WVU Transportable Laboratory was upgraded with a new full-flow dilution tunnel that could be used in addition to the original tunnel. Named the “Clean Dilution Tunnel,” the new addition was designed for and intended to be used exclusively for emissions from CNG-fueled heavy-duty engines. It has been observed from previous research studies that sampling exhaust gases from CNG engines from tunnels that had been exposed to diesel emissions would introduce sampling errors due to re-entrainment of particulates and out-gassing of compounds deposited on tunnel walls. The problem is particularly magnified when sampling CNG PM emissions from tunnels with extensive test history. High background PM levels, from re-entrainment and out-gassing, often result in negative values when testing ultra low emissions vehicles, since PM emissions levels will be closer to the collected background PM levels.

The clean dilution tunnel, designed and operated according to the regulations specified in CFR 40, Part 86, and Subpart N, is of the critical flow venturi – constant volume sampling (CFV-CVS) type, in which the diluted exhaust is drawn through critical flow venturi using a blower. The dilution tunnel was used to mimic the mixing of exhaust gas with ambient air in the

atmosphere and also to cool the exhaust gas sufficiently to reduce the dew point and avoid condensation. The condensation of exhaust gas in the tunnel will lead to artifacts in the values of the emissions reported as moisture will absorb certain gaseous compounds (example NO_2) and will interfere with certain exhaust measuring devices (example NDIR analyzers), and particulate measurements. The inner diameter of the tunnel is 18 inches which was selected according to the CFR 40, which specifies that the diameter should be at least 18 inches for particulate sampling, as in PM1, PM2.5 and PM10 using single dilution method. The Clean Dilution Tunnel was built as a stand alone system so that it could be used with other transportable labs operated by WVU. The tunnel was designed in several small sections as it could be easily transported. The tunnel consisted of 5 sections.

- Inlet Section: This section connects the mixing section with the HEPA filtered dilution air filtration system. This was designed as a necking section which reduces from 24 inches diameter on the mixing section side to 20 inches on the dilution air entrance side.
- Mixing Section: This section was made of a 24 inch diameter flanged section connected to an 18 inch flanged section via ribs welded between the two sections. This section was connected to the tunnel extension with an orifice plate in between the flanges. The orifice plate aids in inducing turbulent mixing between the dilution air and the exhaust gas which was introduced upstream of the orifice plate.
- Tunnel Extending Sections: Consists of two 18-inch diameter 7-ft long sections connected to each other by flanges. This section aids in thorough mixing of the exhaust and the dilution air before reaching the sampling section, satisfying the 10-diameter rule.
- Sampling Section: Consists of two 3-ft sections with the sampling ports located in the middle of each 3-ft section. The two sampling sections was connected to the tunnel extension section by flanges effectively positioning the first sampling zone at 15 ft 6 in from the mixing orifice, which meets and exceeds the 10-diameter rule set forth in CFR 40. The regulated emissions were sampled from first sampling zone while the unregulated emissions were sampled in the following sampling zone. Each regulated sampling zone consists of 8 sampling ports with flanges of 4.25 inch outer diameter while unregulated sampling zone consists of 8 sampling ports with alternating flanges of 4.25 inch and 7 inch outer diameters in order to accommodate probes of different sizes.

- **Outlet Section:** It is a reducing section with 18-inch flange connecting the sampling section to the critical flow venturi via a 12inch flexible tube fitted to an unflanged end, as shown in the figure below.

The above five sections were connected to each other with bolted flanges and gasket to have a leak proof seal. The gasket used was made of compressed non-asbestos, buna-nitrile material, which will prevent the material from out gassing under high temperature conditions. The fully connected tunnel was checked for leaks by injecting gas of known concentrations and measuring the same (propane injection).

Critical Flow Venturi

A constant mass flow rate was maintained in the tunnel by drawing the diluted exhaust through Critical Flow Venturi at choked condition. The CFV-CVS system can operate at nominal flow rates from 1000 to 3000 scfm which can be changed in increments of 500 scfm by threading the correct plug into the throat of the venturi. The change in the venturi throat diameter by the plug changes the flow rate. The nominal flow rates obtained at different throat diameters is shown in the table below.

Table 3-1 Venturi Throat Diameter and Flow Rates

Throat Diameter	Flow Rate
inches	SCFM
0.429	1000
0.701	1500
0.997	2000
1.324	2500
1.694	3000

At choked conditions the flow rate through the CFV is a function of the diameter of the venturi throat and the upstream temperature and pressure. The mass flow rate is then determined using the following equation

$$Q = \frac{K_v P}{\sqrt{T}} \quad \text{Equation 3.2}$$

Where

- Q = the flow rate in scfm at standard conditions (20° C and 101.3 kPa)
K_v = the discharge coefficient of the venturi
P = the absolute pressure at the inlet of the venturi in kPa
T = the absolute temperature at the inlet of the venturi in °K

The calibration of the venturi using an accurate flowmeter and a restrictor valve traceable to NIST standards is discussed in detail in the next chapter.

Secondary Dilution Tunnel and Particulate Sampling

A double dilution method in accordance with the CFR 40 was employed for collecting the particulate matter onto the filter. This method essentially involves drawing the diluted exhaust from the full flow dilution tunnel into the secondary dilution tunnel at the sampling zone. The sample in the secondary dilution tunnel can be further diluted by additional air in order to keep the filter face temperature below 125 °F, although secondary stage dilution was not used for this study. The diluted exhaust from the secondary tunnel is passed through two fluorocarbon coated glass fiber filters (T60A20), housed in a stainless steel filter holder, to collect particulate matter, which consists of elemental carbon, soluble organic fraction, sulfates and bound water. The T60A20 filters used for collecting PM exhibited 99.95% collection efficiency for particle size of 0.3µm and below.

The secondary dilution tunnel consists of 30 inches long stainless steel tube of 3-in diameter providing sufficient residence time in order to mix with the secondary air and reduce the temperature to 125 °F. The exhaust is drawn into the secondary tunnel through a 0.5-inch diameter transfer tube from the sampling zone. The flow into the dilution tunnel is controlled by two rotary vane pumps and two mass flow controllers, one each for the total secondary tunnel flow and secondary dilution air flow. The mass flow controller is recalibrated periodically using a laminar flow element. The range of total secondary tunnel flow is 0-6 scfm and 0-3 scfm for secondary dilution airflow.

Gaseous Emissions Sampling System.

The gaseous emissions sampling system consisted of heated probes with “tip span” feature, heated sample lines and gas analyzer bench built in accordance to CFR 40 regulations.

The samples were drawn 10-diameters downstream of the mixing zone in order to ensure thorough mixing of the exhaust with dilution air and a fully developed turbulent flow. The exhaust emissions were sampled by gas analyzers via heated lines and the flow to the analyzers were controlled by flow meters and magnahelic pressure regulators. Four separate heated probes and sample lines were used to sample THC, NO_x, CO/CO₂ and aldehydes. The temperature of the probes and the sample lines were controlled and maintained by a Temperature Control Module (TCM) (Burlingame, 2004). The sample lines were chosen depending on the gas to be analyzed by the analyzer, Teflon coated lines were used for sampling CO, CO₂, NO_x and aldehydes while a stainless steel heated line was used for analyzing THC as the line was maintained at a higher temperature.

The mass emissions rates of the exhaust gases from the test were determined by measuring the concentration and the total flow.

Criteria Pollutants Sampling System

The analyzers used for sampling regulated gaseous emissions were housed in the analytical trailer, where all the dynamometer control and signal conditioning devices were placed. The gas analyzers used heated lines to sample from the dilution tunnel. The samples were conditioned for a set humidity and temperature, using chillers and temperature control module. The regulated emissions bench consisted of CO₂ analyzer, CO analyzer, NO_x analyzer and THC analyzer. The operating principle and the sample condition required for these analyzers are explained in the following sections.

Oxides of Nitrogen (NO_x) Analyzer.

The regulated emissions bench consisted of two Rosemount Model 955 NO_x analyzers one for analyzing NO and the other for analyzing NO_x. Both NO and NO_x samples were sampled from same heated probe and sampling line, which were maintained at a temperature of 240 °F (115.5 °C) during the test. The sample line was maintained at a high temperature in order to prevent condensation of water, thereby reducing losses of water soluble NO₂.

The analyzer uses heated chemiluminescent method to determine NO and NO_x. For NO determination the sample is quantitatively converted into NO₂ by gas-phase oxidation with molecular ozone. As a result of this reaction, approximately 10% of the NO₂ molecules are

raised to an electronically excited state, followed by immediate reversion to the non-excited state accompanied by emissions of photons. The photons emitted impinge on a photo-multiplier detector generating a low-level DC current proportional to the amount of NO present in the sample. The NO_x analyzer operates on the same principle as the NO analyzer, except the sample is passed through a converter where NO₂ is converted into NO before entering into the reaction chamber. Now the analyzer response will be proportional to the NO present in the original sample plus the NO produced by dissociation of NO₂.

Carbon Monoxide (CO)/Carbon Dioxide (CO₂) Analyzer

Even though CO and CO₂ emissions are not regulated, they were measured continuously in order to determine dilution factor in the tunnel and to calculate fuel consumption of the vehicle being tested. The CO and CO₂ in the sample were analyzed using Horiba Model AIA-210 and Rosemount Model 880A Non-Dispersive InfraRed analyzers. Both carbon monoxide and carbon dioxide were sampled from the same heated probe and heated sample line. The sample line was maintained at a temperature of 240 °F (115.5 °C) in order to avoid water condensation in the sample line, thereby preventing water soluble compounds in the exhaust from dissolving in condensed water. The sample was passed through a refrigerator/dryer system before entering into the analyzer to remove any traces of water in the sample as it would affect the analyzer response. The sample was passed through heated filter element in order to prevent particulate matter entering into the analyzer.

NDIR analyzer works on the principle of selective absorption of infrared energy. The analyzer consists of two cells, a flow through sample cell and a sealed reference cell, through which two equal energy infrared beams are passed. The difference between the infrared energy absorbed by the two cells is continuously measured, using solid state electronics, and it is proportional to the amount of CO/CO₂ present in the sample. There are two CO analyzers in the bench, one for low CO which had an operating range from 0-100ppm and 0-2500ppm and the other one for high CO which had an operating range of 0-1000ppm and 0-5000ppm. The CO₂ analyzer had an operating range of 0-2% and 0-6%.

Total Hydrocarbon (THC) Analyzer

A Beckman Model 402 hydrocarbon analyzer working on the principle of Heated Flame Ionization Detector was used to analyze Total Hydrocarbons (THC). The HC sampling system included a heated probe with heated sampling line maintained at a temperature of 375°F (190.5°C) in order to prevent heavier hydrocarbons from condensing, and reducing error in the HC measurement. The analyzer has an operating range from 5-250,000ppm carbon.

The hydrocarbon analyzer consists of a burner which works as a sensor through which a regulated flow of sample gas is passed. The flame in the burner is sustained by regulated flows of fuel gas and air (40% hydrogen and 60% helium). The hydrocarbon passing through the flame undergoes a complex ionization process that produces electrons and positive ions. Polarized electrodes collect these ions, causing current to flow through an electronic measuring circuit. The ionization current generated is proportional to the rate at which carbon atoms enter the burner, and hence a measure of the concentration of the hydrocarbons in the original sample.

Media Conditioning and Weighing

The media used in collecting PM for gravimetric analysis were conditioned and pre-weighed in the WVU EERL facility before transporting them to the test site. The filters were conditioned in an environmentally controlled chamber maintained at 70 °F with a relative humidity of 50%, for at least 1 hour before being weighed according to CFR 40 specifications. The 70mm filters were placed in the glass petri dishes, with their lids closed but not sealed in order to prevent dust from accumulating on the media while allowing for humidity exchange. Two reference filters were conditioned with the test filters and placed in the environmental chamber in order to account for change in the filter weight due to fluctuation in humidity. The reference filters were weighed before and after any set of media were weighed to ensure that the conditions in the environmental chamber were stable.

The filters were pre-weighed after a stabilization period of 24 hours using a Metler – Toledo Microbalance. The balance was interfaced with a computer in which the filter weights were logged for future reference and use. The filters were conditioned for several hours in the chamber before the petri dishes were sealed and packed in padded envelopes for shipping to the test site.

Media Labeling

A unique number with a barcode was assigned for each media in order to identify the media with their respective pre and post weights while automating the process of tracking filter weights. The barcode labels were placed on the petri dishes and on the QA/QC sheet to identify the media with test sequence and run numbers. As there were various media types involved in this project, a color coding system was followed for identifying the media with the species to be sampled. The probes and the sampling system on the dilution tunnel were also color coded to aid in loading the sampling media at correct locations on the tunnel.

Media Shipping and Tracking

The petri dishes containing the filter media were sealed and placed in padded envelopes after they had been pre-weighed. The set of envelopes containing media required for one test were placed together to aid in quick loading of the media into the sampling system. The sealed media were transported overnight to the test site in coolers filled with frozen water pouches. After the media was received at the test site it was placed in the conditioning room until used. A media tracking application was developed to identify the media with the test sequence and run number. The tracking tool also aided in QA/QC protocol. The used media were placed back into their respective petri dishes in the conditioning room and were tracked before shipping to the location, where they were analyzed.

Media Handling and Use

The media required for particulate matter emissions were removed from their storage location and loaded into their sampling device. The media loading was done in a controlled environment when the exhaust was ready to be sampled. Before loading the media, the barcodes were logged into a used media database with respect to the test sequence and run number so that the sample collected on the media can now be associated with a particular test. A set of media were used as field blank to study the effect of transportation and conditioning at the test site on the filter mass.

4 Emissions Testing Procedure

Set-up

The chassis dynamometer, which is built onto a flat bed trailer, was set-up on a flat surface and leveled to prevent variation in the vehicle's inertial loading, which is simulated using rotating flywheels. The instrumentation trailer that houses the analyzers, dilution tunnel, dynamometer control, and signal conditioning devices was placed close to the chassis dynamometer. This reduced the length of exhaust tubing between the tail pipe and the dilution tunnel, in-turn reducing thermophoretic and other particulate matter losses in the transfer tube. Since a new dilution tunnel was used for this test the tunnel was mounted close to the instrumentation trailer using height adjustable stands. The blower/CFV was placed at the end of the dilution tunnel and a flexible air duct was used in connecting the tunnel to the blower/CFV. The HEPA filtered dilution air was connected to the inlet of the dilution tunnel by a flexible air duct. After all the connections were made to the dilution tunnel the instrument trailer was prepared for testing.

The instrument trailer set-up included preparing emissions bench, environmental chamber and dynamometer controls. The connections between the gas bench, probes, sample lines and secondary dilution tunnel were left attached to the primary dilution tunnel, installed in the trailer during transportation, so that the system is ready for testing with minimum set-up time. Since a clean dilution tunnel was used for this test the probes, sampling lines and the secondary dilution tunnel was attached after the primary dilution tunnel was assembled. The probes were attached such that they were facing upstream of the flow. Sampling system was leak checked and blown out with high pressure air to clean the lines from any residual particulate matter. The primary dilution tunnel was covered with heat insulation wraps to prevent thermophoretic loss of particulate matter. Thermocouples were installed at mixing zone, sampling zone, secondary dilution air inlet, and at the filter face.

The laboratory was capable of testing the vehicles without the need for electrical power at the test location. When available and convenient, power is taken from the source at the test location. However, if unavailable, a 135 hp (100 kW) generator was used to power the blower, power absorber, and instrumentation.

The air compressor and zero air generators were powered well in advance in order to store enough air which is required in running NO_x and HC analyzers. The analyzers were powered and allowed to stabilize once the air required to operate them was available. After the

stabilization period the temperatures were verified and the analyzers were prepared for calibration.

Analyzer Calibration

The calibration of the analyzers was performed in accordance with the regulations stated in CFR 40, Part 86, and Subpart N. All the analyzers were calibrated to the range of emissions level that was observed in the vehicle being tested. The span gases used to calibrate the analyzers had an accuracy of 1% traceable to NIST, whereas the zero reference was attained by using the zero air generated at the site. The flame in the HFID analyzer used for HC analysis was fueled by a mixture of 40% hydrogen and 60% helium. Once the analyzers are stabilized the temperature of the sampling lines are verified and a 10 point calibration was performed. A gas divider was used to obtain 10 equally spaced concentration levels by mixing the span gas and the zero air. The analyzers were allowed to stabilize at each calibration point and a computer averaged reading of that value was recorded. After the calibration the data points corresponding to the gas concentration were fitted to a polynomial curve which is used in converting the ADC codes to engineering units. The analyzers were checked for zero and span values before and after each test and the drift value was found to be more than 3% for THC, 2% for CO/CO₂ and NO_x they were recalibrated and the test was repeated. The analyzers were recalibrated with different span gas concentration if the emissions were out of its range of measurement. The calibration was performed frequently and these calibration files were overwritten by the new calibration points in order to prevent the use of wrong calibration files.

A 'FID burner peaking test' was performed on the THC analyzer to determine the highest Heated Flame Ionization Detector (HFID) response. In this process the analyzer response was measured for 100% span gas and zero air for different combination of FID burner fuel and air pressures. The setting at which the analyzer gave the highest response was selected and used. An 'HC hang-up' check was also performed on the FID analyzer. The sampling probes were back flushed and steps were taken to rectify if the difference in the response was more than 2%.

An oxygen interference test, prescribed in 40 CFR, Part 86, Subpart N, was also performed on the FID. This test was conducted to verify analyzer sensitivity to changes in sample O₂ concentration.

NO_x efficiency test was performed on the NO_x analyzer, in order to determine the converter efficiency in converting NO to NO₂. If the conversion efficiency turned out to be less than 90% then maintenance was performed to rectify the situation.

Water interference check was performed on NDIR analyzers used for analyzing CO/CO₂ as moisture could affect the response of these analyzers. The test was performed by supplying the span gas bubbled through water to the analyzer via dryer/chiller.

Mass Flow Controller Calibration

Mass flow controllers were used in controlling the flow through cyclonic particle classifier, TPM flow through the filter and various other unregulated emissions sampling systems. A Manufacturer-supplied calibration curves was verified against a Laminar Flow Element supplied by Meriam Flow Measurement Devices. Meriam provides a calibration equation and co-efficient for each LFE which is obtained through calibration involving a flow meter that is traceable to NIST standards. A five point calibration verification was performed on the MFCs between fully open and fully closed position. The flow through the LFE was calculated using the following equation

$$\dot{V}_{\text{actual}} = [B \times (\Delta P) + C \times (\Delta P)] \times \frac{\mu_{\text{std}}}{\mu_{\text{flow}}} \quad \text{Equation 5.1}$$

Where

B & C = LFE specific co-efficient

ΔP = Pressure differential measured across LFE

$\frac{\mu_{\text{std}}}{\mu_{\text{flow}}}$ = Viscosity correction factor

The viscosity variations was calculated using the correction factor given in the following equations

$$\text{Correction factor} = \left(\frac{529.67}{459.67 + T(\text{in } ^\circ\text{F})} \right) \times \left(\frac{181.87}{\mu_g} \right) \quad \text{Equation 4.2}$$

$$\mu_g = \frac{14.58 + \left(\frac{459.67 + T(\text{in } ^\circ\text{F})}{1.8} \right)}{110.4 + \left(\frac{459.67 + T(\text{in } ^\circ\text{F})}{1.8} \right)} \quad \text{Equation 4.3}$$

Differential pressure across the LFE and absolute pressure was measured using a Heise pressure reader and the temperature was measured using a Fluke Temperature calibrator. The actual flow measured through the LFE was converted to standard flow by CFR 40 specified standard condition of 20 °C and 101.1 kPa.

CFV-CVS Calibration

The Critical Flow Venturi used in the Constant Volume Sampling system was calibrated using subsonic flowmeter and an accurate flow restrictor as specified in CFR 40. The calibration of the CFV is based on the following flow equation for a critical venturi where gas flow is a function of inlet temperature and pressure.

$$Q_s = \frac{K_v P}{\sqrt{T}} \quad \text{Equation 4.4}$$

Where

Q_s = Flow rate in cfm

P = Absolute inlet pressure, kPa

T = Absolute inlet temperature, °K

K_v = Calibration co-efficient

The calibration set-up was leak checked before taking the readings, initially the blower was started with flow restrictor completely open. The pressure reading was recorded after the system was stabilized. The flow restriction was varied to obtain eight readings in the critical flow range

of the venturi. The air flow rate Q_S at each data point is calculated in standard cubic feet per minute and calibration co-efficient is calculated using the following equation

$$K_V = \frac{Q_S \sqrt{T_V}}{P_V} \quad \text{Equation 4.5}$$

Where

Q_S = Flow rate in standard cubic feet per minute at standard conditions 20 °C and 101.1kPa

T_V = Venturi inlet temperature, °K

P_V = Venturi Inlet Pressure, kPa

During choked flow conditions K_V will have a relatively constant value, as the pressure decreases the flow becomes unchoked and the value of K_V decreases drastically. The calibration co-efficient is determined for a minimum of 8 points in the choked region, the average calibration co-efficient and standard deviation is calculated. If the standard deviation exceeded 0.3% of the average K_V value then corrective action was taken.

CFV-CVS Calibration Verification

The CVS system was verified by injecting a known quantity of propane into the primary dilution tunnel while CFV-CVS system operating. The concentration of the propane was determined using a pre-calibrated HFID analyzer and the mass of propane injected was measured by the flow data and the density of propane. The propane injection test helped in determining leak in the tunnel and any discrepancy in the flow measuring device (CFV-CVS system). CFR 40 proposes a gravimetric method while Horiba describes a critical orifice method in performing the propane injection test.

In the gravimetric method, a small cylinder is charged with pure propane and weighed to the nearest 0.001 grams. After weighing the cylinder some amount of propane is injected into CVS system with the blower operating. The cylinder is reweighed to determine the gravimetric mass of propane injected into the CVS. The HC analyzer was used in measuring the amount of propane injected into the CVS system. The mass measured by the CVS and the gravimetric mass

of propane injected were then used in calculating the percent accuracy using the following equation

$$\%Acc = \frac{G_m - M_{mCVS}}{G_m} \times 100 \quad \text{Equation 4.6}$$

Where

G_m = Gravimetric mass

M_{mCVS} = Mass measured by CVS

If the %Acc was greater than $\pm 2\%$ was considered a failure and necessary action was taken to rectify the error.

The second method used a propane injection kit with a critical flow orifice meter to accurately measure the amount of propane injected into the tunnel. The flow rate of propane through the orifice meter is determined by measuring the inlet temperature and pressure using the following equation

$$q = \frac{A + (B \times P) + (C \times P^2)}{\sqrt{460 + T}} \quad \text{Equation 4.7}$$

Where

q = flow rate through orifice in scfm at standard condition (20 °C and 101.1 kPa)

A, B and C = calibration co-efficients provided by the orifice manufacturer

P = absolute orifice inlet pressure, in psia (guage pressure + atmospheric pressure)

T = orifice inlet temperature in °F

The total flow through CVS is given by the following equation

$$Q = \frac{V}{t} \times 60 \quad \text{Equation 4.8}$$

Where

Q = total volume in scf

V = flow rate in scfm measured by CVS

T = time interval in seconds, usually 300 seconds

The calculated sample concentration was determined by the following equation

$$C_{\text{calc}} = \left(\frac{q}{Q} \times 10^6 \right) \times 3 \quad \text{Equation 4.9}$$

The system error was then given by

$$\text{Error} = \left(\frac{C_{\text{obs}}}{C_{\text{calc}}} - 1 \right) \times 100 \quad \text{Equation 4.10}$$

Where

C_{obs} = measured concentration of the injected propane by HFID analyzer

If the error is greater than $\pm 2\%$, then the cause for discrepancy was found and corrected. The error could be for two reasons, due to leak in the system or the venturi may be heavily loaded and improper calibration of HFID analyzer. The critical flow orifice method was used in the WVU facility because of its size advantage when compared to gravimetric method.

Test Procedure

Before mounting the vehicle on the chassis dynamometer the appropriate flywheel combination was determined and locked in place to simulate the inertial load of the vehicle. The two inertia settings were 20,300 and 41,248 lbs. The outer rear wheel on the drive axle is removed and fitted with hub adapters which are later connected to the face plate. The vehicle was backed onto the dynamometer and the vehicle drive axle which drives the flywheel assembly and power absorbers was connected through a hub adapter. The vehicle was leveled with the drive axle and the tires were checked for any distortion as it would add to the vehicle loading. The vehicle exhaust was now connected to the dilution tunnel via insulated transfer tube. The vehicle was chained down to the dynamometer bed as a safety measure.

The vehicle was made to run at a high speed after being mounted on the dynamometer to warm the lubricating oil in the differentials. This was done to reduce additional load on the vehicle due to cold, highly viscous oil. During differential warm-up, the gas analyzers were zero-spanned with blower operating normally. The driver interface speed monitor and communication head sets were implemented to aid the driver in following the scheduled drive cycle. A dummy test

was conducted by making vehicle to run over the scheduled drive cycle with dummy media loaded in the tunnel to check whether the gas analyzers operated within the range for which they were calibrated and to check the flow through the mass flow controllers. If the analyzers pegged or measured below the range, then they were recalibrated with proper span gas and the mass flow controllers were checked for any malfunction. After the warm-up run, the vehicle was shut down and allowed to soak for twenty minutes. During the soak time, the official media required for various sampling were loaded in their respective holders and mounted onto the tunnel. The media loading was carried out in the controlled chamber to avoid accumulation of dust or other debris, a set of field blanks were maintained to study the effect of transportation on the used and unused media. The color coding was of great help in loading the media onto their respective location on the tunnel. The bags used to sample the dilution air and the exhaust continuously was evacuated before the test using pumps and vacuum gauge to indicate when the bags were fully evacuated.

The driving schedule used for this test was the AQMD refuse truck cycle and the Compaction cycle. A warm-up refuse truck cycle was setup to warm the engine, and the vehicle was left for a 20 minute soak period before the actual testing began. Unregulated samples were collected for two consecutive refuse truck cycle and three consecutive compaction cycles to get enough loading on the media. Temperature, pressure, humidity and the flow data were continuously recorded at a frequency of 10Hz on the data logging computer. The speed of the vehicle was controlled by the driver according to the driving schedule displayed on the monitor placed in the vehicle. The torque set point for the power absorber was controlled by the host computer. If there was any failure in the dynamometer or data acquisition, or any discrepancy in the followed driving schedule, the driver was alerted by the communication head set and the test was repeated. After the completion of one complete refuse or compaction cycle, the vehicle was shut down and allowed to soak for twenty minutes, allowing the vehicle to return to its rested state to eliminate test to test variability. During the soak time, the unregulated media was either replaced or left without changing, depending upon the number of test cycle sample collected into it. Appropriate containers and a new set of media were loaded back in different sampling systems. During the soak time, one of the field engineers was responsible to make sure the flow rate data controlled by the mass flow controller were within limits. If there was any problem, then corrective action was taken before repeating the next set of test cycles. All the data required for emissions

calculation was stored in the data logging computer. This data was reduced by a post processing program to give the emissions results in grams/mile units.

Emissions Calculations

The continuous voltage signal transmitted by the gas analyzers during the test were converted to ADC codes by an analog to digital converter before storing in the computer. The ADC codes were converted to ppm concentration values using the calibration equations of different analyzers by a post processing program. The concentration value, in ppm, together with the total volume of exhaust sampled, dilution factor and background concentration level was used in calculating the distance specific emissions rates.

The total volume of the dilute exhaust drawn through the tunnel over a period of time was given by the following equation. This equation was used in calculation regulated and unregulated emissions in distance specific units.

$$V_{\text{mix}} = \sum_{i=1}^n (V_{(\text{mix})i} \times \Delta t) \quad [\text{CFR40 Part 86}] \quad \text{Equation 4.11}$$

Where

$V_{(\text{mix})i}$ = Instantaneous dilute exhaust gas mixture flow rate (ft^3/sec), was given by the following equation

$$V_{(\text{mix})i} = \frac{K_v \times P_{vi}}{\sqrt{T_{vi}}} \quad [\text{CFR40 Part 86}] \quad \text{Equation 4.12}$$

Δt = Time interval between instantaneous measurement points (seconds)

n = number of instantaneous points taken during the test

K_v = Calibration constant for Critical Flow Venturi corrected to standard conditions during calibration

P_{vi} = Instantaneous absolute pressure at venturi inlet (in. Hg)

T_{vi} = Instantaneous temperature at the venturi inlet ($^{\circ}$ R)

Dilution Factor is a ratio of the theoretical amount of carbon dioxide in the raw exhaust due to stoichiometric combustion to the summation of actual measured concentration of CO, CO₂ and the individual components of the organic matter. The composition of the fuel used is given by C_xH_yO_z as a measurement for the fuel used.

$$DF = \frac{100 \times \left(\frac{x}{x + y/2 + 3.76 \times (x + y/4 - z/2)} \right)}{\left(CO_{2e} + CO_e + \sum OM_e \right) \times 10^{-4}} \quad [\text{CFR40 Part 86}] \quad \text{Equation 4.13}$$

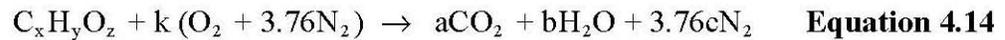
Where

CO_{2e} = Carbon dioxide concentration of the dilute exhaust sample corrected for background, in ppm.

CO_e = Carbon monoxide concentration of the dilute exhaust sample corrected for background, in ppm.

$\sum OM_e$ = Summation of the individual components of the organic matter such as HC_e , CH_3OH_e etc in ppm carbon equivalent.

The numerator is the concentration of the CO_2 present in the stoichiometrically combusted air/fuel mixture which is determined by the following equation



The constants a, b, c is obtained by solving the following equations

$$\begin{aligned} \text{C:} \quad & x = a \\ \text{H:} \quad & y = 2b \\ \text{O:} \quad & z + 2k = 2a + b \\ \text{N}_2: \quad & k = c \end{aligned}$$

This gives the following result

$$\begin{aligned} a &= x \\ b &= y/2 \\ c &= x + y/4 - z/2 \end{aligned}$$

Equations to Calculate Distance Specific Mass of Regulated Emissions

The distance specific mass of the regulated emissions, is defined as the ratio of the mass of an exhaust constituent to the distance traveled by the vehicle. The mass of each of the exhaust constituent is determined using the following general equations.

$$\dot{CO}_{mass} = \sum_{i=1}^n \left[\frac{(CO_e)_i}{1 \times 10^6} \times V_{(mix)i} \times \rho_{CO} \times \Delta t \right] - \frac{CO_d}{1 \times 10^6} \times \left(1 - \frac{1}{DF} \right) \times V_{mix} \times \rho_{CO}$$

[CFR40 Part 86] **Equation 4.15**

Where

$(CO_e)_i$ = Instantaneous carbon monoxide concentration of the dilute exhaust sample taken from the CO analyzer, in ppm.

$V_{(mix)i}$ = Instantaneous dilute exhaust gas mixture flow rate, in scfm.

ρ_{CO} = Density of carbon monoxide which is 32.97 g/ft³ at STP.

Δt = Time difference between two instantaneous measurement points, in sec.

CO_d = Concentration of carbon monoxide in the dilution air corrected for water vapor, in ppm.

$$CO_d = (1 - 0.000323 \cdot R) \cdot CO_{dm} \quad \text{[CFR40 Part 86] **Equation 4.16**}$$

R = Relative humidity.

CO_{dm} = Concentration of carbon monoxide of the dilution air as measured, in ppm.

DF = Dilution Factor.

V_{mix} = Total volume of dilute exhaust gas mixture for the entire test, in ft³.

Similarly the mass of Carbon dioxide is determined by the following equation

$$\dot{CO}_{2mass} = \sum_{i=1}^n \left[\frac{(CO_{2e})_i}{1 \times 10^6} \times V_{(mix)i} \times \rho_{CO_2} \times \Delta t \right] - \frac{CO_{2d}}{1 \times 10^6} \times \left(1 - \frac{1}{DF} \right) \times V_{mix} \times \rho_{CO_2}$$

[CFR40 Part 86] **Equation 4.17**

Where

$(CO_{2e})_i$ = Instantaneous carbon dioxide concentration of the dilute exhaust sample taken from the CO₂ analyzer, in ppm.

$V_{(mix)i}$ = Instantaneous dilute exhaust gas mixture flow rate, in scfm.

ρ_{CO_2} = Density of carbon dioxide which is 51.81 g/ft³ at STP.

Δt = Time difference between two instantaneous measurement points, in sec.

CO_{2d} = Concentration of carbon dioxide in the dilution air corrected for water vapor, in ppm.

DF = Dilution Factor.

V_{mix} = Total volume of dilute exhaust gas mixture for the entire test, in ft^3 .

The mass of the oxides of nitrogen was calculated by the following equation

$$\dot{\text{NO}}_{\text{xmass}} = K_H \times \sum_{i=1}^n \left[\frac{(\text{NO}_{\text{x}e})_i}{1 \times 10^6} \times V_{(\text{mix})i} \times \rho_{\text{NO}_x} \times \Delta t \right] - \frac{\text{NO}_{\text{x}d}}{1 \times 10^6} \times \left(1 - \frac{1}{\text{DF}} \right) \times V_{\text{mix}} \times \rho_{\text{NO}_x}$$

[CFR40 Part 86] **Equation 4.18**

Where

$(\text{NO}_{\text{x}e})_i$ = Instantaneous oxides of nitrogen concentration of the dilute exhaust sample taken from the NO_x analyzer, in ppm.

$V_{(\text{mix})i}$ = Instantaneous dilute exhaust gas mixture flow rate, in scfm.

ρ_{NO_x} = Density of oxides of nitrogen which is 54.16 g/ft^3 at STP assuming that they are in the form of NO_2 .

Δt = Time difference between two instantaneous measurement points, in sec.

K_H = Humidity correction factor, which is given by

$$K_H = \frac{1}{(1 - 0.0026 \times (H - 75))} \quad [\text{CFR40 Part 86}] \quad \text{Equation 4.19}$$

$$H = \frac{(43.478 \times R_i \times P_d)}{\left(P_b - \frac{(P_d \times R_i)}{100} \right)} \quad [\text{CFR40 Part 86}] \quad \text{Equation 4.20}$$

H = Absolute humidity of the engine intake air in grains of water per pound of dry air.

R_i = Relative humidity of the engine intake air, in %.

P_d = Saturated vapor pressure, mm Hg, at the engine intake air dry bulb temperature

P_b = Barometric pressure, mm Hg.

$\text{NO}_{\text{x}d}$ = Concentration of oxides of nitrogen in the dilution air corrected for water vapor, in ppm.

R = Relative humidity.

DF = Dilution Factor.

V_{mix} = Total volume of dilute exhaust gas mixture for the entire test, in ft^3 .

The mass of hydrocarbons is determined by using the following equation

$$\text{THC}_{\text{mass}} = \sum_{i=1}^n \left[\frac{(\text{HC}_e)_i}{1 \times 10^6} \times V_{(\text{mix})i} \times \rho_{\text{HC}} \times \Delta t \right] - \frac{\text{HC}_d}{1 \times 10^6} \times \left(1 - \frac{1}{\text{DF}} \right) \times V_{\text{mix}} \times \rho_{\text{HC}}$$

[CFR40 Part 86]

Equation 4.21

Where

$(\text{HC}_e)_i$ = Instantaneous carbon dioxide concentration of the dilute exhaust sample taken from the CO₂ analyzer, in ppm.

$V_{(\text{mix})i}$ = Instantaneous dilute exhaust gas mixture flow rate, in scfm.

ρ_{HC} = Density of hydrocarbons for CNG fueled vehicle which is 18.85 g/ft³ at STP.

Δt = Time difference between two instantaneous measurement points, in sec.

HC_d = Concentration of hydrocarbons in the dilution air, in ppm.

DF = Dilution Factor.

V_{mix} = Total volume of dilute exhaust gas mixture for the entire test, in ft³.

The mass of particulate matter collected on the filter in the secondary dilution tunnel and in the cyclonic separators provides a proportional sampling of the PM emissions. The following equation is used to determine the total amount of PM present in whole diluted exhaust flowing through the primary dilution tunnel.

$$\dot{P}_{\text{mass}} = (V_{\text{mix}} + V_{\text{sf}}) \times \left[\frac{P_f}{V_{\text{sf}}} - \left(\frac{P_{\text{bf}}}{V_{\text{bf}}} \times \left(1 - \frac{1}{\text{DF}} \right) \right) \right] \quad [\text{CFR40 Part 86}]$$

Equation 4.22

Where

P_{mass} = Uncorrected mass of PM emitted during one complete test, in grams.

V_{mix} = Total diluted exhaust flowing through the primary dilution tunnel corrected for standard conditions, in SCF.

V_{sf} = Total Sample dilute exhaust flow through the secondary dilution tunnel corrected for standard conditions, in SCF.

P_f = Actual mass of PM collected on the sample filter, in grams.

P_{bf} = Actual mass of PM collected on the background filter, in grams.

DF = Dilution factor.

$$PM = P_{mass} * KH$$

Equation 4.23

PM = Corrected mass of PM, in grams.

K_H = Humidity correction factor.

5 Results and Discussion

Fifteen vehicles were tested over the CARB Transient and Cruise modes of operation. The sampling and characterization of the exhaust samples targeted the following criteria pollutants.

- a. CO
- b. NO_x (and NO₂ by the difference method (NO_x – NO))
- c. THC
- d. TPM
- e. CO₂

Cycle average distance-specific emissions for individual trucks that were tested over the two test cycles are presented in Table 6-1 to Table 6-30.

Table 5-1 Distance-specific emissions on UDDS cycle, Test weight 20,300 lbs

Run Seq. No.	CO	NO _x ¹	NO _x ²	FIDHC	CO ₂	mile/gal	BTU/mile	Miles
5279-1	5.01	13.82	13.81	0.75	2085	4.61	27748	5.50
5279-2	3.87	13.61	12.45	0.69	2046	4.70	27215	5.52
5279-3	4.01	13.67	12.54	0.64	1982	4.85	26362	5.15
5279 Average	4.30	13.7	12.9	0.69	2038	4.72	27108	5.39
Std. Dev.	0.62	0.1	0.8	0.06	52	0.12	699	0.21
CV%	14.5	0.8		8.2	2.5	2.6	2.6	3.8

Table 5-2 Distance-specific emissions on in-use cycle, Test weight 20,300 lbs

Run Seq. No.	CO	NO _x ¹	NO _x ²	FIDHC	CO ₂	mile/gal	BTU/mile	Miles
5274-2	2.32	10.55	10.48	0.41	1718	5.60	22823	15.43
5274-3	2.25	9.93	9.31	0.42	1675	5.75	22255	15.50
5274-4	2.19	9.61	9.05	0.42	1671	5.76	22203	15.40
5274 Average	2.25	10.0	9.61	0.42	1688	5.70	22427	15.45
Std. Dev.	0.06	0.5	0.76	0.01	26	0.09	344	0.05
CV%	2.8	4.8		1.4	1.5	1.5	1.5	0.3

Table 5-3 Distance-specific emissions on GCM Part 1, Test weight 20,300 lbs

Run Seq. No.	CO	NO _x ¹	NO _x ²	FIDHC	CO ₂	mile/gal	BTU/mile	Miles
5278-1	4.90	47.05	46.63	2.17	2846	3.37	37896	5.99
5278-2	4.76	48.51	48.53	2.28	2710	3.54	36087	5.96
5278-3	4.54	50.65	45.86	2.34	2806	3.42	37364	5.95
5278 Average	4.73	48.7	47.0	2.27	2787	3.45	37116	5.97
Std. Dev.	0.18	1.8	1.4	0.09	70	0.09	930	0.02
CV%	3.8	3.7		3.9	2.5	2.5	2.5	0.3

Table 5-4 Distance-specific emissions on GCM Part 2, Test weight 20,300 lbs

Run Seq. No.	CO	NO _x ¹	NO _x ²	FIDHC	CO ₂	mile/gal	BTU/mile	Miles
5276-1	2.07	11.58	11.58	0.48	1378	6.98	18321	21.48
5276-3	1.87	12.48	11.66	0.52	1357	7.09	18032	21.42
5276-4	1.99	13.67	12.79	0.47	1354	7.11	17992	21.40
5276 Average	1.98	12.6	12.0	0.49	1363	7.06	18115	21.43
Std. Dev.	0.10	1.0	0.7	0.03	13	0.07	180	0.04
CV%	5.3	8.3		5.5	1.0	1.0	1.0	0.2

Table 5-5 Distance-specific emissions on UDDS cycle, Test weight 41,248 lbs

Run Seq. No.	CO	NO _x ¹	NO _x ²	FIDHC	CO ₂	mile/gal	BTU/mile	Miles
5270-1	5.60	13.08	13.12	0.71	2171	4.43	28897	5.46
5270-2	5.60	13.49	12.36	0.68	2153	4.46	28660	5.43
5270-3	5.52	12.64	11.65	0.60	2134	4.50	28404	5.56
5270 Average	5.57	13.1	12.4	0.67	2152	4.46	28654	5.48
Std. Dev.	0.04	0.4	0.7	0.06	18	0.04	247	0.07
CV%	0.8	3.2		8.4	0.9	0.9	0.9	1.2

Table 5-6 Distance-specific emissions on in-use cycle, Test weight 41,248 lbs

Run Seq. No.	CO	NO _x ¹	NO _x ²	FIDHC	CO ₂	mile/gal	BTU/mile	Miles
5271-1	2.66	9.01	9.04	0.46	1652	5.83	21954	15.40
5271-2	2.84	7.82	7.37	0.37	1566	6.14	20823	15.30
5271-3	2.51	9.03	8.48	0.45	1674	5.75	22242	15.32
5271-4	2.27	8.73	8.22	0.43	1651	5.83	21927	15.47
5271 Average	2.57	8.65	8.28	0.43	1636	5.89	21737	15.37
Std. Dev.	0.24	0.57	0.69	0.04	47	0.17	626	0.07
CV%	9.5	6.6		10.1	2.9	3.0	2.9	0.5

Table 5-7 Distance-specific emissions on GCM Part 1, Test weight 41,248 lbs

Run Seq. No.	CO	NO _x ¹	NO _x ²	FIDHC	CO ₂	mile/gal	BTU/mile	Miles
5267-1	4.13	54.16	54.11	2.31	2774	3.46	36928	5.99
5267-2	4.44	54.91	55.00	2.41	2874	3.34	38256	5.98
5267-3	4.53	54.01	49.09	2.54	2866	3.35	38169	5.97
5267 Average	4.37	54.4	52.7	2.42	2838	3.39	37784	5.98
Std. Dev.	0.21	0.5	3.2	0.12	55	0.07	743	0.01
CV%	4.8	0.9		4.8	2.0	2.0	2.0	0.1

Table 5-8 Distance-specific emissions on GCM Part 2, Test weight 41,248 lbs

Run Seq. No.	CO	NO _x ¹	NO _x ²	FIDHC	CO ₂	mile/gal	BTU/mile	Miles
5269-2	2.05	13.04	13.02	0.50	1296	7.42	17229	21.46
5269-3	1.91	12.14	11.30	0.48	1289	7.46	17137	21.33
5269-4	1.66	12.97	12.11	0.46	1277	7.54	16971	21.37
5269 Average	1.87	12.7	12.1	0.48	1287	7.47	17113	21.39
Std. Dev.	0.20	0.5	0.9	0.02	9	0.06	131	0.06
CV%	10.6	3.9		4.7	0.7	0.8	0.8	0.3

Carbon dioxide emissions are an indication of the amount of fuel consumed, as most of the carbon in the fuel is converted into CO₂ during combustion. The trends in CO₂ emissions follow the same trends observed in the fuel consumption data which qualitatively confirms the observed fuel consumption results.

6 Conclusions

West Virginia University performed chassis dynamometer testing to evaluate the torque and exhaust emissions from one 2005 Volvo tractor on the WVU Transportable Heavy-duty Vehicle Emissions Laboratory. The test vehicle was exercised over three cycles provided by Oak Ridge National Laboratory (ORNL). Measurement of torque and distance-specific values fuel usage rate, total particulate matter, oxides of nitrogen, total hydrocarbons, carbon monoxide, and carbon dioxide were made and the results of the tests have been provided to the sponsor.