ORNL/TM-2015/728

Supply Chain-Based Solution to Prevent Fuel Tax Evasion: Final Report

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OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

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SUPPLY CHAIN-BASED SOLUTION TO PREVENT FUEL TAX EVASION: FINAL REPORT

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ACRONYMS AND ABBREVIATIONS

ALD	Authorized Location Database
API	Application Programming Interface
boERS	Back-Office Evidential Reasoning System
BOL	Bill-of-Lading
BOS	Back-Office System
CCC	Command and Control Center
CONOPS	Concept of Operations
COTR	Contracting Officer's Technical Representative
csv	Comma Separated Values
dll	Dynamic-Linked Library
EOE	Errors, Omissions, and Evasions
FDAS	Fuel Distribution Auditing System
FMCSA	Federal Motor Carrier Administration
FHWA	Federal Highway Administration
FTE	Fuel Tax Evasion
FTP	File Transfer Protocol
gal	Gallon
GAO	Government Accountability Office
GPS	Global Positioning System
GUI	Graphical User Interface
ID	Identification
ISE	Innovative Software Engineering, Inc.
km/hr	Kilometer per hour
l	Liter
lb	pound
LBT	Liquid Bulk Tanker, Inc.
NTRC	National Transportation Research Center
obERS	On-Board Evidential Reasoning System
obTD	On-Board Telematics Device
OEM	Original Equipment Manufacturer
ORNL	Oak Ridge National Laboratory
SBCU	Sensor Bank Control Unit
sec	Second
STSWRF	Safeguarding Truck-Shipped Wholesale and Retail Fuels
T2TCU	Tractor-To-Trailer Communications Unit
TBOS	Telematics Back Office System
ULSD	Ultra-Low Sulfur Diesel

ABSTRACT

The primary source of funding for the United States' transportation system is derived from motor fuel and other highway use taxes. Loss of revenue attributed to fuel tax evasion (FTE) has been assessed to be somewhere between $1 billion and $3 billion per year. Any solution that addresses this problem needs to include not only the tax collection agencies and auditors, but also the carriers transporting petroleum products and the carriers' customers. This report presents a system developed by the Oak Ridge National Laboratory (ORNL) for the Federal Highway Administration which has the potential to reduce or eliminate many FTE schemes. The solution balances the needs of tax auditors and those of the fuel-hauling companies and their customers.

The system has three main components. The on-board sub-system composed of sensors, tracking and communication devices, and software (the on-board Evidential Reasoning System, or obERS) to detect, monitor, and geo-locate the transfer of fuel at different locations. The back-office sub-system (boERS) uses self-learning algorithms to determine the legitimacy of the fuel loading and offloading (important for tax auditors), and detect potential illicit operations such as fuel-theft (important for carriers and their customers). The third sub-system, the Fuel Distribution Auditing System or FDAS, is a centralized database, which together with a user interface allows tax auditors to query the data submitted by the fuel-hauling companies and correlate different parameters to quickly identify any anomalies. Industry partners in this effort included Barger Transport of Weber City, Virginia (fleet); Air-Weigh of Eugene, Oregon (sensors and harnesses); Liquid Bulk Tanker, Inc. (LBT) of Omaha, Nebraska (three five-compartment trailers); and Innovative Software Engineering, Inc. (ISE) of Coralville, Iowa (on-board telematics device and back-office system).

ORNL conducted a pilot test with the three instrumented vehicles collecting real-world data during an eight-month period (October 2014 to June 2015). The solution developed and tested in the pilot test had federal- and state-level tax auditors as its main audience. However, in order for the technology to be adopted the eventual solution has to address the needs of fuel-hauling companies and their customers (i.e., fuel theft and cocktailing).

The functionality of the current system is as follows. Sensors in the hatches allow the obERS to recognize when one is open (always a suspicious activity, unless it happens at locations where maintenance is performed on the vehicle). The fuel-theft concerns are addressed by a self-learning algorithm deployed on the boERS that continuously processes the data from the field to construct probability distributions of measures such as elapsed time of fuel loading and offloading by driver, vehicle, and compartment; valve actuation sequences; elapsed time between the first two valve actuations (by driver, compartment, and location); and other parameters. Probability thresholds, which can be set up by the carrier, determine how to classify the observed events. The boERS also keeps track of valve sequencing at a given location and analyzes these actuations to help identify any suspicious activities.

Technical and economic recommendations from this project include: (a) simplification of the driver data-entry task; (b) reduction of system deployment cost; (c) inclusion of capabilities that make the system more appealing to industry (i.e., identification and avoidance of missed fuel deliveries); and (d) incorporation of additional capabilities to the FDAS beyond those tested in the field operational testing.

Path to commercialization recommendations include: (a) identifying a company willing to further develop, test, and certify a hardened system with a price point the market will bear; (b) transferring ERS software to licensee; (c) identifying a fleet or fleets who want this technology for carrier benefits or a trailer manufacturer who wants to offer it as optional technology; and (d) identifying a server location for the deployment of FDAS.

EXECUTIVE SUMMARY

The primary source of funding for the United States' transportation system is derived from motor fuel and other highway use taxes. Loss of revenue attributed to fuel tax evasion (FTE) has been assessed to be somewhere between $1 billion and $3 billion annually. Any solution that addresses this problem must include not only the needs of the tax collection agencies and auditors, but also the needs of the carriers transporting petroleum products and their' customers. This report presents a system developed by the Oak Ridge National Laboratory (ORNL) for the Federal Highway Administration (FHWA) which has the potential to reduce or eliminate many FTE schemes. The solution balances the needs of tax auditors and those of the fuel-hauling companies and their customers.

The system has three main components. The on-board sub-system composed of sensors, tracking and communication devices, and software (the on-board Evidential Reasoning System, or obERS) to detect, monitor, and geo-locate the transfer of fuel at different locations. The back-office sub-system (boERS) uses self-learning algorithms to determine the legitimacy of the fuel loading and offloading (important for tax auditors), and detect potential illicit operations such as fuel-theft (important for carriers and their customers). The third sub-system, the Fuel Distribution Auditing System or FDAS, is a centralized database, which together with a user interface allows tax auditors to query the data submitted by the fuel-hauling companies and correlate different parameters to quickly identify any anomalies.

Three fully instrumented tanker trucks from Barger Transport of Weber City, Virginia, participated (at no cost to the project) in the pilot test for this project. The three fuel hauling vehicles were similar (i.e., same types of trailers and two tractor models), and were equipped with the same type of sensors: hatch sensors, valve sensors, and weight sensors. Those sensors and their wiring and harnesses were developed by Air-Weigh, of Eugene, Oregon. The trailers, which had five compartments per trailer, were provided from new stock (at no cost to the project) by Liquid Bulk Tank (LBT) of Omaha, Nebraska. The information from the on-board sensors registered valve actuations, hatch openings, vehicle weight, vehicle location, and driver input. This information was captured in the form of fuel logs by the obERS, an ORNL-developed application (running on the on-board telematics device and transmitted at regular intervals to the telematics-provider back-office system (BOS)). The on-board telematics device and BOS were developed by Innovative Software Engineering (ISE) located in Coralville, Iowa. The BOS processed the "raw" information by a second ORNL-developed application, the boERS. This system generated the driver reports, and with the input from the carrier when needed, the FDAS reports.

ORNL conducted the pilot test with the three instrumented vehicles collecting real-world data during an eight-month period (October 2014 to June 2015). The data was collected during normal operations of the fuel-hauling company, and the twelve drivers that drove these vehicles were trained to input the fuel data into the on-board device (the valve and hatch sensors did not alter the way these trailer components were operated, so no training was needed regarding these sensors). During the test, about 700 fuel logs were submitted from the instrumented vehicles and processed by the boERS application. The vehicles logged a total of 375,000 miles and transported more than 7.5 million gallons of fuel. There were 2,478 unique odometer events (examples of events are valve actuation, hatch opening, data entry) recorded by the system, and the drivers entered 958 bill-of-lading (BOL) information events capturing load information for 77% of deliveries. This amount of participation was not unexpected since this system was installed on a real-world setting, and due to the nature of the business, the trucks were sometimes driven by drivers unfamiliar with the system. There were several different types of driver miss-entries experienced in the pilot test. About 15% of the loading data (10% of the offloading data) had at least one compartment with loading (or offloading) valve activity, but no driver information entry was made for that compartment. Approximately 5% of the time during loading (about 11% of the time during offloading) a driver entered loading information but not offloading information, and vice-versa.

One of the primary purposes of the FTE system is to help manage and track fuel diversions. There was no actual fuel diversion numbers entered by any drivers during the pilot test, although seven events (or about 0.7% of the trips) appeared to require a fuel diversion number. All seven cases were identified by the boERS.

Weight sensors installed on the trucks measured steer, drive, and trailer weight. In the pilot test, there were two main difficulties in getting the weight data. The first one was that it is common practice, especially at offloading, to release the air suspension bags of the trailer in order to lower the back of the trailer an inch-or-two to assure that the product is completely drained from the trailer. Since the trailer weight sensor relied on the air suspension bags to assess weight, the trailer weight was not available when the bags were deflated. The second issue encountered was that the tractor ignition key was typically turned off when loading or offloading fuel. This meant that data was buffered (i.e., the data is captured) for the trailer, and there were no steer and drive weights for every corresponding trailer weight. While this made it possible to determine the trailer weight change (typically about 55,000 lb for a full load) as fuel flowed into or out of the trailer, the total weight of the vehicle was not available at that point in time.

Part of the test was conducted during the winter of 2015, and snow and road-added chemicals adversely affected the first generation of the wire and sensor connections deployed on the vehicles, mostly due a defective manufacturing process. Additionally, some enclosures leaked, producing corrosion on the circuit boards. This caused some of the sensors to malfunction and they therefore, provided only limited usable data. These defects were corrected, and the hardware hardened and replaced. However, as a consequence of these issues, and prior to the correction, hardening and replacement, there was a period of time in which some of the instrumented vehicles were not able to collect data. However, the second generation of the hardware greatly improved the reliability of the system.

The solution developed and tested in the pilot test had federal- and state-level tax auditors as its main audience. However, in order for the technology to be adopted the eventual solution has to address the needs of fuel-hauling companies and their customers. The main concerns of carriers are fuel-theft and cocktailing, and these were taken into consideration when the architecture of the system was designed. Sensors in the hatches allow the obERS to recognize when one of the hatches is open (always a suspicious activity, unless it happens at a location where maintenance is performed on the vehicle). In those cases, a tampering alert is submitted from the vehicle in real-time to the telematics back-office and made immediately available to the carrier/dispatcher. Based on the location where this alert is triggered, the carrier can then take the appropriate action. In a similar way, any sensor that becomes disconnected (including valve and hatch sensors and tractor and trailer databus connections) generates a tampering alert that is conveyed in real-time to the carrier.

The fuel-theft issue is a more complicated problem since this activity can happen during normal operations and involves the opening and closing of valves. This needs to be differentiated from legitimate actions taken by drivers and other operators. This is addressed by a self-learning algorithm deployed on the boERS that continuously processes the data from the field to construct probability distributions of measures such as elapsed time of fuel loading and offloading by driver, vehicle, and compartment; valve actuation sequence; elapsed time between the first two valve actuations (by driver, compartment, and location), and other parameters. The obERS timestamps each valve actuation, and adds the corresponding weigh-sensors reading (for trailer and tractor, when available), location information and odometer reading. Those timestamps are later used by the boERS to determine the valve-actuation sequencing as well as the elapsed time during which fuel was flowing. Each one of these measures becomes an observation for the probability distributions of those events, and those probability distributions are constantly updated by the boERS application. Probability thresholds, which can be set up by the carrier, determine how to classify the observed events. The boERS also keeps track of valve sequencing at a given location and analyzes these actuations to help identify any suspicious activities (i.e., opening and closing of the primary valve without opening the emergency or belly valve).

Technical and economic recommendations from this project include (a) simplification of the driver data-entry task; (b) reduction of system deployment cost; (c) inclusion of capabilities that make the system more appealing to industry (i.e., identification and avoidance of missed fuel delivery); and (d) incorporation of additional capabilities to the FDAS beyond those tested in the field operational testing.

Path to commercialization recommendations include (a) identifying a company willing to further develop, test, and certify a hardened system with a price point the market will bear; (b) transferring ERS software to licensee; (c) identifying and establishing a fleet or fleets who want this technology for carrier benefits, or trailer manufacturers who wants to offer it as optional technology; and (d) identifying a server location for the deployment of FDAS.

1. INTRODUCTION

The primary source of funding for the United States' transportation system is derived from motor fuel and other highway use taxes. Therefore, the collection and remittance of these taxes to the Highway Trust Fund is a priority for the U.S. Department of Transportation's Federal Highway Administration (FHWA). Loss of revenue attributed to fuel tax evasion (FTE) has been assessed to be somewhere between $1 billion per year, or 25% of the total tax collected. Several countermeasures, including moving the point of taxation up in the supply chain –1988 for gasoline and 1994 for diesel [1]–and adding red-dye markers to diesel fuel–1993 [1]– to be used for non-taxable purposes, resulted in significant increases in the tax revenue collected and were attributed to a decrease in FTE. Nevertheless, there still exists fuel tax avoidance schemes that cannot be easily addressed by a single countermeasure but require a more comprehensive supply chain–based solution. These solutions need to include not only the tax-collection agencies and auditors, but also the carriers transporting petroleum products and their customers (see Appendix A for a detailed description of the fuel distribution actors and interactions).

This report presents a system developed by Oak Ridge National Laboratory (ORNL) for FHWA which has the potential to reduce the number of or eliminate many FTE schemes. The system has three main components. For the vehicle transporting the fuel, it combines on-board sensors, tracking and communication devices, and software to detect, monitor, and geo-locate the transfer of fuel among different locations. This component also generates safety, tampering, and sensor malfunctioning alerts. A second component of the system consists of software running on a service-provider's back office system which, by means of self-learning algorithms, can determine the legitimacy of the fuel loading and offloading activities (important for tax auditors) and can detect potentially illicit operations such as fuel-theft (important for carriers and their customers, and may in and of themselves justify the deployment costs). The final component of the system is a centralized database, which together with a user interface allows tax auditors to query the data submitted by the fuel-hauling companies and correlate different parameters to quickly identify any anomalies. ORNL, in collaboration with several industry partners, developed this system and conducted a pilot test using three instrumented vehicles that collected real-world data during an eight-month period.

1.1 A REVIEW OF FTE-RELATED LITERATURE

A significant amount of research has been conducted to determine the amount of FTE that the nation faces and in trying to control or minimize this problem. As early as the mid-1980s, federal and state tax officials in conjunction with industry representatives assessed the losses to the federal government due to FTE at $1 billion per year [2]. In the same report, the Government Accountability Office (GAO) identifies the most prevalent methodology to evade fuel taxes was a scheme named "daisy chaining." This method involved a company buying tax-free fuel, selling that fuel to other companies in the network that are implementing this scheme, and finally selling the fuel to a retailer as tax-paid fuel but not submitting the collected tax to the Internal Revenue Service. The last company selling the fuel typically does not have any assets or they ceased operations making it impossible for the Internal Revenue Service to collect the taxes, if the scheme was discovered. The counter measure to this was to move the point of taxation up in the distribution system so a lower number of companies would be involved, making it easier for the government to audit these transactions.

As a consequence of implementing the daisy chaining countermeasure, numerous other schemes of FTE started to appear, or became more evident. A National Cooperative Highway Research Program (NCHRP) Report 623 [3] describes in detail many of these schemes:

- bootlegging across state lines (i.e., fuel is bought into state A which has a lower fuel tax than a neighboring state B where it is sold without filing the proper "export" documentation; the differential in fuel tax is the amount evaded);
- false claims of export (i.e., a reverse of the previous scheme);
- cocktailing (i.e., blending taxable and non-taxable fuels and collecting fuel tax for the entire load; the fuel-tax-per-gallon times the number of non-taxable fuel gallons blended is the amount of tax evaded);
- failure to splash dye (i.e., when the terminal dying equipment is malfunctioning, a tank trucker can effectively purchase fuel as tax free (i.e., fuel to be used for construction or farming equipment is required to have dye added directly to the tank for blending; by not adding the dye to the fuel due to equipment malfunction, the tax that is typically collected on undyed fuel is not paid at the terminal);
- failure to remit tax payments (tax-free fuel is purchased and sold as tax paid, but the tax collected is not remitted to the corresponding tax collection agency); and other schemes.

Focusing on the State of Montana, Balducci et al., [4] presents a very comprehensive study aimed at determining the FTE rates. Similar to the NCHRP Report [3], this study includes a description of the most prevalent schemes to avoid paying fuel taxes, but also analyses and quantifies tax evasion in Montana. Using different techniques to estimate revenue losses, the authors conclude that in 2004, errors, omissions and evasion (EOE) associated with diesel fuel taxes were about 16.3 percent of the total tax liability (equivalent to 43.4 million gallons or $12.1 million). In contrast, they found that EOE related to gasoline taxes was not as significant as those of diesel (about 2.1 percent of the total tax liability—equivalent to 10.3 million gallons or $2.8 million in 2004). The study also presents a series of recommendations which include performing random and targeted retailer audits; obtaining and sharing data with neighboring jurisdictions on a more consistent basis; centralizing Fuel Tax Administration; mandating electronic tax reporting, and taking other measures to curtail FTE.

Marion and Muehlegger [5] used econometric models to assess the effect that the addition of red dye to untaxed fuel had on FTE. This regulatory innovation (implemented in 1993) had the potential to significantly decrease the cost of regulatory enforcement. The authors observed that after implementation of this regulation, the sales of diesel fuel rose by 26% while sales of heating oil, a suitable and untaxed diesel substitute, decreased by the same amount. They found that this effect was higher in states with higher fuel tax rates, and that reducing the cost of auditing greatly improves tax compliance.

Other studies have investigated alternative transportation-related user fees to replace those collected through fuel taxes. The Transportation Research Board (TRB) Special Report 285 [6] addresses the effect of improving fuel efficiencies in fuel-tax collected, and forecasted a decrease in revenue if the fuel-tax rate is maintained. Two alternatives are identified: (1) toll roads and toll lanes, and (2) road use metering and mileage charging. The implementation of these alternatives, however, could be cost prohibitive and could face strong public opposition (see Oh and Sinha [7]). For example, in 2003 New Jersey found that the annual cost of toll collection was about 92% of what it cost the federal government to collect the fuel tax across the entire nation during that year (Capps et al [8]).

Virginia's Long-Range Multimodal Transportation Plan 2007-2035 [9] included the review of several other studies in which similar conclusions as those presented in the Oh and Sinha report [7] were found. All three reports conclude that an enhancement to the current fuel-tax system is the most effective course of action for the next decade or longer term.

As described above, most of the approaches to curb FTE rely on improving FTE-curbing policies and procedures (e.g., auditing), and only a few involve the deployment of technology (e.g., red dye applied to diesel). In a previous phase of the study presented in this report, ORNL investigated the inclusion of a chemical marker and sensor system as an indicator of fuel dilution. This technology, deployed on tanker trucks, would serve as an aid to identification of illegal activities associated with FTE. The ORNL team successfully identified and rigorously tested a fuel marker with the following characteristics: compatibility with fuels and engines, production of no objectionable emissions or by-products, no visibility to the naked eye, chemical stability under thermal extremes over a period of months, and sufficiently high optical yields to produce detectable fluorescence in the parts-per-billion range. A suite of sensors attached to a fuel transport vehicle provided the critical information needed to evaluate whether or not FTE has occurred. An on-board communications system was able to collect and format sensor signals from the tanker (hatch and valve switches, fuel level sensor, marker concentration sensor, vehicle weight), convey the sensor signals from the tanker to the tractor, and send the data packets to a back-office system (BOS) for processing. Although this study proved the technical feasibility of this FTE detection solution, it also identified and demonstrated the need to substantially decrease the cost of chemical markers required to make the system economically viable.

1.2 SYSTEM CONCEPT OF OPERATIONS

During the pilot test, the concept of operations (CONOPS) changed from its original inception at the beginning of this research. The CONOPS (i.e., original CONOPS) is depicted in Figure 1. In that CONOPS the vehicles are equipped with a communications system, a Global Positioning System (GPS) device, valve sensors, and nano-chemical marker sensors. In addition, the vehicles may have weight monitoring sensors. After loading fuel at the fuel-terminal rack, an electronic version of the bill of lading and a route to be followed by the vehicle to its final destination are sent to a command and control center (CCC) which monitors fuel transportation activities in real time (box 1 in Figure 1). The arrival of the electronic information from the vehicle at the rack activates the evidential reasoning tools for profiling analysis. As the vehicle proceeds to the final destination it sends, at regular intervals, spatial location, marker, and fuel volume information to the CCC (box 2 in Figure 1). This information is used to determine if there are nano-marker changes or actuation of the valves at non-authorized locations. The information is also used to determine any deviation from the pre-declared route from origin to destination. If the vehicle deviates from its pre-declared route (shown as a black roadway in Figure 1) to an alternate route (shown as a gray roadway in Figure 1), the location information sent to the CCC at regular intervals is used to direct law-enforcement to interdict the vehicle or to disable it using vehicle immobilization technology if deployed on board. If the vehicle does not deviate from its pre-declared route, it will continue sending spatial location, marker, and fuel volume information to the CCC up to the point when it gets to its final destination (retail facility).

As mentioned above, the results of the proof-of-concept test showed that, although technical feasibility, the cost of the nano-chemical markers was prohibitive. Those markers were eliminated when the Pilot Test was conducted. Discussions with law enforcement pointed out of the unfeasibility of real-time interdictions due to lack of personnel to carry out these activities. This eliminated the requirement to file the route that the vehicle would follow from origin to destination, as well as the need monitor the vehicle location with a given frequency. And in turn, it eliminated the need to have a CCC, which was supplanted by a more decentralized telematics back office system. In this way, the system deployed in the Pilot Test was greatly simplified and its deployment cost substantially reduced.

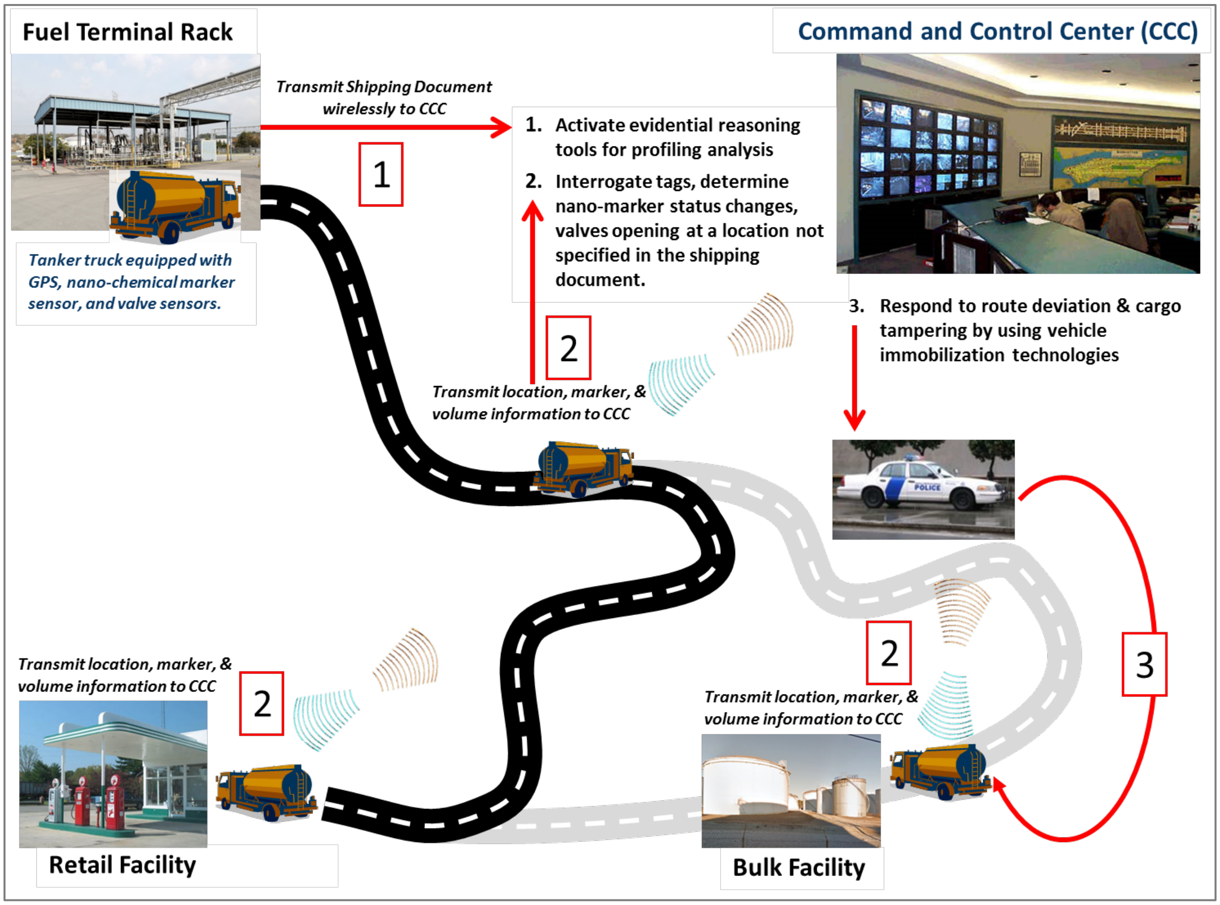


Figure 1. Safeguarding Truck-Shipped Wholesale and Retail Fuels (STSWRF) original concept of operations.

The CONOPS for the pilot test is depicted in Figure 2. The tanker, equipped with hatch and valve state (open or closed) monitoring switches, and axle group weight sensors, sends all opening and closing event data to the tractor cab via the trailer-to-tractor communication unit (T2TCU). The on-board telematics device (obTD), using the ORNL-developed on-board Evidential Reasoning System (obERS) collects the trailer's sensor information and any information provided by the driver through the obTD fuel-tracking user interface, timestamps the information, and adds spatial location information for each event (box 0 in Figure 2). Since there is no-predetermined route from origin to destination, the system does not monitor the vehicle as it travels. However, when the vehicle stops, if valves or hatches are actuated, the system records the information on the obTD. When the driver logs out the obERS, through the obTD communications system, sends the collected information to the telematics back office system or TBOS (box 1 in Figure 2). There, the ORNL-developed back-office Evidential Reasoning System (boERS) analyzes the information received from the vehicle generating valve actuation sequences and dwell-times for fuel flowing (i.e., added vehicle weight: loading; loss of vehicle weight: offloading). Using past fuel logs, the boERS application makes a determination of the legitimacy of the event observed. For an event deemed to be suspect for FTE (e.g., the intended fuel off-loading location is different from the actual fuel off-loading location, and no fuel-diversion number[1] entered), the boERS reports evidential information to

[1] A fuel diversion occurs when a shipment of petroleum products is diverted from the destination stated on the original bill of lading. There are many valid reasons that can trigger the diversion of a fuel shipment. When this happens, the shipper, the transporter or an agent must obtain a fuel-diversion number from a third-party agency. This number serves as proof that the diversion of the fuel was a legitimate operation, and also allows for the correct computation of the tax owed to the state where the shipment originated and ended.

the Fuel Distribution Auditing System (FDAS) via the TBOS. The FDAS is available to regulators for auditing suspicious activity. For events deemed to be suspect, the boERS reports evidential information to the carrier through the TBOS. This information is provided to the carrier through the standard web-linked graphical user interface (GUI).

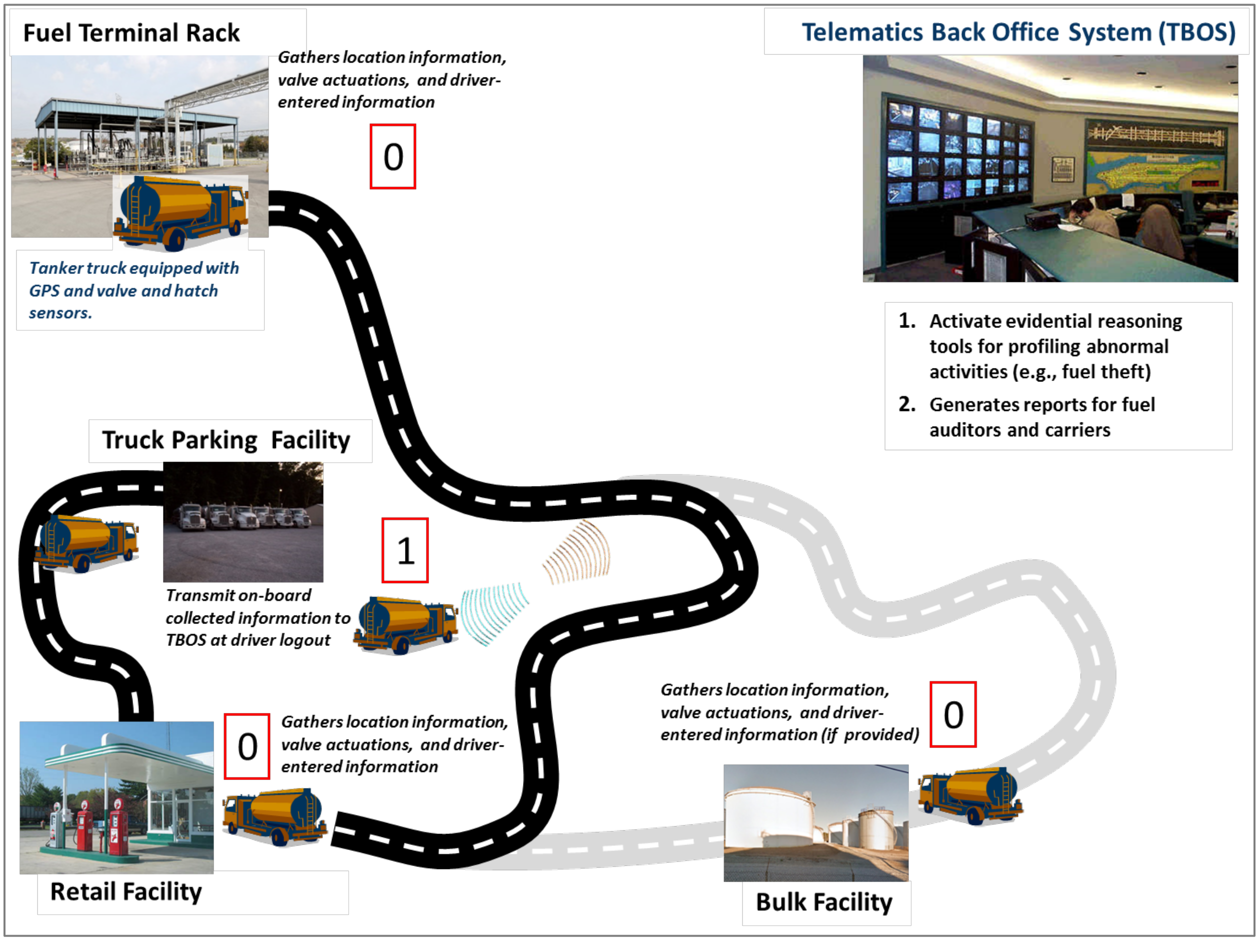


Figure 2. Safeguarding Truck-Shipped Wholesale and Retail Fuels (STSWRF) implemented concept of operations.

1.3 SYSTEM ARCHITECTURE

The architecture of the system deployed in the pilot test was composed of the following:

- discrete, trailer-borne valves (emergency and loading);
- hatch and weight sensors;
- a T2TCU;
- a modified J560 connector; tractor weight sensors;
- an obTD with a fuel-information user interface and equipped with GPS and wireless-cellular communication systems;
- a boERS application running on the telematics provider's BOS;
- a web-based carrier interface running on the telematics provider's BOS; and
- the FDAS application running on ORNL servers.

In addition, and just for research purposes during the pilot test, the system had an FTP (file-transfer protocol) server located at ORNL that collected all the information generated during the tests (on-board and back-office).

Figure 3 is a schematic diagram of the system that was implemented in the three vehicles that participated in the pilot test. The valve and hatch sensors determine the state (open or closed) of these elements and the time at which these actuations occur, while the tanker weight sensor measures the weight at the tanker axle. Because of safety concerns, the tanker is typically not energized (i.e., the vehicle engine is shut off and the ignition key is in the off position) while fuel loading and offloading operations are performed. During this time, the on-board sensors store valve and hatch actuation information together with tanker weight. Once the ignition key is turned to the on position, the information generated while loading or offloading fuel is released to the tractor data bus. To accomplish this, the T2TCU provides a J1939 private network on the tanker and a buffered link between the tanker J1939 data bus to that of the tractor, where the sensor messages from the valves and hatches are read by the obTD. These J1939 compatible sensors post directly to the tanker's J1939 data bus. Thus, the obTD has to periodically inform the tractor-sideT2TCU of the current time, so the T2TCU can time-stamp the buffered data.

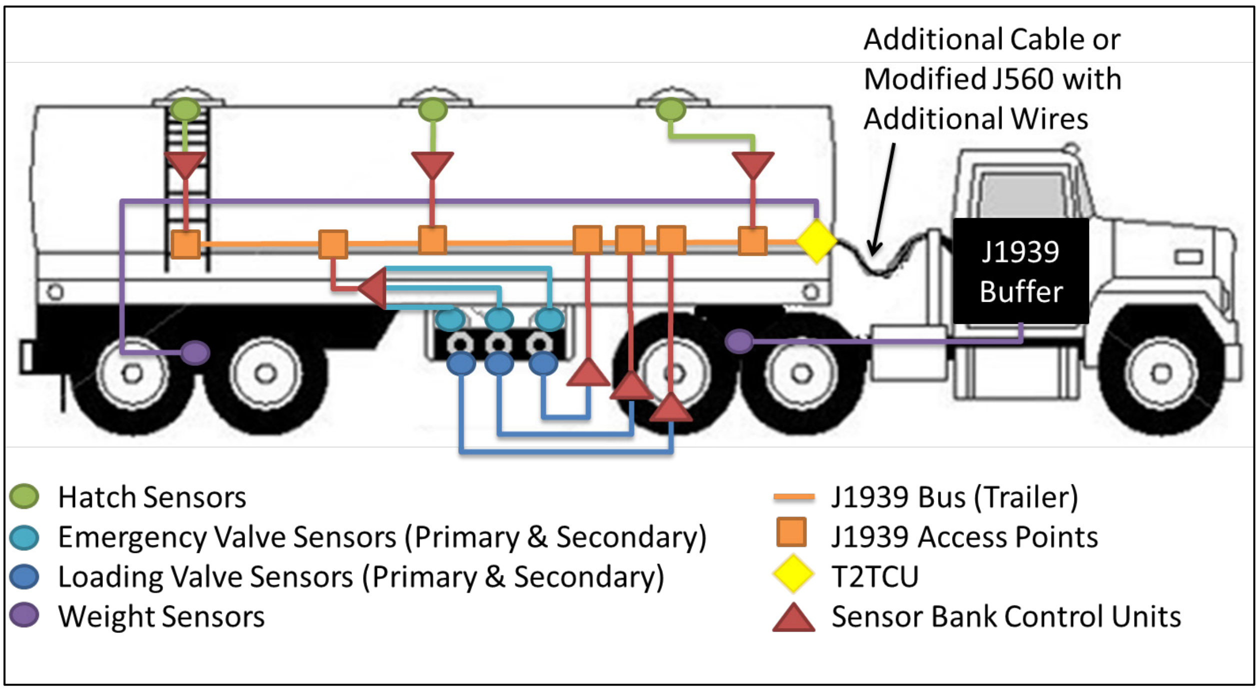


Figure 3. Safeguarding Truck-Shipped Wholesale and Retail Fuels architecture using J1939-compatible switches.

The T2TCU sends this data to the tractor cab via a parallel cable and posts the data to the tractor's J1939 data bus. This information is then retrieved by the telematics device and passed to the tractor-borne-ERS. ORNL also installed a modified J560 connector on the tractor, but could not install this modified connector on the tanker due to space limitations inside the sealed connections box. Both types of connectors were tested in the lab, and all the systems were designed to work either way.

Subsequently, the information is processed by software. Figure 4 shows a schematic representation of the software applications developed and deployed during the pilot test, as well as the data flows among these applications. The top-left box in the figure represents the on-board component of the system; that is, the obTD with its communication system.

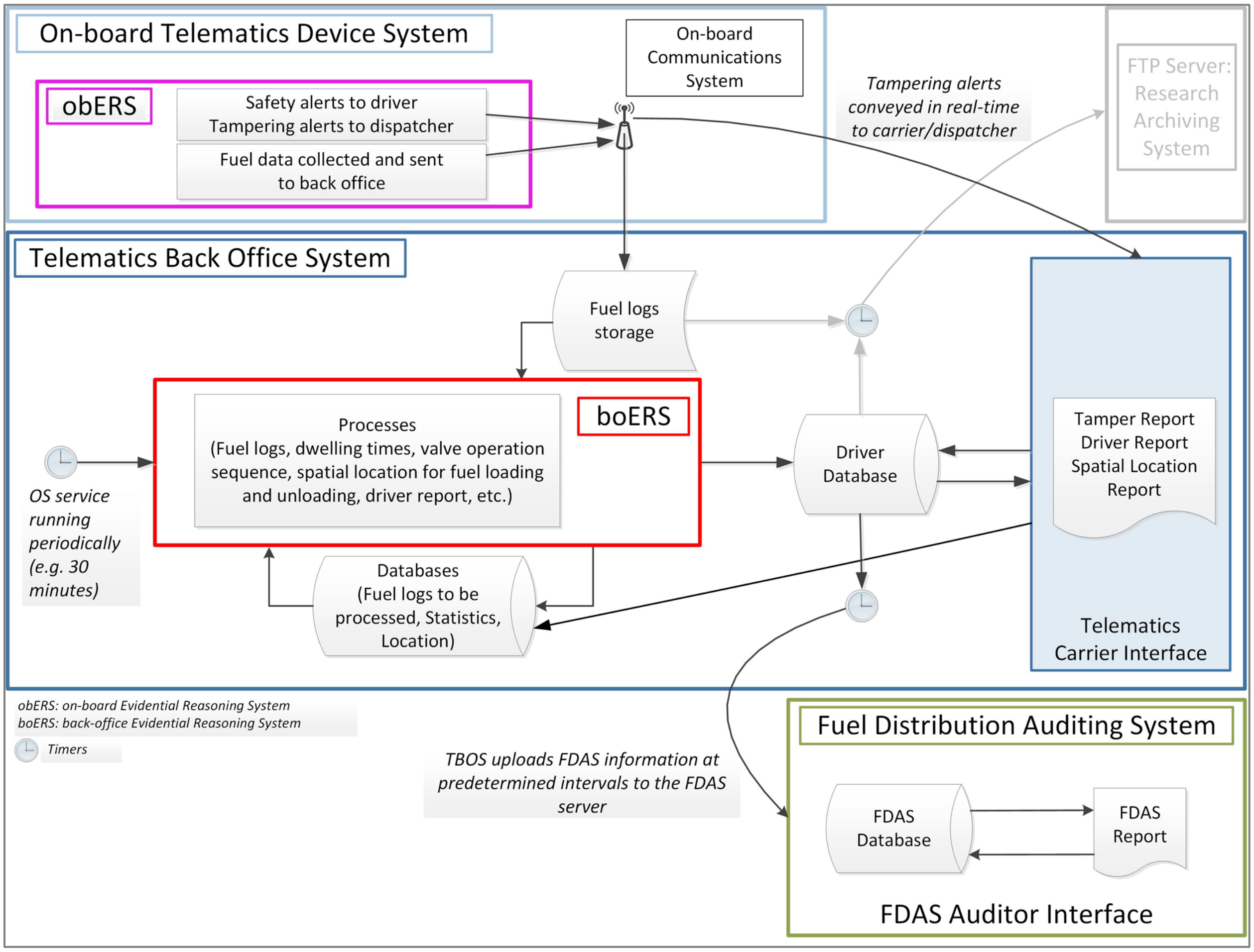


Figure 4. Sub-systems software applications and interactions.

The center box in Figure 4 shows the different applications that reside on the TBOS. These applications receive information from the vehicle, processes the data collected on-board and analyzes it using historical information, identifies missing data such as missing fuel-diversion numbers, identifies suspicious activities and generates corresponding alerts, and creates a driver report summarizing all the activities and identified alerts. The driver report is then made available to the carrier through a telematics-provider carrier's interface. This interface allows the carrier to add any missing information to the driver report (e.g., fuel diversion numbers not available at the time of the delivery of the fuel) and to correct any flags associated with activities that are not deemed suspicious. An example of the latter is offloading fuel for the first time at a new location. If this location is not in the database of authorized locations, the boERS will set a flag to indicate a potentially suspicious activity. The carrier can correct this by adding this new location to the database of authorized fuel distribution locations. This task is accomplished by means of the telematics-provider carrier's interface.

The TBOS submits to the FDAS those driver reports that are of a certain age (one-week old for the pilot test). This transmission occurs with a pre-selected frequency (once a day in the pilot test), and the driver reports are revised to eliminate information that is not relevant to tax auditors (e.g., any flags that are associated with suspicious activities indicating possible fuel theft).

For the pilot test, ORNL deployed an FTP server as depicted on the upper-right corner of Figure 4. This server was a repository of all the information collected and generated in the project, including all the fuel logs (on-board information), driver reports and FDAS reports (back-office information).

1.4 PILOT TEST VEHICLE EQUIPMENT

Three vehicles participated in the pilot test (see Figure 5). Two tractors were Kenworth Model T660 and one was a T680 model. The three tankers were all Liquid Bulk Tanker, Inc. (LBT) Model BKZ 9904C, TAG-HA2-ESF9200X5SD five compartment tankers. Compartments 1-5 (front to back) can hold 3,100, 1,250, 1,100, 1,100, 2,650 gallons of fuel, respectively, which total to 9,200 gallons of fuel.

Figure 5. One of the three pilot test vehicles.

Figure 6 illustrates the system architecture as implemented for the pilot test. On the tractor, Innovative Software Engineering Inc. (ISE) telematics units (see Figure 7) were installed in all three tractors. The telematics had a combo global positioning system (GPS)/cellular antenna.

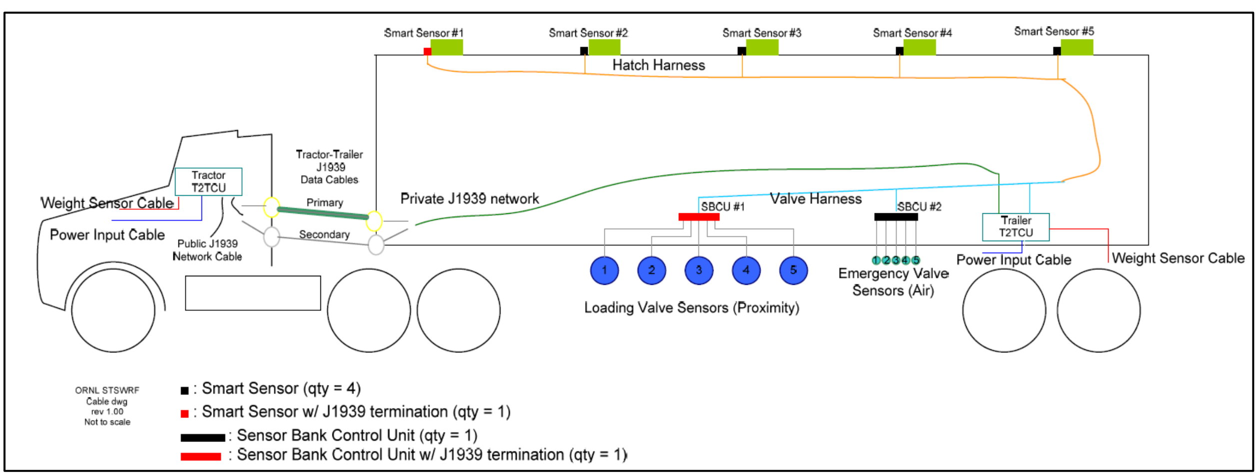
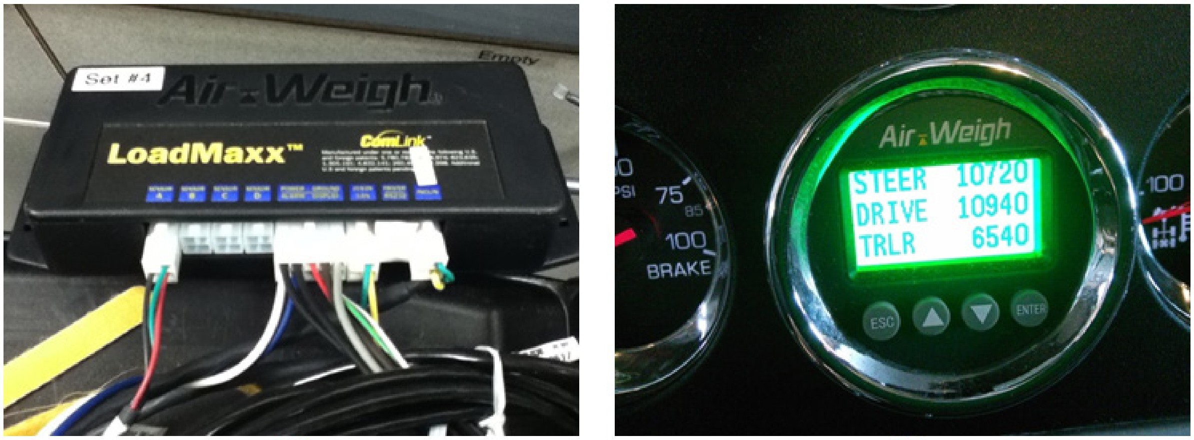


Figure 6. System architecture as implemented for the pilot test.

Figure 7. Innovative Software Engineering Inc. (ISE) telematics device.

The T2TCU system consists of a tractor-side and tanker-side unit. The tractor T2TCU (see Figure 8a) is a modified LoadMaxx system manufactured by Air-Weigh. In addition to the standard steer and drive weight sensors (display shown in Figure 8b), the unit also has a connection to talk to the tanker T2TCU.



(a) (b)

Figure 8. (a) Tractor T2TCU unit that provides steer and drive weights to a driver display and telematics device, and also sends messages to and from the telematics device to the tanker system. (b) Tractor weight display gauge.

There were 15 tanker components to monitor (loading valve, emergency valve, and hatch for each of the five compartments) along with tanker weight. The loading valves are mounted with a sensor (see Figure 9) that allows the system to detect if the handle is opened or closed. The emergency, or "belly" valves on the bottom on the compartment are pneumatic, and their open/closed state is reported to the system (see Figure 10).

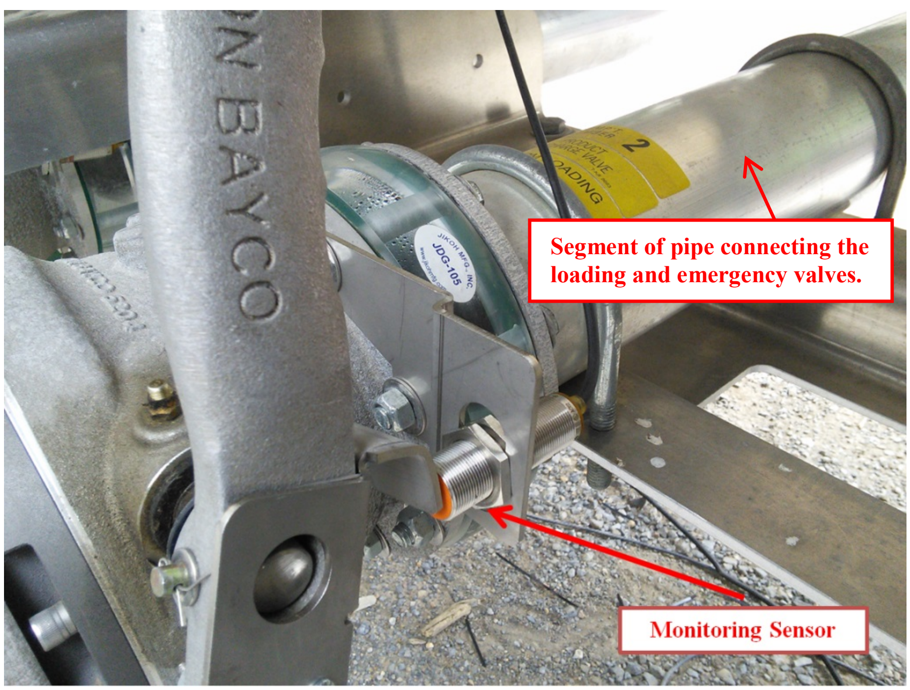


Figure 9. Loading valve sensor.

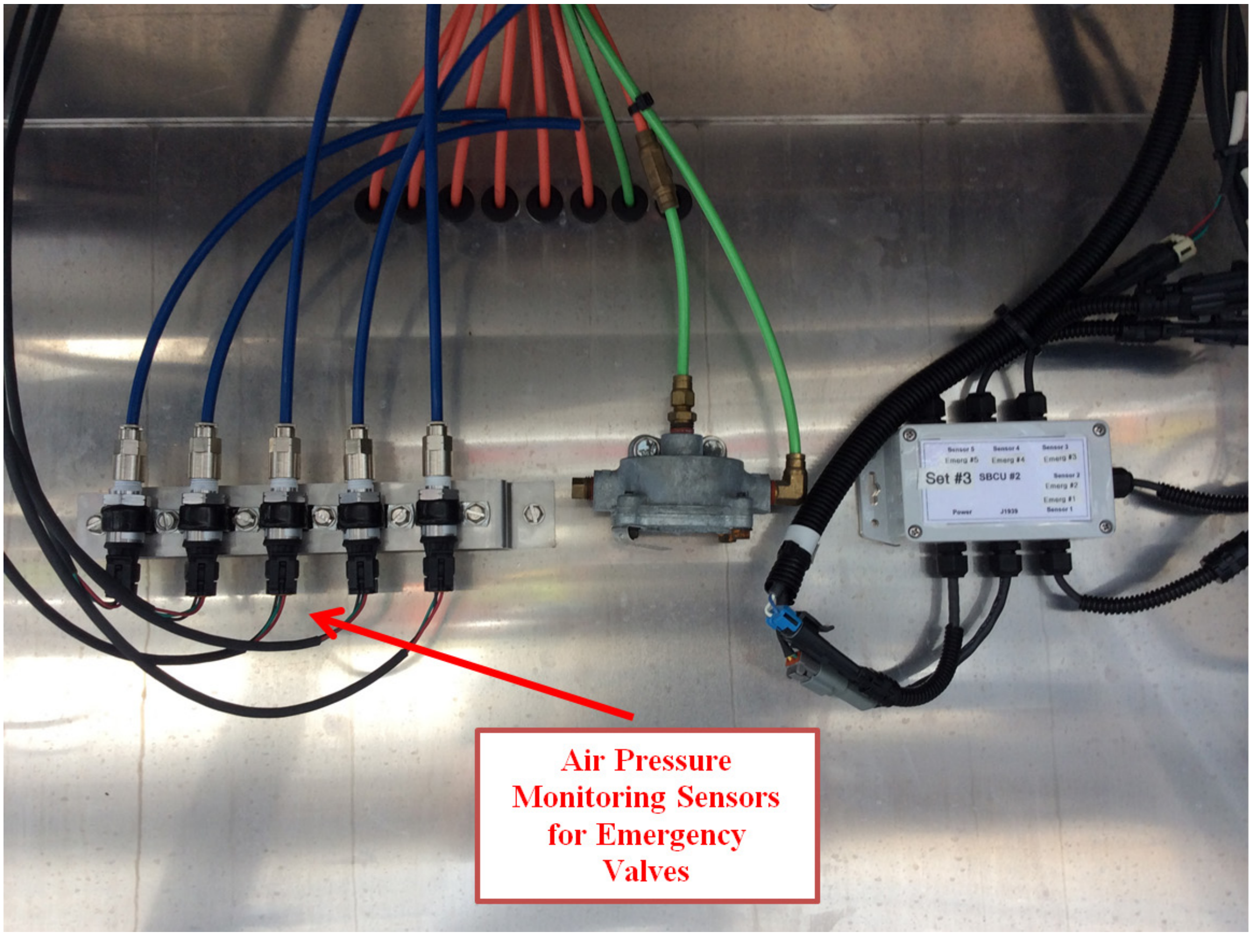


Figure 10. Emergency valve sensor monitoring.

The hatches are also equipped with sensors to determine if they are open or closed (see Figure 11).

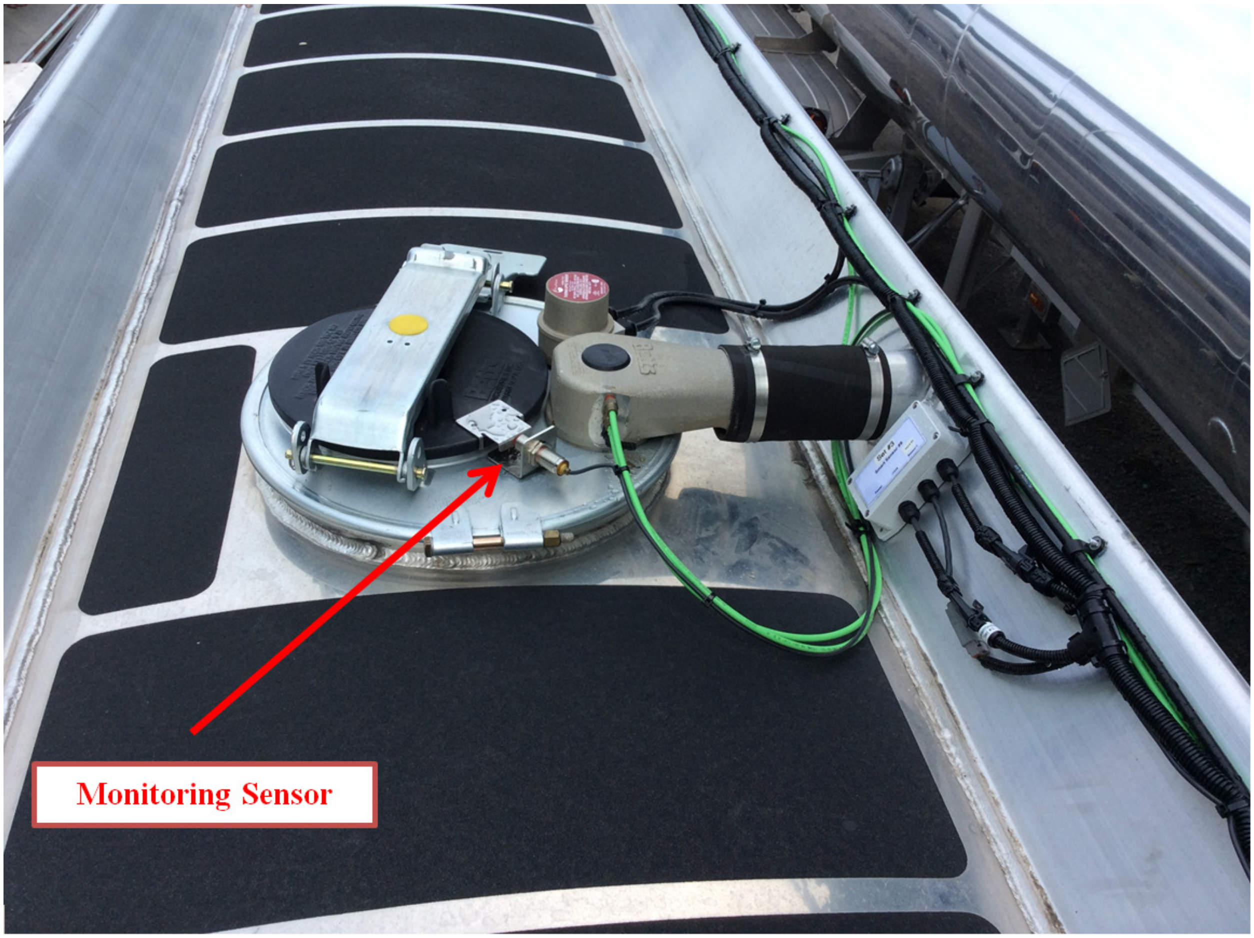


Figure 11. Pilot test hatch sensors.

The status of the 15 sensors and tanker weight are reported to the in-cab system. As shown in Figure 6, the Air-Weigh implementation includes electronic devices that measure open/closed status and reports the status via an SAE J1939 vehicle databus protocol. Thus, there is a private J1939 network on the tanker. The status of multiple devices is reported to an aggregator device; the tanker T2TCU (Figure 12). Air-weigh referred to devices that report the status of only one sensor as “Smart Sensors” (see Figure 13a), and referred to devices that report the status of 5 sensors as “Sensor Bank Control Units (SBCUs)” (see Figure 13b). The Smart Sensors were used for the hatches, and the SBCU’s were used with the loading and emergency valves. The messages from those devices went to the tanker T2TCU, which sent them, along with tanker weight, to the tractor.

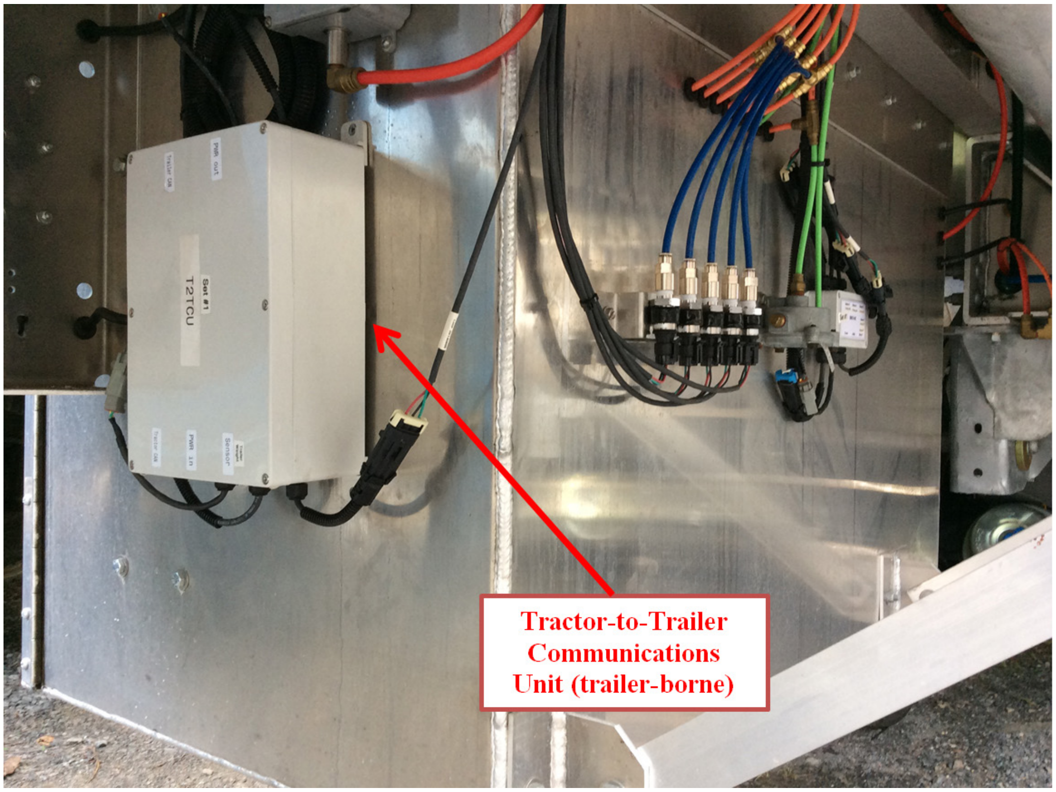


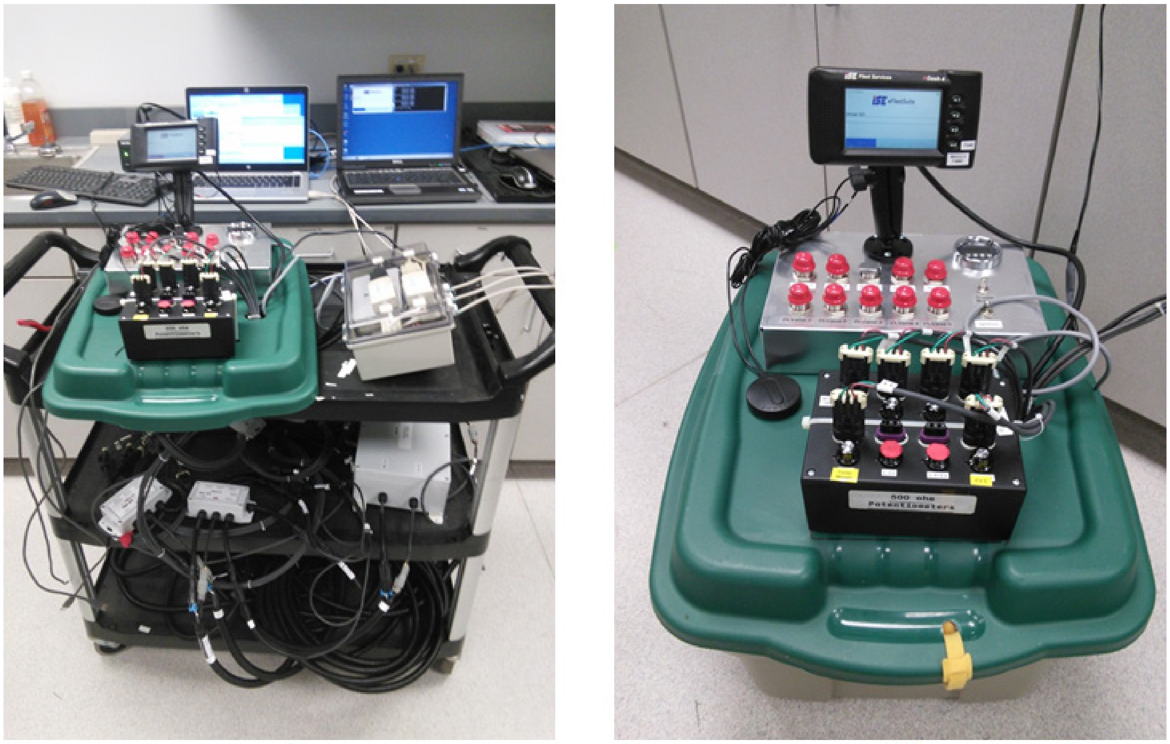
Figure 12. Tanker system components with tanker T2TCU.

(a) (b)

Figure 13. (a) "Smart Sensor" and (b) "Sensor Bank Control Unit (SBCU)" which relayed open/closed status to the tractor via the T2TCU system.

1.5 TEST EQUIPMENT

To facilitate testing prior to installing equipment on the vehicles, ORNL developed a box containing a vehicle databus simulator reader and writer, all the equipment for one vehicle (the telematics device, the tractor T2TCU, the tanker T2TCU, 5 smart sensors, 2 SBCU's and cabling), along with control knobs to simulate opening and closing of all 15 valves or hatches and adjust weights (see Figure 14).



(a) (b)

Figure 14. Benchtop setup (a), including interface panel (top shelf, left) and connections box (top shelf, right) constructed by ORNL to facilitate testing. All equipment for one tractor and tanker contained in a box (b) with control knobs to simulate opening and closing valves and adjust weights.

The test box was put in a passenger car (see Figure 15) and driven around on roads in the Knoxville, Tennessee area. This was done so that ORNL developers could operate the simulated valves and enter fuel information into the telematics device (see Appendix B for more information about this GUI). This effort allowed the team to evaluate and fix several technical issues prior to instrumenting the test vehicles, and to assure that the system was well-tested prior to their installation on the test vehicles.

Figure 15. Passenger car testing.

To read and simulate databus signals, the ORNL team used a variety of hardware and software tools, including a National Instruments NI USB-9862 vehicle databus to USB converter and custom developed software, as well as a PCAN-USB vehicle databus to USB converter and vendor software (see Figure 16).

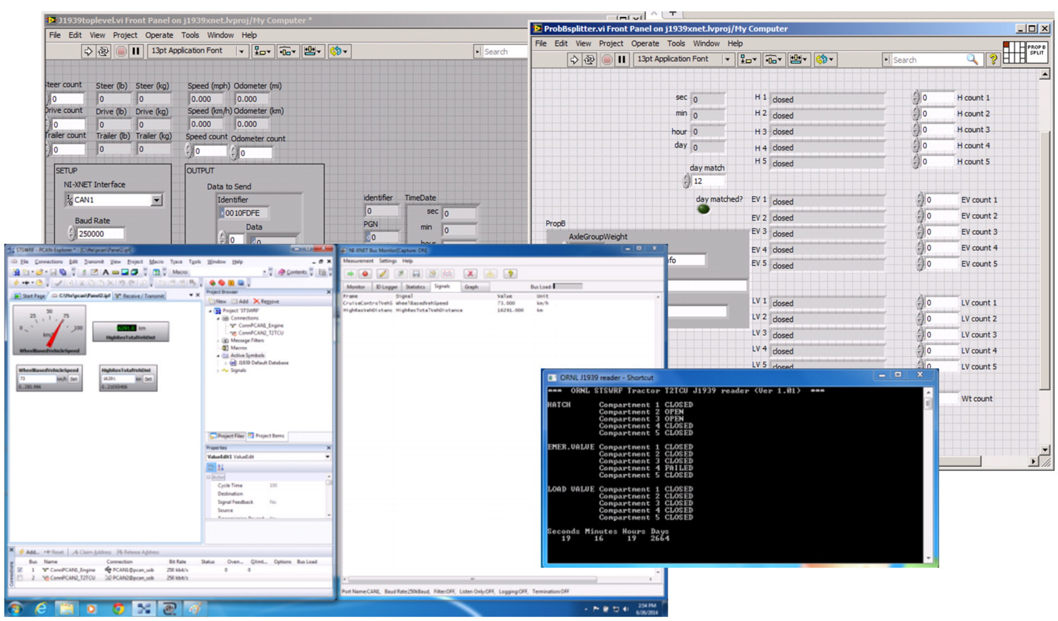


Figure 16. Computer interfaces used in system testing.

1.6 DATA FLOWS AND ALGORITHMS

The obERS application resides on the obTD. It is a dynamic-linked library (dll) application that is event driven. Every time a valve or a hatch sensor changes its state (closed-to-open or open-to-closed) the obERS is notified. These events have properties such as timestamp, location (latitude and longitude), odometer reading, vehicle weight (tractor and tanker), vehicle dynamic state (moving or stationary), and other properties (see Appendix C for the obERS Application Programming Interface [API], or obERS API). The events and their properties are captured by software running on the obTD that is capable of reading information from the vehicle databus (see Appendix D for a description of the messages posted to the vehicle databus by the deployed sensors), on-board clock, and GPS device. The obTD can set the relevant obERS properties and call its methods[2]. Those interactions are depicted in Figure 17.

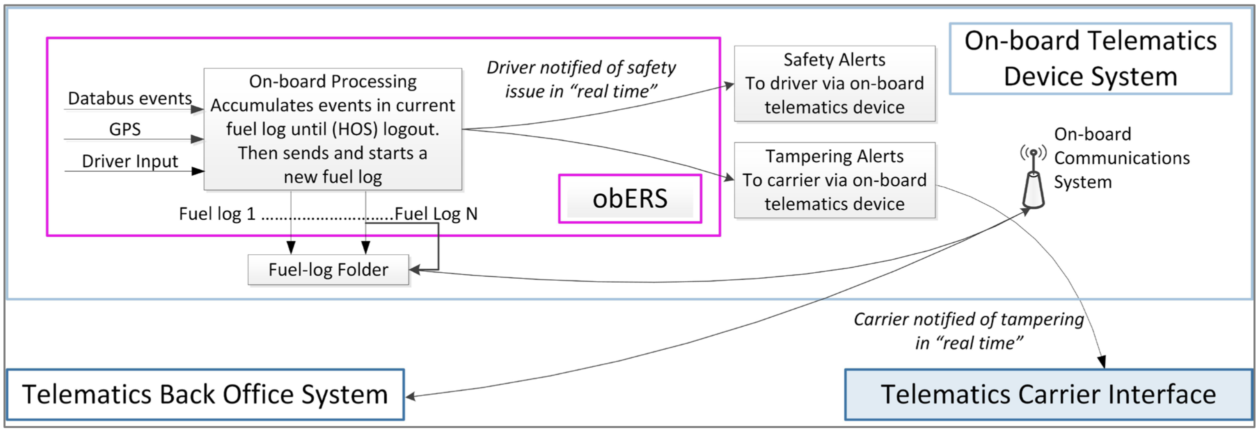


Figure 17. On-board software applications and data flows.

The obERS captures these events and analyzes them in real-time. If the software determines that an event may be related to a tampering action (e.g., a sensor is disconnected), it immediately instructs the obTD to send an alert to the BOS and directly to the carrier interface. If the application determines that an unsafe condition exists (e.g., the vehicle starts to move and there is an open valve or hatch), the obERS sends a real-time alert to the driver through the obTD interface. Both types of alerts (tampering and safety) are also recorded in the fuel-log file that is compiled on-board (see Appendix C for more details on the fuel-log file). The obERS also monitors sensors to determine if there are any that are malfunctioning. If a sensor malfunctions, then the obERS records this event as an alert and adds it to the fuel log file, but it does not relay the alert in real-time since no action can be taken by either the driver or the dispatcher/carrier until the vehicle goes back to the garage.

The obTD provides a GUI for the driver to enter information related to the fuel being loaded or offloaded by compartment, including fuel type, quantity, bill-of-lading (BOL) number, destination, and fuel-diversion number (if required and available). This information also passes to the obERS application which adds it to the fuel-log file. When the driver logs out, the obERS application closes the current fuel-log file and instructs the obTD to send that file (or files) to the back office system.

The fuel-log files received from each instrumented vehicle are stored in the TBOS servers, and metadata describing these files is added to a database (see Figure 18). The metadata includes the vehicle identification (ID) that submitted the fuel-log file, the driver ID, the time at which the first event contained in the file was registered, the time at which the last event contained in the file was registered, the time at which the driver logged in (if this is the first fuel-log file of the series[3]), the time at which the driver logged out, plus other parameters.

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[2] In object-oriented programming, a procedure associated with an object class.

[3] Because of telematics provider data transmission bandwidth constraints, files transmitted from the vehicles to the back office had to have a maximum size which was set at 16KB. Fuel-log files that were larger than this maximum size were subdivided into smaller files such that this constraint could be met. In general, this resulted in the transmission of more than one fuel-log file every time files were sent from the vehicle to the back office.

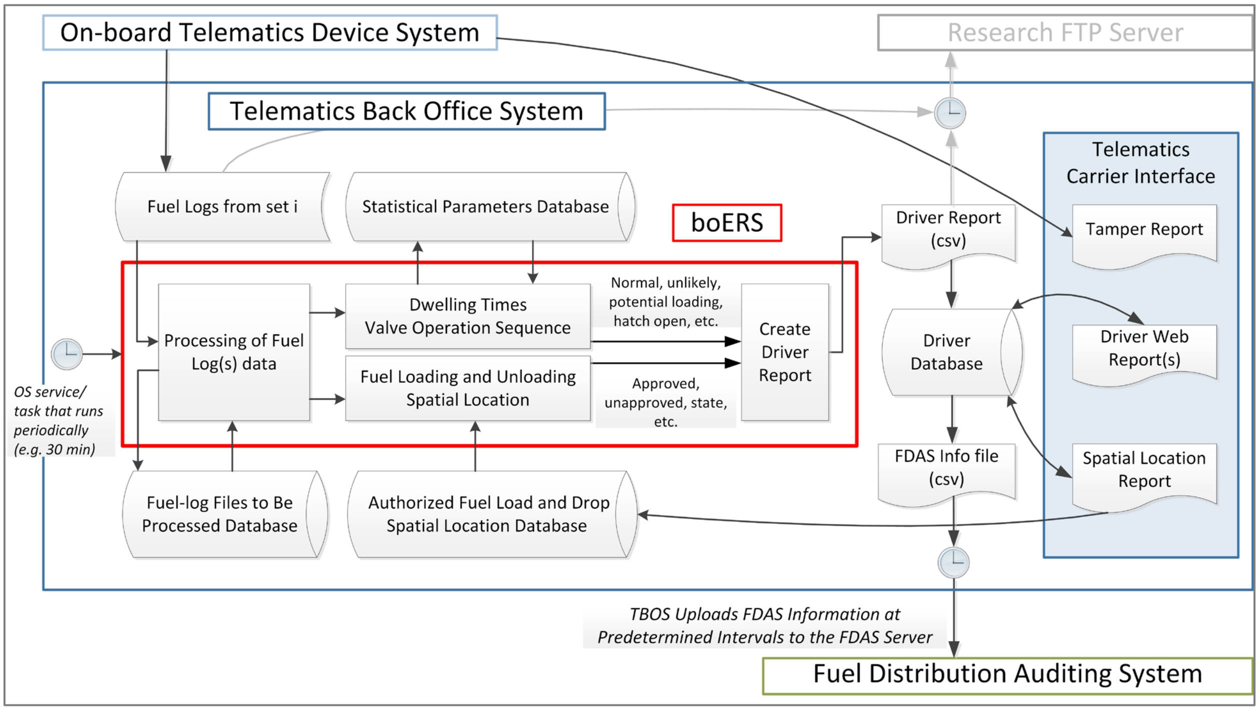

Figure 18. Back-office software applications and data flows.

A determination was made to group events that happen by each driver's shift, and to display those events to the carrier, organized by shift. Since an event that indicates the driver ended his/her shift does not exist (i.e., the obTD only keeps track of hours-of-service duty-status changes), the boERS application has a function that makes this determination. The shift-determination algorithm uses the time stamps of the fuel-log files received, as well as past history of shift lengths for the driver, to determine if all of the fuel-log files from the vehicles for that driver and that shift have already been received from the vehicle. If the determination is that not all of the fuel-log files have been received, then the files that have already been submitted from the vehicle are not processed.

The shift-determination algorithm checks the status of each set of fuel-log files with a certain frequency (e.g., 30 minutes). Once it has been determined that the shift for the driver under consideration has ended and no more fuel-log files are expected from the vehicle, the files are processed by the boERS application. A record in the fuel-log files contains information about a single-point event (call it a micro-event) such as "primary valve for compartment ***c*** opened at time ***t*** at location (***latitude***, ***longitude***)." The boERS groups all of the micro-events for each compartment at each location, and based on the time stamps of these micro-events, determines: (1) the valve sequencing that the driver followed, (2) the elapsed time during which fuel flowed[4], and (3) by taking into consideration the change in vehicle weight associated to this valve operation sequencing, whether fuel was loaded or off-loaded. These fuel loading or offloading events are associated with the information entered manually by the driver indicating the type of fuel for each compartment, quantity of fuel, destination, and BOL number. For the case of fuel offloading events, fuel diversion numbers are required (if available) at the time of the event.

The boERS has self-learning algorithms that are used to identify suspicious activities related to cargo integrity. Consider, for example, fuel theft of small quantities of fuel. This can be detected in different ways. One way is to look at the amount of time that fuel flows out of a compartment. If this time is

[4] For fuel to flow in or out of a given compartment, both its emergency (or belly) valve and its primary (or secondary) valve are required to be open.

much shorter than would normally be required to off-load that compartment, fuel theft might have occurred. The boERS keeps and constantly updates (with new information collected) probability distributions of fuel-flowing elapsed times by vehicle ID, driver ID, and compartment. These probability distributions are used to screen all of the fuel-flowing events identified during a given driver's shift to determine the likelihood (***p)*** of observing an elapsed time equal to or smaller than the one being analyzed. The probability ***p*** is then compared against thresholds classifying these observed events. The boERS application has default thresholds as follows:

- Event classified as a *Normal Event*: ***p*** is larger than 75%;
- Event classified as a *Likely Event*: ***p*** is between 25% and 75%;
- Event classified as a *Rare Event*: ***p*** is between 5% and 25%;
- Event classified as an *Unlikely Event*: ***p*** is less than 5%.

These thresholds can be changed by the carrier's management to better fit their decision-making process in determining how a "suspicious activity" should be defined and flagged (see Appendix E for the boERS API). For example, an unlikely event can be defined by a carrier operating in a very trusting environment as an event with a less than 0.1% probability of being observed. For a different carrier with a more problematic environment, the threshold could be set to events with less than 10% probability of being observed. Whether they are default values or carrier-defined values, these thresholds are used to classify the observed events. If the probability ***p*** was less than 5% (or 0.1% and 10% as in the example), then that event is classified as an unlikely event and a flag is associated with that particular event.

Continuing with the same example, another way in which fuel-theft of small quantities of fuel can happen is by operating the emergency and primary (or secondary) valves in a given sequence. For example, if the emergency valve for a given compartment is opened and closed with the primary valve closed, the segment of pipe ***sp*** that runs from the emergency valve to the primary valve (see Figure 9) will be loaded with fuel (assuming that there is fuel in that compartment). If after that the primary valve is opened and closed with the emergency valve closed, then the small amount of fuel (roughly 5 gallons) contained in ***sp*** will flow. Notice that in this case, the elapsed time for fuel flowing would be null based on the definition given above (i.e., both emergency and primary valves should be open at the same time) and therefore the threshold tests would not identify this as a suspicious activity. However, the boERS also keeps track of valve sequencing. If an event involving a valve actuation sequence like the one just described is observed, then the event is flagged for further investigation by the carrier.

The actuation of the tanker hatches is also analyzed by the boERS (note: opening of a hatch will generate a real-time tampering alert from the vehicle). The boERS searches a database of authorized locations and if the hatch is opened at a location that was not authorized for such an activity, a flag is attached to the event. In the same way, the locations of the processed fuel loading and offloading events are compared against the database of authorized locations for those events. If the location where one such event occurred is not in the database, the event is flagged. These flags are conveyed to the carrier through the Spatial Location Report available through the telematics carrier interface (see Appendix F for more details about this interface). The carrier then has the opportunity to add unidentified locations to the database of authorized locations, or to further investigate the event if necessary.

The algorithms that determine whether an event happened at an authorized location or not, also compare the destination of a fuel load as stated by the driver at the fuel terminal in the BOL with the actual location where the fuel is delivered. If these two locations (i.e., the stated and the final destination) are different, and occur in different states, then the algorithm determines that a fuel-diversion number is required for this delivery. If the fuel-diversion number is not provided by the driver to the obERS at the time of the delivery, the event is flagged as "missing fuel-diversion number" so the carrier/dispatcher can correct the problem and provide the missing information.

Additional tests are conducted by the boERS algorithms to identify missing or incorrect information, and flags are generated and associated to the corresponding events. Once the processing of the fuel-log files is complete, the boERS generates a Driver Report (see Appendix G) which is stored in a database residing in the TBOS. The Driver Report is then made available to the carrier through the telematics carrier interface for further analysis of the events (if necessary) and to enter any missing information (e.g., fuel-diversion numbers). For the pilot test, copies of the Driver Reports together with the associated fuel-log files were sent daily to an ORNL FTP server for data archiving and to be used by the researchers to monitor the performance of the different software applications. If any problems were identified, those were corrected and a new version of the software was deployed.

After the carrier has had the opportunity to add any missing information to the Driver Report, a subset of the fields included in that report are extracted, and the FDAS Report is generated (see Appendix H). During the pilot test this action took place once a Driver Report was one-week old. That is, the carrier had one week to supply missing information such as fuel-diversion numbers and to make any other corrections that were deemed necessary; after that, the FDAS Report is generated and submitted to the FDAS. Figure 19 depicts the data flow from the TBOS to the FDAS.

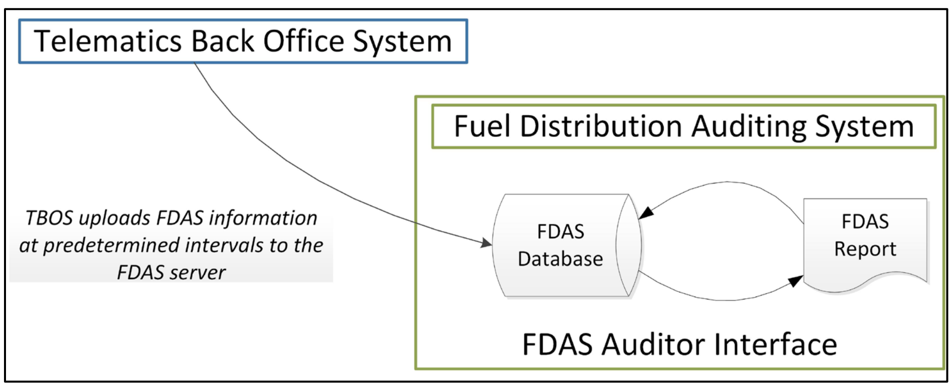

Figure 19. FDAS software application and data flows.

When the FDAS receives the reports from the TBOS, it parses and saves the information to a database. The system offers a GUI to tax auditors to query the data contained in that database and filters the results by carrier, fuel type, as well origin and destination (see Figure 20).

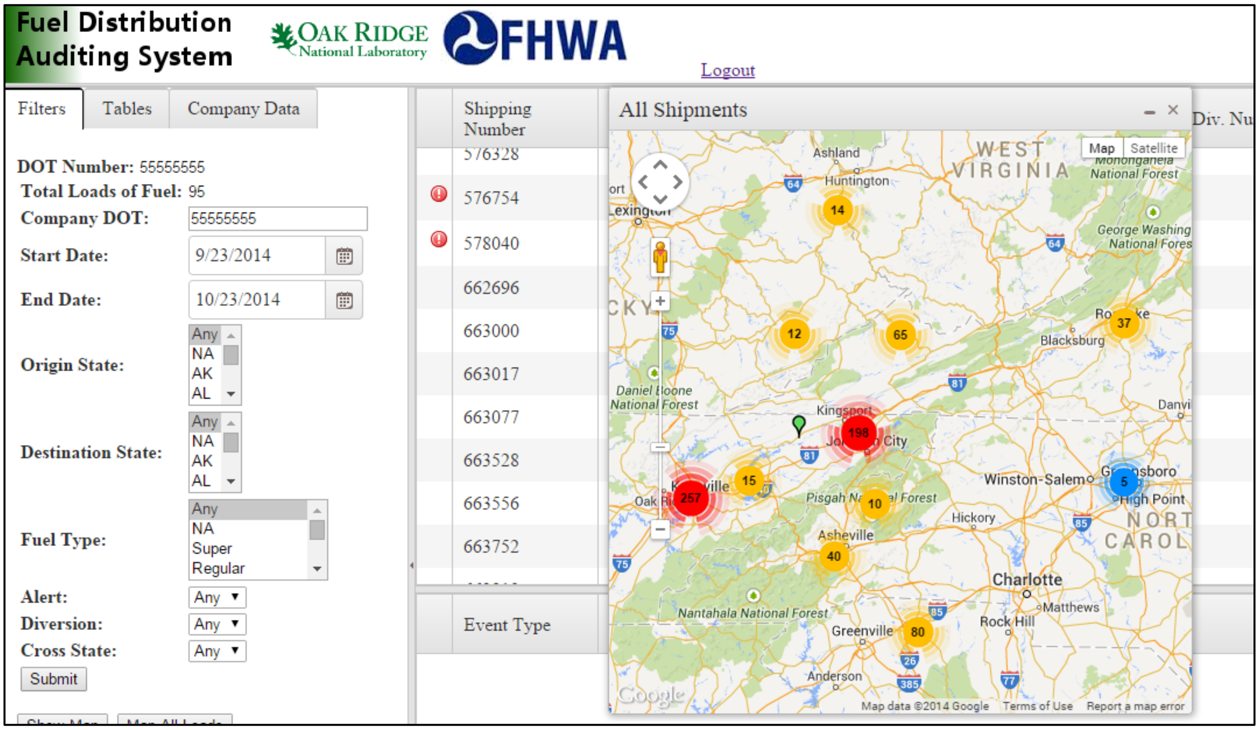

Figure 20. Fuel Distribution Auditing System tax auditor's interface.

2. PILOT TEST DATA COLLECTED AND RESULTS

Three fully instrumented Barger Transport tanker trucks participated in the pilot test at no cost to the project. The three vehicles were similar (i.e., they all had the same type of tankers, and involved two tractor models), and were equipped with the same type of sensors: hatch sensors, valve sensors, and weight sensors. Those sensors and their wires and harnesses were developed by Air-Weigh. The tankers, which consisted of five compartments with capacities equal to 3,100 gallons, 1,250 gallons, 1,100 gallons, 1,100 gallons, and 2,650 gallons for compartments 1 to 5 (tanker front to rear) respectively, were provided from new stock by LBT, at no cost to the project. As discussed previously, the information from the on-board sensors registering valve actuations, hatch openings, vehicle weight, vehicle location, and driver input was captured in the form of fuel-logs by the obERS application running on the obTD, and they were transmitted at regular intervals to the TBOS. The obTD and BOS were developed by ISE. At the TBOS, the "raw" information is processed by the boERS application generating the driver reports and, with the input from the carrier when needed, the FDAS reports.

2.1 GENERAL STATISTICS

The pilot test ran just over eight months, staring in October 2014 and ending in June 2015. During that period, about 700 fuel-log files[5] were submitted from the three instrumented vehicles (vehicles A, B, and C) and processed by the boERS application (see Table 1). The data was collected during normal operations of the fuel hauler participating in the test. The twelve drivers that drove these vehicles were trained and were also provided with a "quick reference" guide on how to input the fuel data on the obTD (note: the addition of the valve and hatch sensors did not alter the way these elements were operated so no new training was needed).

Table 1. Pilot Test General Statistics

Vehicle ID	Miles Logged	Days in Pilot Test	Number of Fuel-Log Files	Diesel Transported (Gallons)	Gasoline Transported (Gallons)	Other Transported (Gallons)	Total Transported (Gallons)
Vehicle A	103,805	238	166	280,335	2,289,965	982	2,571,282
Vehicle B	132,735	232	313	427,201	2,839,156	14,139	3,280,496
Vehicle C	137,913	237	213	675,605	1,010,108	0	1,685,713
Total	374,453	706	692	1,383,141	6,139,229	15,121	7,537,491

Figure 21 presents a distribution of fuel-log files by vehicle and by date for the month of October 2014. Each point indicates the transmission of a fuel-log file (which could have been more than one file, if the total size of the information being transmitted was above the maximum allowed per file). The month is divided into weeks separated by thick vertical lines, with each week starting on a Monday. The horizontal axis in the chart indicates the number of days that have elapsed from the beginning of the pilot test, which was Wednesday, October 1, 2014. As shown in Figure 21, Vehicle B submitted a higher number of fuel-log files than the other two vehicles (Table 1). Appendix I contains the charts for the remainder of the pilot test fuel-log files (i.e., November 2014 through June 2015). The same pattern is observed in the charts shown in the appendix. That is, Vehicle B generated more fuel-log files than either of the other two vehicles. The main reason for this is that during most of the pilot test, two trained drivers operated Vehicle B while Vehicles A and C were each operated by only one trained driver. The main

[5] As explained earlier, because of communication bandwidth constraints the fuel-log files had to be divided into sub-files of no more than 16KB. This resulted in the transmission of about 1,300 files, for a total of 15.5MB of data.

difference between a “trained” and a “non-trained” driver was that the former knew how to login to the telematics device and how to enter fuel-related information. This was very important, since for a vehicle to generate a fuel-log file, the driver must be logged in, and when that driver logged out of the obTD, the information gathered was submitted to the TBOS. If a driver did not log in, the system still collected the information (valve actuations, vehicle weight, spatial location, odometer reading, hatch opening and closing, etc.), but could not assign these fuel-log files to any driver and therefore the files were not processed. In an operational system, it is expected that all drivers will be trained, and this issue would not exist.

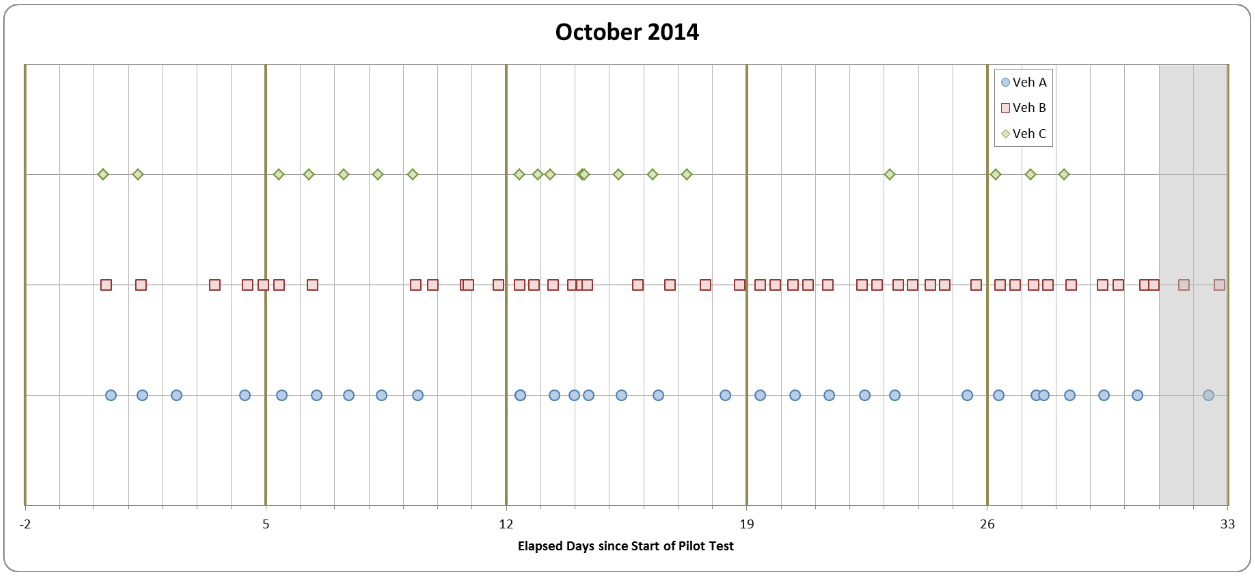

Figure 21. Pilot test fuel-log files by vehicle and day in the month of October 2014.

The pilot test area of operations covered mostly Virginia, Tennessee, and Kentucky; although fuel was delivered to other states as well. Figure 22 and Figure 23 show maps of the fuel-loading and offloading sites during the pilot test for the three participating vehicles. The size of the circles is proportional to the number of times the sites were visited.

There were three major loading sites and many offloading sites. Some of the latter are not represented in the map because they were visited only a few times during the pilot test (e.g., fuel was transported from Knoxville, Tennessee to near Wilmington, Ohio only twice during the pilot test so that location is not shown on the map). The participating vehicles logged a total of 375,000 miles during the pilot test. Figure 24 shows a distribution of distance traveled between the fuel terminal and the retail fuel locations for 390 randomly selected trips. The average distance was about 139 miles, with a standard deviation of 66 miles. A few trips covered very long distances (i.e., more than 400 miles), and slightly over 25% of the trips had a length of over 200 miles.

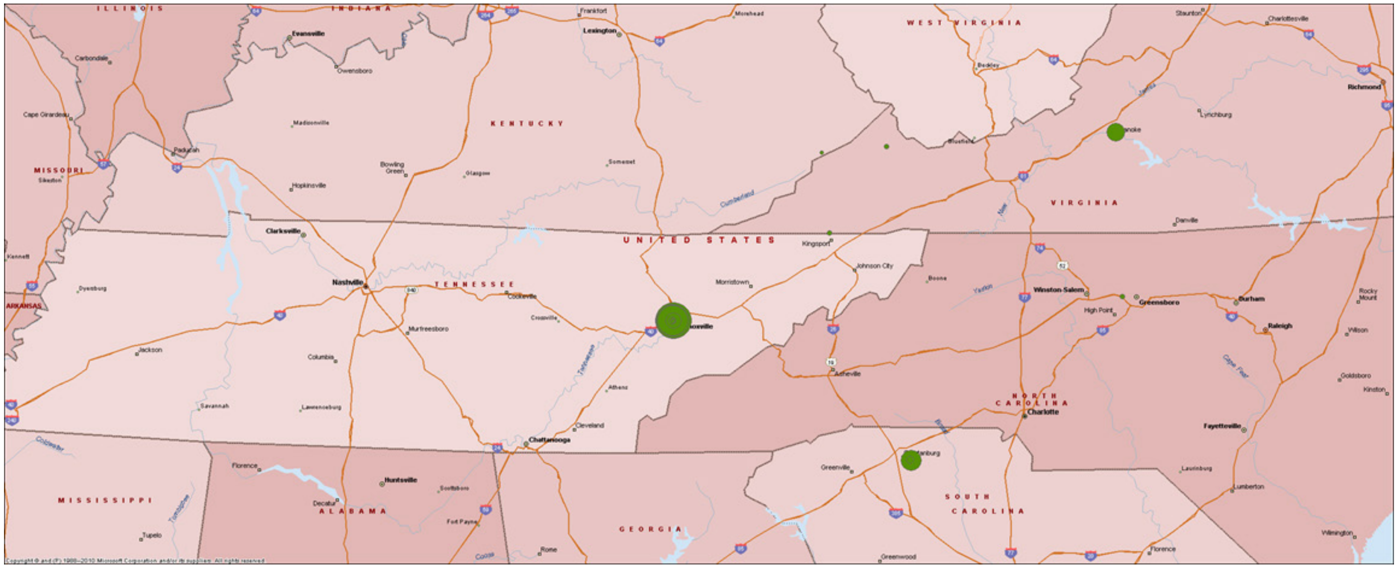

Figure 22. Pilot test fuel loading sites.

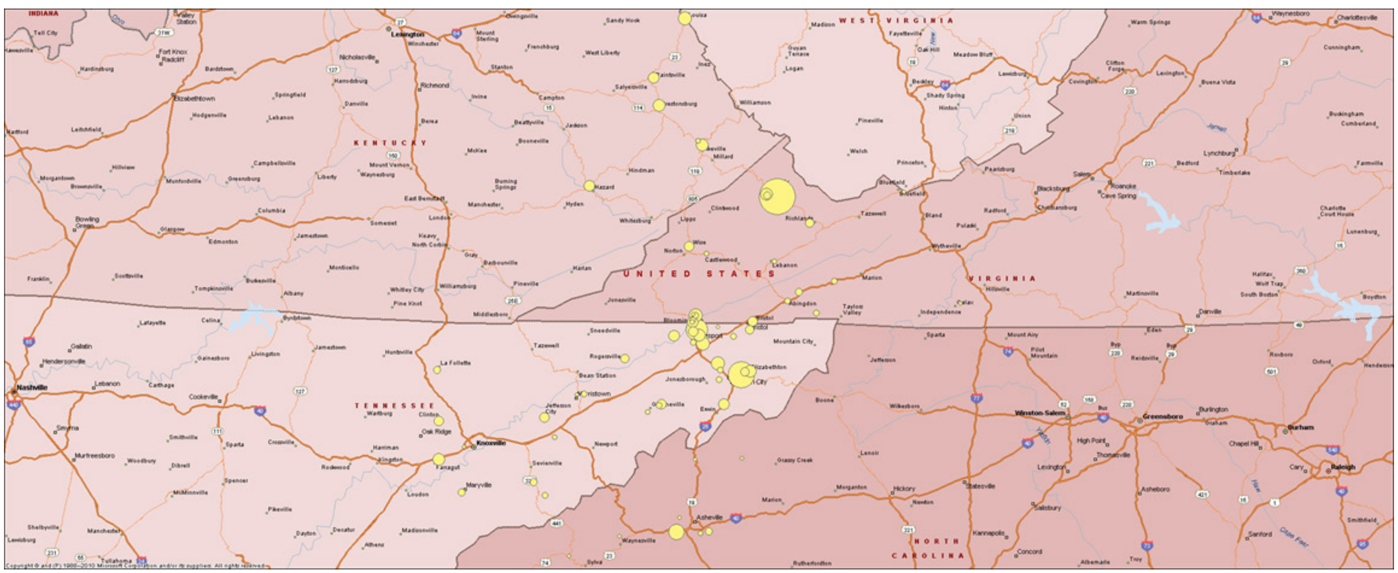

Figure 23. Pilot test fuel offloading sites.

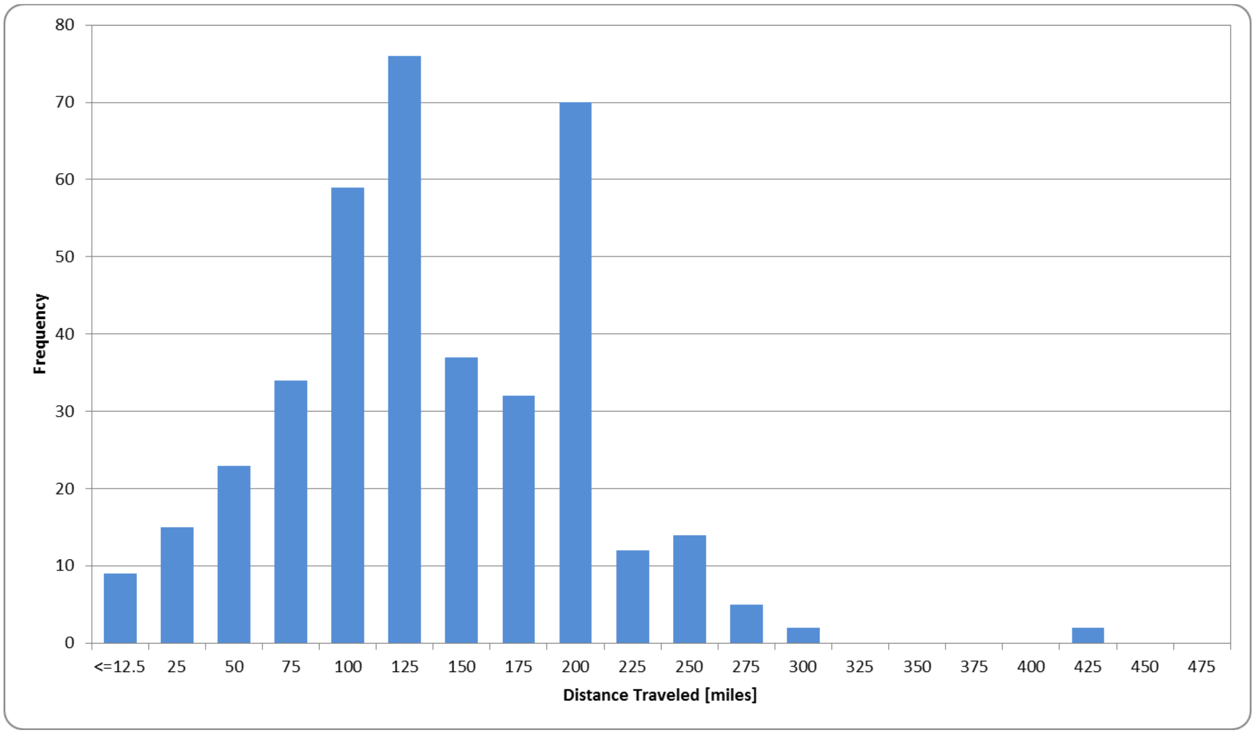

Figure 24. Distance distribution for 390 randomly selected trips.

Part of the pilot test was conducted during the winter of 2015. During that time, snow and road-added chemicals adversely affected the first-generation wiring and sensor connections deployed on the vehicles (mostly due a defective manufacturing process). Additionally, the T2TCU enclosures leaked, leading to corrosion on the circuit boards. This caused some of the sensors to malfunction and provide only limited usable data. For example, if a compartment's emergency valve did not provide actuation information but the primary valve was working correctly (a typically observed malfunction scenario), information could still be gathered regarding fuel deliveries; however, no inferences about suspicious activities could be made.

These defects were corrected by hardening and/or replacement of the hardware. As a consequence, there was a period of time in which some of the instrumented vehicles were not able to collect data (for example, see Appendix I for the number of fuel-log files generated in March and April 2015). The second-generation hardware greatly improved the reliability of the system. Table 2 presents, for each of the three instrumented vehicles, the number of compartments that had both the emergency and primary valve sensors and switches operational, or had just one of the two operational for the entire pilot test. This data covers the periods of time for both the first- and second-generation hardware. Vehicle A had the least reliability (only 81% of the time did it have both the emergency and primary valve sensors and switches operational[6]), followed by Vehicle B (98.8%) and Vehicle C (99.2%). For the overall pilot test, having both the emergency and primary valve sensors and switches simultaneously operable was 94.9%.

[6] The primary and emergency valves always worked in the sense that they always allowed the loading and offloading of the tanker compartments. From the point of view of the system tested in the pilot test, if a sensor or a switch was not able to send information to the obTD through the vehicle databus, then that valve was considered not operational.

Table 2. Valve Switch Reliability* During Pilot Test

Vehicle ID	Period	All Valves	Only Primary	Only Emergency	Total	Reliability
Vehicle A	Pilot Test	450	103	2	555	81.1%
Vehicle B	Pilot Test	1,055	10	3	1,068	98.8%
Vehicle C	Pilot Test	840	7	0	847	99.2%
All Vehicles	Pilot Test	2,345	120	5	2,470	94.9%

* Instances When Indicated Valves Were Operational

When the information presented in Table 2 is divided into the period preceding and the period following the hardware upgrade, it is clear that the system reliability improved substantially (see Table 3). After March 2015, in all the observed cases, both the emergency and primary valve switches were operational.

Table 3. Valve Switch Reliability* Before and After Hardware Upgrade

Vehicle ID	Period	All Valves	Only Primary	Only Emergency	Total	Reliability
Vehicle A	Oct 2014 to Feb 2015 (Before)	180	103	2	285	63.2%
Vehicle A	Mar 2015 to June 2015 (After)	270	0	0	270	100.0%
Vehicle B	Oct 2014 to Feb 2015 (Before)	827	10	3	840	98.5%
Vehicle B	Mar 2015 to June 2015 (After)	228	0	0	228	100.0%
Vehicle C	Oct 2014 to Feb 2015 (Before)	460	7	0	467	98.5%
Vehicle C	Mar 2015 to June 2015 (After)	380	0	0	380	100.0%
All Vehicles	Oct 2014 to Feb 2015 (Before)	1,467	120	5	1,592	92.1%
All Vehicles	Mar 2015 to June 2015 (After)	878	0	0	878	100.0%

* Instances When Indicated Valves Were Operational

The obERS application collects information about many different events. Besides valve and hatch state change, which are events of primary interest in this project, other events such as tanker and tractor databus state change, driver login and logout, and fuel-flowing events are also captured. Table 4 presents the number of observations by event type and driver, both in terms of the actual number of observations and a percentage of total events. The four drivers highlighted in Table 4 (Driver 84/D84, Driver 12/D12, Driver 19/D19 and Driver 42/D42) were the drivers that participated for the longest time in the pilot test, and as a consequence of their experience, they had a higher number of events. The column labeled "All Drivers" presents the totals for all twelve drivers that operated the three instrumented vehicles. As expected, the largest number of observations corresponds to valve actuations (valve state changes and valve sensor state changes), followed by fuel-flowing events. Hatch sensor state changes were also significant in number. These were mostly due to vibrations and other issues and were corrected when the hardware was hardened or replaced as explained above. The hatch state changes events were also associated with the vibration issue. They are more noticeable for driver D12, who drove Vehicle A most of the time (see Table 5, which presents the same information as in Table 4, but by vehicle instead of by driver).

In an attempt to capture tampering activities, the obERS monitored tanker and tractor databus disconnects. While the tractor databus disconnections were few (as expected), the number of tanker databus disconnections was high. Once this issue was investigated, it was determined that it was due to the frequency with which the information about the databus connectivity was posted and passed to the obTD software that monitored this connection. A higher frequency of data postings or a relaxation of the frequency that the obTD expects a tanker "heartbeat" message" would solve this issue and greatly reduce the false-positive rate for tanker disconnections.

Table 4. Number and Share (Percent) of Observations by Pilot Test Event Type and Driver

Event Type	Driver D84	Driver D12	Driver D19	Driver D42	All Drivers
Driver Login	146 (1.5%)	134 (0.9%)	155 (1.4%)	159 (1.2%)	691 (1.2%)
Driver Logout	145 (1.5%)	133 (0.9%)	155 (1.4%)	158 (1.2%)	687 (1.2%)
Tanker Databus State Change	139 (1.4%)	200 (1.4%)	162 (1.4%)	117 (0.9%)	708 (1.2%)
Fuel Flowing	1,727 (17.2%)	2,478 (17.3%)	1,972 (17.6%)	1,654 (12.7%)	8,574 (15.0%)
Valve State Change	6,090 (60.8%)	7,248 (50.7%)	7,124 (63.7%)	9,652 (74.4%)	36,853 (64.5%)
Valve Sensor State Change	1,215 (12.1%)	1,486 (10.4%)	1,181 (10.6%)	284 (2.2%)	4,753 (8.3%)
Hatch Sensor State Change	537 (5.4%)	2,239 (15.7%)	419 (3.7%)	418 (3.2%)	3,909 (6.8%)
Initial Check	0 (0.0%)	2 (0.0%)	1 (0.0%)	0 (0.0%)	4 (0.0%)
Vehicle Moves	1 (0.0%)	90 (0.6%)	0 (0.0%)	263 (2.0%)	354 (0.6%)
Tractor Databus State Change	4 (0.0%)	3 (0.0%)	5 (0.0%)	0 (0.0%)	16 (0.0%)
Hatch State Change	12 (0.1%)	274 (1.9%)	17 (0.2%)	18 (0.1%)	336 (0.6%)
Alarm Reset	4 (0.0%)	0 (0.0%)	0 (0.0%)	256 (2.0%)	260 (0.5%)
TOTAL	10,020 (100%)	14,287 (100%)	11,191 (100%)	12,979 (100%)	57,145 (100%)

Table 5. Number and Share (Percent) of Observations by Pilot Test Event Type and Vehicle

Event Type	Vehicle A	Vehicle B	Vehicle C	All Vehicles
Driver Login	166 (1.0%)	313 (1.4%)	212 (1.3%)	691 (1.2%)
Driver Logout	165 (1.0%)	312 (1.4%)	210 (1.2%)	687 (1.2%)
Tanker Databus State Change	237 (1.4%)	321 (1.4%)	150 (0.9%)	708 (1.2%)
Fuel Flowing	2,985 (17.3%)	3,713 (16.1%)	1,876 (11.1%)	8,574 (15.0%)
Valve State Change	9,360 (54.3%)	14,374 (62.3%)	13,119 (77.8%)	36,853 (64.5%)
Valve Sensor State Change	1,610 (9.3%)	2,829 (12.3%)	314 (1.9%)	4,753 (8.3%)
Hatch Sensor State Change	2,309 (13.4%)	1,164 (5.0%)	436 (2.6%)	3,909 (6.8%)
Initial Check	2 (0.0%)	2 (0.0%)	0 (0.0%)	4 (0.0%)
Vehicle Moves	90 (0.5%)	1 (0.0%)	263 (1.6%)	354 (0.6%)
Tractor Database State Change	5 (0.0%)	9 (0.0%)	2 (0.0%)	16 (0.0%)
Hatch State Change	292 (1.7%)	22 (0.1%)	22 (0.1%)	336 (0.6%)
Alarm Reset	0 (0.0%)	4 (0.0%)	256 (1.5%)	260 (0.5%)
TOTAL	17,221 (100.0%)	23,064 (100.0%)	16,860 (100.0%)	57,145 (100.0%)

As discussed previously, the pilot test drivers were trained by ORNL, and Barger also received a "step-by-step" guide on how to operate the system (each vehicle had a hardcopy of this guide in the cabin). Nevertheless, some mistakes were made by the drivers. For example, in most cases, the drivers entered fuel type, fuel quantity, BOL information, etc. after loading at a terminal, as they were instructed to do. But in many cases, once they arrived at the destination and delivered the fuel, the fuel information (fuel type, fuel quantity, etc.) was not confirmed as it should have been. This created discrepancies between the fuel loaded and fuel offloaded information. This issue can be corrected with additional driver training as soon as it is observed, since it is simpler to enter offloading information (the user has to simply check the information which the system "remembers" from the previous loading event) than to enter fuel loading information again (the user has to type fuel volumes, select fuel type, type BOL numbers, etc.). Another example of driver error was accidental miss-entry of information or typos, which is not uncommon for human-data entry tasks. For example, during one ride-along, the BOL number entered in the obTD was one character off from the BOL printed at the terminal. Another example involves more complicated loading or offloading scenarios. For instance, with more information to be hand-entered, the opportunity for human error is greater in cases where a "splash-mix" load where regular fuel is loaded into one compartment and a smaller amount of ethanol is later loaded into the same compartment (possibly at another location) to obtain a desired blend.

As an illustration of a system working normally (i.e., a system where all of the required fuel-related information is always entered), Table 6 and Table 7 present the same information as that which was shown in Table 4 and Table 5, but for a subset of the fuel-log files collected in which both loading and offloading information was entered by the drivers. Notice that although the number of events is lower (as expected, since only matching loading and offloading files were considered) there is not much difference in the percentage of the time each individual event occurred.

Table 6. Number and Share (Percent) of Observations by Event Type and Driver for Matching Loading and Offloading Driver Information

Event Type	Driver D84	Driver D12	Driver D19	Driver D42	All Drivers
Driver Login	105 (1.8%)	63 (1.1%)	113 (1.6%)	78 (1.5%)	400 (1.5%)
Driver Logout	83 (1.4%)	61 (1.0%)	96 (1.3%)	75 (1.5%)	361 (1.4%)
Tanker Databus State Change	77 (1.3%)	51 (0.9%)	82 (1.1%)	30 (0.6%)	260 (1.0%)
Fuel Flowing	1,300 (21.8%)	1,296 (22.1%)	1,558 (21.5%)	1,082 (21.4%)	5,714 (21.4%)
Valve State Change	3,847 (64.5%)	3,620 (61.8%)	4,789 (66.1%)	3,696 (73.0%)	17,869 (66.8%)
Valve Sensor State Change	401 (6.7%)	239 (4.1%)	476 (6.6%)	72 (1.4%)	1,247 (4.7%)
Hatch Sensor State Change	147 (2.5%)	433 (7.4%)	115 (1.6%)	6 (0.1%)	737 (2.8%)
Initial Check	0 (0.0%)	2 (0.0%)	0 (0.0%)	0 (0.0%)	2 (0.0%)
Vehicle Moves	1 (0.0%)	0 (0.0%)	0 (0.0%)	4 (0.1%)	5 (0.0%)
Tractor Databus State Change	0 (0.0%)	0 (0.0%)	2 (0.0%)	0 (0.0%)	5 (0.0%)
Hatch State Change	6 (0.1%)	91 (1.3%)	15 (0.2%)	6 (0.1%)	120 (0.4%)
Alarm Reset	1 (0.0%)	0 (0.0%)	0 (0.0%)	13 (0.3%)	14 (0.1%)
TOTAL	5,968 (100.0%)	5,856 (100.0%)	7,246 (100.0%)	5,062 (100.0%)	26,734 (100.0%)

Table 7. Number and Share (Percent) of Observations by Event Type and Vehicle for Matching Loading and Offloading Driver Information

Event Type	Vehicle A	Vehicle B	Vehicle C	All Vehicles
Driver Login	80 (1.0%)	220 (1.07%)	100 (1.7%)	400 (1.8%)
Driver Logout	79 (1.0%)	182 (1.4%)	100 (1.7%)	361 (1.4%)
Tanker Databus State Change	64 (0.8%)	160 (1.2%)	36 (0.6%)	260 (1.0%)
Fuel Flowing	1,648 (21.6%)	2,828 (21.4%)	1,238 (21.0%)	5,714 (21.4%)
Valve State Change	4,910 (64.4%)	8,645 (65.4%)	4,314 (73.2%)	17,869 (66.8%)
Valve Sensor State Change	275 (3.6%)	900 (6.8%)	72 (1.2%)	1,247 (4.7%)
Hatch Sensor State Change	461 (6.0%)	270 (2.0%)	6 (0.1%)	737 (2.8%)
Initial Check	2 (0.0%)	0 (0.0%)	0 (0.0%)	2 (0.0%)
Vehicle Moves	0 (0.0%)	1 (0.0%)	4 (0.1%)	5 (0.0%)
Tractor Databus State Change	2 (0.0%)	2 (0.0%)	1 (0.0%)	5 (0.0%)
Hatch State Change	100 (1.3%)	14 (0.1%)	6 (0.1%)	120 (0.4%)
Alarm Reset	0 (0.0%)	1 (0.0%)	13 (0.2%)	14 (0.1%)
TOTAL	7,621 (100.0%)	13,223 (100.0%)	5,890 (100.0%)	26,734 (100.0%)

Table 8 shows the volume of fuel hauled during the pilot test by fuel type and by driver. The first column of the table shows the fuel types that were available to the drivers. The Regular-Ethanol, Premium-Ethanol, and Plus-Ethanol can be bought already blended (one BOL and one input from the driver) or blended separately (i.e., regular gasoline from one terminal and ethanol from another terminal - with two different BOLs requiring two inputs from the driver). The remaining columns show the quantity of fuel (gallons) that was transported by the driver shown in the header of the table (i.e., the four main drivers and all of the drivers that operated the three instrumented vehicles), with the second set of five columns indicating the percentages to the total number of gallons loaded. Table 9 shows the same information as in Table 8, but this time by vehicle.

Table 8. Number and Share (Percent) of Gallons Loaded by Fuel Type and Driver

Fuel Type	Driver D84	Driver D12	Driver D19	Driver D42	All Drivers
Premium	9,988 (0.7%)	4,588 (0.2%)	1,200 (0.1%)	1,000 (0.1%)	17,856 (0.2%)
Regular	55,000 (3.7%)	17,576 (0.8%)	27,700 (1.6%)	29,000 (2.0%)	148,874 (2.0%)
Ethanol	8,739 (0.6%)	863 (0.0%)	0 (0.0%)	0 (0.0%)	9,721 (0.1%)
Ultra-Low Sulfur Diesel (ULSD)	209,800 (14.3%)	208,831 (9.8%)	64,900 (3.7%)	234,403 (16.5%)	789,741 (10.5%)
Dyed ULSD	144,000 (9.8%)	14,800 (0.7%)	0 (0.0%)	429,600 (30.3%)	593,400 (7.9%)
Kerosene	0 (0.0%)	0 (0.0%)	2,400 (0.1%)	0 (0.0%)	5,400 (0.1%)
Regular-Ethanol	992,260 (67.4%)	1,792,601 (83.7%)	1,605,800 (90.7%)	680,067 (48.0%)	5,686,209 (75.4%)
Premium-Ethanol	42,180 (2.9%)	99,793 (4.7%)	45,900 (2.6%)	37,300 (2.6%)	246,186 (3.3%)
Plus-Ethanol	7,700 (0.5%)	2,704 (0.1%)	22,800 (1.3%)	0 (0.0%)	33,204 (0.4%)
Regular-Premium	1,800 (0.1%)	0 (0.0%)	0 (0.0%)	5,100 (0.4%)	6,900 (0.1%)
TOTAL	1,471,467 (100.0%)	2,141,756 (100.0%)	1,770,700 (100.0%)	1,416,470 (100.0%)	7,537,491 (100.0%)

Table 9. Number and Share (Percent) of Gallons by Fuel Type and Vehicle

Fuel Type	Vehicle A	Vehicle B	Vehicle C	All Vehicles
Premium	5,668 (0.2%)	11,188 (0.3%)	1,000 (0.1%)	17,856 (0.2%)
Regular	17,576 (0.7%)	82,700 (2.5%)	48,598 (2.9%)	148,874 (2.0%)
Ethanol	982 (0.0%)	8,739 (0.3%)	0 (0.0%)	9,721 (0.1%)
ULSD	265,535 (10.3%)	278,201 (8.5%)	246,005 (14.6%)	789,741 (10.5%)
Dyed ULSD	14,800 (0.6%)	149,000 (4.5%)	429,600 (25.5%)	593,400 (7.9%)
Kerosene	0 (0.0%)	5,400 (0.2%)	0 (0.0%)	5,400 (0.1%)
Regular-Ethanol	2,147,415 (83.5%)	2,616,684 (79.8%)	922,110 (54.7%)	5,686,209 (75.47%)
Premium-Ethanol	116,602 (4.5%)	96,284 (2.9%)	33,300 (2.0%)	246,186 (3.3%)
Plus-Ethanol	2,704 (0.1%)	30,500 (0.9%)	0 (0.0%)	33,204 (0.4%)
Regular-Premium	0 (0.0%)	1,800 (0.1%)	5,100 (0.3%)	6,900 (0.1%)
TOTAL	2,571,282 (100.0%)	3,280,496 (100.0%)	1,685,713 (100.0%)	7,537,491 (100.0%)

The total number of gallons loaded for each type of fuel was obtained from the information provided by the drivers. There were some instances in which, as explained above, the drivers did not enter fuel information (fuel type, fuel amount); therefore, the information shown in Table 8 and Table 9 underestimate the volumes of fuel transported. Nevertheless, whether the driver entered fuel information or not, the system captured all of the instances in which fuel was loaded and offloaded (e.g., the actuation of the valves was always captured by the obTD and thereby the obERS). For the three vehicles participating in the pilot test, the fuel type that was most frequently hauled was a blend of regular gasoline and ethanol (75.4% of the total volume transported) followed by Ultra Low Sulfur Diesel (ULSD) (10.5%), premium gasoline blended with ethanol (3.3%) and regular gasoline (2.0%).

Table 10 and Table 11 present the same information as in the previous two tables, but this time for the subset of fuel-log files in which the driver entered fuel information when loading and offloading the cargo (i.e., complete information was provided by the driver). Although the volumes are smaller (as expected), the distribution of the type of fuels hauled is roughly the same.

Table 10. Number and Share (Percent) of Gallons by Fuel Type and Driver for Matching Loading and Offloading Driver Information

Fuel Type	Driver D84	Driver D12	Driver D19	Driver D42	All Drivers
Premium	2,800 (0.3%)	0 (0.0%)	1,200 (0.1%)	0 (0.0%)	4,000 (0.1%)
Regular	22,130 (2.0%)	0 (0.0%)	5,900 (0.4%)	0 (0.0%)	47,628 (1.0%)
Ethanol	4,474 (0.4%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	4,474 (0.1%)
ULSD	166,300 (15.0%)	103,003 (9.4%)	36,000 (2.7%)	163,802 (18.7%)	510,306 (10.4%)
Dyed ULSD	119,400 (10.7%)	7,400 (0.7%)	0 (0.0%)	272,900 (31.1%)	399,700 (8.2%)
Kerosene	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Regular-Ethanol	764,200 (68.7%)	925,373 (84.6%)	1,269,100 (93.5%)	416,000 (47.5%)	3,748,795 (76.7%)
Premium-Ethanol	26,300 (2.4%)	58,258 (5.3%)	36,000 2.7%)	23,500 (2.7%)	156,465 (3.2%)
Plus-Ethanol	5,200 (0.5%)	0 (0.0%)	8,600 (0.6%)	0 (0.0%)	13,800 (0.3%)
Regular-Premium	800 (0.1%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	800 (0.0%)
TOTAL	1,111,604 (100.0%)	1,094,034 (100.0%)	1,356,800 (100.0%)	876,202 (100.0%)	4,885,968 (100.0%)

Table 11. Number and Share (Percent) of Gallons by Fuel Type and Vehicle for Matching Loading and Offloading Driver Information

Fuel Type	Vehicle A	Vehicle B	Vehicle C	All Vehicles
Premium	0 (0.0%)	4,000 (0.2%)	0 (0.0%)	4,000 (0.1%)
Regular	0 (0.0%)	28,030 (1.1%)	19,598 (1.9%)	47,628 (1.0%)
Ethanol	0 (0.0%)	4,474 (0.2%)	0 (0.0%)	4,474 (0.1%)
ULSD	133,603 (9.6%)	205,801 (8.4%)	170,902 (16.5%)	510,306 (10.4%)
Dyed ULSD	7,400 (0.5%)	119,400 (4.9%)	272,900 (26.3%)	399,700 (8.2%)
Kerosene	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Regular-Ethanol	1,183,262 (85.1%)	2,011,905 (81.9%)	553,628 (53.3%)	3,748,795 (76.7%)
Premium-Ethanol	66,465 (4.8%)	68,500 (2.8%)	21,500 (2.1%)	156,465 (3.2%)
Plus-Ethanol	0 (0.0%)	13,800 (0.6%)	0 (0.0%)	13,800 (0.3%)
Regular-Premium	0 (0.0%)	800 (0.0%)	0 (0.0%)	800 (0.0%)
TOTAL	1,390,730 (100.0%)	2,456,710 (100.0%)	1,038,528 (100.0%)	4,885,968 (100.0%)

Table 12 through Table 15 show the volume of fuel hauled when the fuel offloading events were considered. There is a substantial difference between the totals presented in Table 8 and Table 9 with respect to those of Table 12 and Table 13 (about 500,000 gallons total or about 6.7% of all of the fuel hauled in the pilot test). This indicates that the drivers sometimes made mistakes when entering the data at the destination, or did not enter the data at all. Consider, for example, driver D19 and compare to Table 14. Driver D19 offloaded more Regular-Ethanol fuel (1,271,100 gallons) than what was loaded (1,269,100 gallons) for a difference of 2,000 gallons. During the pilot test, this driver also offloaded 2,000 gallons less of Premium-Ethanol than was reportedly loaded (34,000 gallons versus 36,000 gallons). The net difference between these two cases is 0 gallons (i.e., between the total fuel loaded and the total fuel offloaded). Notice that in these two tables, the four selected drivers as well as “All Drivers” have discrepancies in these two rows. The fuel-information user interface running on the obTD had a drop-down list of the different fuels (same list as shown in the first column of Table 8 through Table 15) and the driver had to select one of those when loading and offloading (see Appendix G for more details about the interface). Mistakes were made when selecting these types of blended fuels which resulted in some mislabeled fuel types. These errors, however, can be corrected by the carrier (through the TBOS carrier interface [see Appendix F]) or easily found using the FDAS interface if they are not corrected.

Table 12. Number and Share (Percent) of Gallons Offloaded by Fuel Type and Driver

Fuel Type	Driver D84	Driver D12	Driver D19	Driver D42	All Drivers
Premium	10,008 (0.7%)	2,794 (0.1%)	1,200 (0.1%)	1,000 (0.1%)	15,002 (0.2%)
Regular	59,750 (4.1%)	9,438 (0.8%)	21,900 (1.3%)	6,100 (0.5%)	124,387 (1.8%)
Ethanol	6,132 (0.4%)	863 (0.0%)	0 (0.0%)	0 (0.0%)	7,114 (0.1%)
ULSD	203,500 (14.1%)	198,738 (9.8%)	45,900 (2.8%)	211,402 (16.9%)	718,144 (10.2%)
Dyed ULSD	143,000 (9.9%)	14,800 (0.7%)	0 (0.0%)	393,700 (31.4%)	560,500 (8.0%)
Kerosene	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	3,000 (0.0%)
Regular-Ethanol	969,460 (67.1%)	1,696,001 (84.0%)	1,504,100 (92.1%)	610,767 (48.7%)	5,317,760 (75.9%)
Premium-Ethanol	43,900 (3.0%)	94,285 (4.7%)	42,700 (2.6%)	31,300 (2.5%)	233,598 (3.3%)
Plus-Ethanol	7,700 (0.5%)	2,704 (0.1%)	17,000 (1.0%)	0 (0.0%)	27,404 (0.4%)
Regular-Premium	1,800 (0.1%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1,800 (0.0%)
TOTAL	1,445,250 (100.0%)	2,019,623 (100.0%)	1,632,800 (100.0%)	1,254,269 (100.0%)	7,008,709 (100.0%)

Table 13. Number and Share (Percent) of Gallons Offloaded by Fuel Type and Vehicle

Fuel Type	Vehicle A	Vehicle B	Vehicle C	All Vehicles
Premium	2,794 (0.01%)	11,208 (0.4%)	1,000 (0.1%)	15,002 (0.2%)
Regular	9,438 (0.4%)	84,251 (2.7%)	30,698 (2.1%)	124,387 (1.8%)
Ethanol	982 (0.0%)	6,132 (0.2%)	0 (0.0%)	7,114 (0.1%)
ULSD	247,342 (10.2%)	247,600 (8.0%)	223,202 (15.2%)	718,144 (10.3%)
Dyed ULSD	14,800 (0.6%)	148,000 (4.8%)	397,700 (27.0%)	560,500 (8.0%)
Kerosene	0 (0.0%)	3,000 (0.1%)	0 (0.0%)	3,000 (0.0%)
Regular-Ethanol	2,046,468 (84.1%)	2,480,476 (80.0%)	790,816 (53.7%)	5,317,760 (75.9%)
Premium-Ethanol	109,896 (4.5%)	95,402 (3.1%)	28,300 (1.9%)	233,598 (3.3%)
Plus-Ethanol	2,704 (0.1%)	24,700 (0.8%)	0 (0.0%)	27,404 (0.4%)
Regular-Premium	0 (0.0%)	1,800 (0.1%)	0 (0.0%)	1,800 (0.0%)
TOTAL	2,434,424 (100.0%)	3,102,569 (100.0%)	1,471,716 (100.0%)	7,008,709 (100.0%)

Table 14. Number and Share (Percent) of Gallons by Fuel Type and Driver for Matching Loading and Offloading Driver Information

Fuel Type	Driver D84	Driver D12	Driver D19	Driver D42	All Drivers
Premium	2,800 (0.3%)	0 (0.0%)	1,200 (0.1%)	0 (0.0%)	4,000 (0.1%)
Regular	22,130 (2.0%)	0 (0.0%)	5,900 (0.4%)	0 (0.0%)	47,628 (1.0%)
Ethanol	1,274 (0.1%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1,274 (0.0%)
ULSD	168,300 (15.1%)	103,003 (9.4%)	36,000 (2.7%)	165,802 (18.9%)	512,705 (10.5%)
Dyed ULSD	119,400 (10.7%)	7,400 (0.7%)	0 (0.0%)	271,900 (31.0%)	398,700 (8.2%)
Kerosene	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Regular-Ethanol	764,400 (68.8%)	923,362 (84.4%)	1,271,100 (93.7%)	414,000 (47.2%)	3,751,235 (76.8%)
Premium-Ethanol	27,300 (2.5%)	60,261 (5.5%)	34,000 (2.5%)	24,500 (2.8%)	155,868 (3.2%)
Plus-Ethanol	5,200 (0.5%)	0 (0.0%)	8,600 (0.6%)	0 (0.0%)	13,800 (0.3%)
Regular-Premium	800 (0.1%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	800 (0.0%)
TOTAL	1,111,604 (100.0%)	1,094,026 (100.0%)	1,356,800 (100.0%)	876,202 (100.0%)	4,886,010 (100.0%)

Table 15. Number and Share (Percent) of Gallons by Fuel Type and Vehicle for Matching Loading and Offloading Driver Information

Fuel Type	Vehicle A	Vehicle B	Vehicle C	All Vehicles
Premium	0 (0.0%)	4,000 (0.2%)	0 (0.0%)	4,000 (0.1%)
Regular	0 (0.0%)	28,030 (1.1%)	19,598 (0.1.9%)	47,628 (1.0%)
Ethanol	0 (0.0%)	1,274 (0.1%)	0 (0.0%)	1,274 (0.0%)
ULSD	133,603 (9.6%)	205,200 (8.4%)	173,902 (16.8%)	512,705 (10.5%)
Dyed ULSD	7,400 (0.5%)	119,400 (4.9%)	271,900 (26.2%)	398,700 (8.2%)
Kerosene	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Regular-Ethanol	1,181,300 (84.9%)	2,019,307 (82.2%)	550,628 (53.0%)	3,751,235 (76.8%)
Premium-Ethanol	68,468 (4.9%)	64,900 (2.6%)	22,500 (2.2%)	155,868 (3.2%)
Plus-Ethanol	0 (0.0%)	13,800 (0.0%)	0 (0.0%)	13,800 (0.3%)
Regular-Premium	0 (0.0%)	800 (0.0%)	0 (0.0%)	800 (0.0%)
TOTAL	1,390,771 (100.0%)	2,456,711 (100.0%)	1,038,528 (100.0%)	4,886,010 (100.0%)

Information about the BOLs generated during the pilot test is shown in Table 16 (by driver) and Table 17 (by vehicle) for all of the fuel-log files. About 8.4% of the fuel-hauling trips involved two BOLs. For these cases, this happened when the blending of gasoline and ethanol was done in the tanker while the fuel was being transported. In this case, the two types of fuel to be blended were bought at two different terminals, and therefore two BOLs were generated. As discussed earlier, Vehicle B was the most active, generating 4,058 BOLs. Of all of the drivers, D12 generated the greatest number of BOLs (2,067) which was expected since he was also the driver that transported the largest amount of fuel during the pilot test (2,141,756 gallons).

Table 16. Number and Share (Percent) of BOL Information by Driver

BOL Type	Driver D84	Driver D12	Driver D19	Driver D42	All Drivers
Single BOL	1,727 (87.7%)	2,478 (94.3%)	1,972 (95.4%)	1,654 (88.0%)	8,574 (91.6%)
Two BOLs	243 (12.3%)	151 (5.7%)	95 (4.6%)	225 (12.0%)	783 (8.4%)
TOTAL	1,970 (100.0%)	2,629 (100.0%)	2,067 (100.0%)	1,879 (100.0%)	9,357 (100.0%)

Table 17. Number and Share (Percent) of BOL Information by Vehicle

BOL Type	Vehicle A	Vehicle B	Vehicle C	All Vehicles
Single BOL	2,985 (93.8%)	3,713 (191.5%)	1,876 (88.6%)	8,574 (91.6%)
Two BOLs	197 (6.2%)	345 (8.5%)	241 (11.4%)	783 (8.4%)
TOTAL	3,182 (100.0%)	4,058 (100.0%)	2,117 (100.0%)	9,357 (100.0%)

2.2 FUEL DIVERSIONS

One of the primary purposes of the STSWRF system is to help manage and track fuel diversions. When fuel is purchased at the terminal, a destination state is declared for tax purposes. If the actual destination state is different from the declared state, a fuel diversion number is required to rectify the taxes. There are several nefarious reasons to change the destination of the cargo (e.g., paying a lower tax rate on the fuel in a different state). However, there are also legitimate reasons for this to happen, such as a dispatcher instructing the driver to deliver to a different location after he is already in route.

There were 2,478 unique odometer readings recorded by the on-board system. One delivery typically consists of one fuel loading followed by one offloading. There were, however some instances of offloading of some compartments at one location, and the other compartments at another location. During the pilot test there were 958 BOL events where a driver entered information on the obTD at the time of offloading. Since each BOL involves a loading and offloading event, 1916 events are associated with the BOLs. This indicates that the drivers entered information on the obTD about 77% of the time. This level of participation was not unexpected since on the pilot test was conducted using a real-world fleet, and due to the nature of the business sometimes the trucks were driven by drivers unfamiliar with the on-board system. There were several different types of driver miss-entry. About 15% of the data had at least one compartment with loading valve activity, but no GUI entry for that compartment. About 10% of the data had at least one compartment with offloading valve activity, but no GUI entry for that compartment. About 5% of the time, a driver entered loading information but not offloading. About 11% of the time, a driver entered offloading information but not loading. Sometimes when the drivers entered information on the GUI, it was while the sensors were not working; 20% of the time for loading, and 22% of the time for offloading.

There were no actual fuel diversion numbers entered by any drivers during the pilot test. However, there were a few that were entered during the development time shortly prior to the start of the pilot test. Seven events appear to have a missing fuel diversion number. Seven out of 958 BOL events is about 0.7% of the trips which needed fuel diversion numbers. Table 18 lists details of these seven trips.

Table 18. Deliveries Requiring a Fuel Diversion Number

Date	BOL	Driver ID	Vehicle ID	Origin State	Declared State	Actual State
25-Oct-14	XX16435	D19	Vehicle B	Tennessee	Tennessee	Virginia
3-Dec-14	XX41398	D19	Vehicle B	Tennessee	Tennessee	Virginia
17-Dec-14	XX23650	D19	Vehicle B	Tennessee	Tennessee	Kentucky
26-Jan-15	XX68862	D84	Vehicle A	Tennessee	Tennessee	Virginia
27-Jan-15	XX82803	D42	Vehicle C	Tennessee	Tennessee	Virginia
11-Feb-15	XX30815	D19	Vehicle B	Tennessee	Virginia	Kentucky
23-May-15	XX63411	D31	Vehicle A	Tennessee	Tennessee	Virginia

2.3 WEIGHT

Weight sensors installed on the trucks measured steer axle, drive axle, and rear tanker axle weight. Table 19 shows calibrated weights for each truck taken in September 2014 at certified pit scales at the NTRC. Vehicle A was loaded with 8,401 gallons of Regular Ethanol 10% which were mixed at the rack. Vehicle B was loaded with 8,399 gallons of Regular Ethanol 10% which were mixed on the tanker. Vehicle C was loaded with 8,401 gallons of Regular Ethanol 10% which were mixed at the rack.

Table 19. Reported Vehicle Weights Measured at the NTRC Certified Pit Scale (Pounds)

Vehicle ID and State	Measured Steer (lb)	Measured Drive (lb)	Measured Tanker (lb)	Calculated Tractor (lb)	Calculated Total Vehicle (lb)	Date
Vehicle A Empty	10,440	10,310	6,570	20,750	27,320	September 22, 2014
Vehicle A Loaded	11,940	33,090	32,700	45,030	77,730	September 22, 2014
Vehicle A Difference	1,500	22,780	26,130	24,280	50,410	
Vehicle B Empty	10,730	10,400	6,570	21,130	27,700	September 23, 2014
Vehicle B Loaded	12,740	33,090	32,490	45,830	78,320	September 23, 2014
Vehicle B Difference	2,010	22,690	25,920	24,700	50,620	
Empty	10,370	10,120	6,550	20,490	27,040	September 22, 2014
Loaded	11,920	32,830	32,720	44,750	77,470	September 22, 2014
Difference	1,550	22,710	26,170	24,260	50,430	

Table 20 shows weights for one of the pilot test delivery loaded with 8,700 gallons of regular ethanol. At loading, the total vehicle weight increased 54,538 lb. At offloading, the total vehicle weight decreased 54,939 lb. This example delivery had a slightly larger (301 gal) load than the calibration data in Table 19, but overall, is consistent. The change in weight can be used by the automated system to estimate if the activity was a loading or offloading activity, and even how much fuel was involved in the activity.

Table 20. A Typical Starting and Ending Weight as Reported by Sensors for One Delivery at Loading and Offloading – Vehicle B

Vehicle State	Measured Steer (lb)	Measured Drive (lb)	Measured Tanker (lb)	Calculated Tractor (lb)	Calculated Total Vehicle (lb)	Date
Start Loading	10,798	11,729	6,499	22,527	29,026	May 20, 2015 @10:00AM
End Loading	12,976	35,790	34,798	48,766	83,564	May 20, 2015 @10:23AM
Difference Loaded	2,178	24,061	28,299	26,239	54,538	
Start Offloading	12,937	35,336	34,859	48,273	83,132	May 20, 2015 @10:49AM
End Offloading	10,811	11,861	5,520	22,672	28,192	May 20, 2015 @11:26AM
Difference Offloaded	-2,126	-23,475	-29,339	-25,600	-54,940	

In the pilot test, there were two main difficulties in getting the weight data. The first involves the air suspension bags of the tanker. It is a common practice in the industry to release the air suspension bags of the tanker during offloading of the product in order to lower the back of the tanker an inch-or-two so that the entire product can be offloaded out of the compartment. Unfortunately, the tanker weight sensor that was used in the pilot test relied on the tanker air suspension bags for its weight estimation. As a result, a tanker weight estimate was not available during offloading. A workaround for this could be to use the tractor weight difference (typically +/- 26,000 lb for a full load; i.e., a measure immediately before and immediately after measurement of tanker weight) to determine whether it is a loading or offloading event, and how much fuel is being transferred. The second issue encountered was that the tractor ignition key was typically turned off (for safety reasons) when loading or unloading fuel. This meant that while the ignition key was turned off, that data was buffered on the tanker, but due to the data regime not every recorded tanker weight had corresponding steer and drive weights recorded. While this made it possible to determine the change in the tanker axle group weight (typically +/- 55,000 lb for a full load) as fuel flowed into or out of the truck, the total weight of the vehicle was not available at that point in time. A workaround for this would be to get a good total delta weight by measuring the tractor weights just before the ignition goes off, and right after it comes on.

Vehicle weight while fuel was being loaded into, or offloaded from the tanker was also captured, if the tractor ignition key was not turned off. For example, Figure 25 shows a segment of a fuel-log file for a loading event, and Figure 26 is the corresponding segment for the offloading event. The data in these figures clearly shows weight increasing for loading events and decreasing for offloading events.

Record No	Event Type	Date	Odometer	Tractor ID	Steer Ax Wt	Drive Ax Wt	Trailer Ax Wt	Comp ID	FType	FAmount	FFlow Dir	1st BOL No	BOL Dest	V State V0	VS State V0	V State V1	VS State V1
2	12	5/20/2015 14:00:40	427125.7	69	4898	5320	2948	1	-1	0	-1		-1	1	0	0	0
3	12	5/20/2015 14:00:41	427125.7	69	4898	5320	2948	2	-1	0	-1		-1	1	0	0	0
4	12	5/20/2015 14:00:41	427125.7	69	4898	5320	2948	3	-1	0	-1		-1	1	0	0	0
5	12	5/20/2015 14:00:42	427125.7	69	4898	5320	2948	4	-1	0	-1		-1	1	0	0	0
6	12	5/20/2015 14:00:42	427125.7	69	4898	5320	2948	5	-1	0	-1		-1	1	0	0	0
7	12	5/20/2015 14:01:25	427125.7	69	4898	5330	2966	1	-1	0	-1		-1	1	0	1	0
8	12	5/20/2015 14:01:38	427125.7	69	4898	5330	2966	5	-1	0	-1		-1	1	0	1	0
9	12	5/20/2015 14:01:49	427125.7	69	4898	5330	2976	4	-1	0	-1		-1	1	0	1	0
10	12	5/20/2015 14:01:59	427125.7	69	4898	5330	2956	2	-1	0	-1		-1	1	0	1	0
11	12	5/20/2015 14:06:00	427125.7	69	5348	10294	10568	4	-1	0	-1		-1	1	0	0	0
12	12	5/20/2015 14:06:05	427125.7	69	5348	10294	10686	3	-1	0	-1		-1	1	0	1	0
13	12	5/20/2015 14:07:15	427125.7	69	5596	13016	12654	2	-1	0	-1		-1	1	0	0	0
14	12	5/20/2015 14:09:32	427125.7	69	5936	16780	14596	3	-1	0	-1		-1	1	0	0	0
15	12	5/20/2015 14:09:40	427125.7	69	5936	16780	14596	5	-1	0	-1		-1	1	0	0	0
16	12	5/20/2015 14:09:45	427125.7	69	5950	16926	14596	1	-1	0	-1		-1	1	0	0	0
17	12	5/20/2015 14:10:26	427125.7	69	5954	16976	14532	1	-1	0	-1		-1	0	0	0	0
18	12	5/20/2015 14:10:26	427125.7	69	5954	16976	14532	2	-1	0	-1		-1	0	0	0	0
19	12	5/20/2015 14:10:27	427125.7	69	5954	16976	14532	3	-1	0	-1		-1	0	0	0	0
20	12	5/20/2015 14:10:27	427125.7	69	5954	16976	14532	4	-1	0	-1		-1	0	0	0	0
21	12	5/20/2015 14:10:28	427125.7	69	5954	16976	14532	5	-1	0	-1		-1	0	0	0	0
22	10	5/20/2015 14:22:33	427125.7	69	5886	16234	15766	1	11	2799	0	1262862	42	0	0	0	0
23	10	5/20/2015 14:22:53	427125.7	69	5886	16234	15784	2	11	1201	0	1262862	42	0	0	0	0
24	10	5/20/2015 14:23:14	427125.7	69	5886	16234	15784	3	11	1051	0	1262862	42	0	0	0	0
25	10	5/20/2015 14:23:30	427125.7	69	5886	16234	15784	4	11	1050	0	1262862	42	0	0	0	0
26	10	5/20/2015 14:23:52	427125.7	69	5886	16234	15784	5	11	2599	0	1262862	42	0	0	0	0

Figure 25. Example of fuel loading events from a fuel-log file.

Record No	Event Type	Date	Odometer	Tractor ID	Steer Ax Wt	Drive Ax Wt	Trailer Ax Wt	Comp ID	FType	FAmount	FFlow Dir	1st BOL No	BOL Dest	V State V0	VS State V0	V State V1	VS State V1
27	10	5/20/2015 14:49:11	427136.8	69	5868	16028	15812	1	11	2799	1	1262862	42	0	0	0	0
28	10	5/20/2015 14:49:46	427136.8	69	5874	16088	15840	2	11	1201	1	1262862	42	0	0	0	0
29	10	5/20/2015 14:50:12	427136.8	69	5874	16088	15812	3	11	1051	1	1262862	42	0	0	0	0
30	10	5/20/2015 14:50:27	427136.8	69	5876	16116	15840	4	11	1050	1	1262862	42	0	0	0	0
31	10	5/20/2015 14:50:33	427136.8	69	5876	16116	15812	5	11	2599	1	1262862	42	0	0	0	0
32	12	5/20/2015 14:57:50	427136.8	69	5880	16146	15812	5	-1	0	-1		-1	1	0	0	0
33	12	5/20/2015 14:57:51	427136.8	69	5880	16146	15812	3	-1	0	-1		-1	1	0	0	0
34	12	5/20/2015 14:57:51	427136.8	69	5880	16146	15812	4	-1	0	-1		-1	1	0	0	0
35	12	5/20/2015 14:57:52	427136.8	69	5880	16146	15784	1	-1	0	-1		-1	1	0	0	0
36	12	5/20/2015 14:57:52	427136.8	69	5880	16146	15784	2	-1	0	-1		-1	1	0	0	0
37	12	5/20/2015 15:00:53	427136.8	69	5878	16126	15812	1	-1	0	-1		-1	1	0	1	0
38	12	5/20/2015 15:08:33	427136.8	69	5320	9982	14424	1	-1	0	-1		-1	1	0	0	0
39	12	5/20/2015 15:08:47	427136.8	69	5320	9982	14434	5	-1	0	-1		-1	1	0	1	0
40	12	5/20/2015 15:10:41	427136.8	69	5296	9710	12464	1	-1	0	-1		-1	0	0	0	0
41	12	5/20/2015 15:15:27	427136.8	69	5262	9348	7784	5	-1	0	-1		-1	0	0	1	0
42	12	5/20/2015 15:15:31	427136.8	69	5262	9348	7784	5	-1	0	-1		-1	0	0	0	0
43	12	5/20/2015 15:15:43	427136.8	69	5262	9348	7784	4	-1	0	-1		-1	1	0	1	0
44	12	5/20/2015 15:18:28	427136.8	69	5218	8842	5370	4	-1	0	-1		-1	0	0	1	0
45	12	5/20/2015 15:18:33	427136.8	69	5218	8842	5398	4	-1	0	-1		-1	0	0	0	0
46	12	5/20/2015 15:18:47	427136.8	69	5218	8842	5406	3	-1	0	-1		-1	1	0	1	0
47	12	5/20/2015 15:21:36	427136.8	69	5108	7632	3746	3	-1	0	-1		-1	0	0	1	0
48	12	5/20/2015 15:21:43	427136.8	69	5108	7632	3746	3	-1	0	-1		-1	0	0	0	0
49	12	5/20/2015 15:21:57	427136.8	69	5094	7486	3774	2	-1	0	-1		-1	1	0	1	0
50	12	5/20/2015 15:25:41	427136.8	69	4914	5506	2458	2	-1	0	-1		-1	1	0	0	0
51	12	5/20/2015 15:26:40	427136.8	69	4904	5380	2504	2	-1	0	-1		-1	0	0	0	0

Figure 26. Example of fuel offloading events from a fuel-log file.

A helpful way to visualize the operations at a particular stop is by graphing valve and driver activity for each compartment, along with weight, as a function of time. Consider, for example, Figure 27a. The top portion shows valve and driver activity by compartment versus time; the bottom portion shows corresponding weight values versus time for a loading event. Horizontal lines in the top portion of the graph indicate that both loading and emergency valves are open for that compartment, which in turn is an indication that fuel is flowing. The bottom portion of the graph shows a plot of the steer, drive, tanker, and total weight changes corresponding to each valve state change in the top portion of the graph. Figure 27a shows the weight trending upward as fuel is loaded, and downward (in Figure 27b) as fuel is offloaded. Appendix J contains additional plots of this style in order to highlight some of the different types of valve actuation sequences observed.

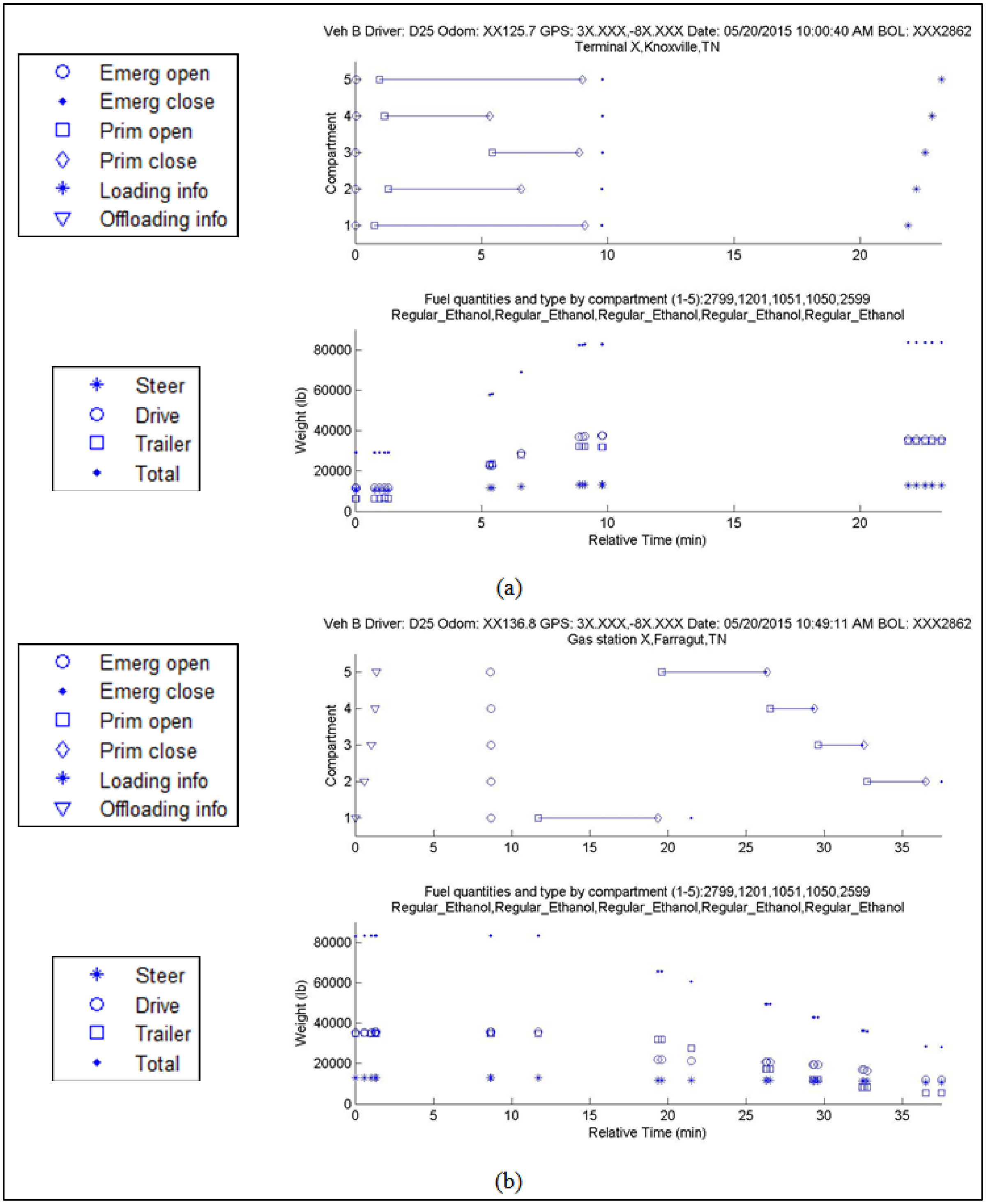

Figure 27. Loading (a) and offloading (b) events versus time with weight data.

2.4 IDENTIFICATION OF EXTRAORDINARY ACTIVITIES

The solution developed and tested in the pilot test had federal- and state-level tax auditors as its main audience. However, in order for the technology to be adopted the eventual solution has to address the needs of fuel-hauling companies and their customers. The main concerns of carriers include miss-delivery or cross-contamination (i.e., a delivery of a product to the wrong storage tank which renders the entire stored amount as contaminated and not saleable), "cocktailing" (e.g., by adding waste oils or other used products to the fuel through the compartment hatch), and fuel theft. Although the solution deployed and tested in this project does not address the cross-contamination issue, it is an essential first step in that direction.

The other two issues, fuel theft and cocktailing, were taken into consideration when the architecture of the system was designed. Sensors in the hatches allow the obERS to recognize when one of those was opened (always a suspicious activity, unless it happens at locations where maintenance is performed on the vehicle). When the sensors are triggered due to a hatch opening, a tampering alert is submitted from the vehicle in real-time to the TBOS and made immediately available to the carrier/dispatcher. Based on the location where this alert is triggered, the carrier can then take the appropriate action. In a similar way, any sensor that becomes disconnected (including valve and hatch sensors, and tractor and tanker databus connections) generates a tampering alert which is conveyed in real-time to the carrier.

2.4.1 Fuel-Flowing Elapsed Times

Addressing the fuel-theft issue is a more complicated problem since this activity can happen during normal operations (opening and closing of valves) and needs to be differentiated from legitimate actions taken by drivers and other operators. This is addressed by a self-learning algorithm deployed on the boERS that continuously processes the data from the field to construct probability distributions of measures such as elapsed time of fuel loading and offloading by the driver, vehicle, and compartment; valve actuation sequence; elapsed time between the first two valve actuations (by the driver, compartment, and location); and other parameters. As discussed previously, the obERS timestamps each valve actuation, and adds the corresponding weight-sensor readings (for tanker and tractor, when available), location information and odometer reading. Those timestamps are later used by the boERS to determine the valve-actuation sequencing as well as the elapsed time during which fuel is flowing (note: for fuel to flow out or into a compartment, both the emergency and actuation valves have to be opened). Each one of these measures become an observation for the probability distributions of those events (e.g., fuel-flowing time ***fft*** for compartment ***c***, vehicle ***v***, driver ***d***, at a given location ***l***), and those probability distributions are constantly updated by the boERS application. The distributions are also combined (e.g., aggregated for all of the drivers that have driven vehicle ***v***) and used by the boERS algorithms to assess the likelihood of occurrence of the observed event ***fft***. Probability thresholds, which can be set up by the carrier, determine how to classify these observed events.

Table 21 presents the parameters defining the fuel-flowing elapsed time distributions for loading and offloading activities for selected drivers and tanker compartment. The data to build the distributions shown in Table 21 was selected from the data collected during the pilot test. Because elapsed-time cannot be negative, a log-normal distribution was used. The parameters for this distribution (Mu and Sigma, analogous to the mean and standard deviation of a standard normal distribution) are included in the table. The mean elapsed times, as expected, are larger for compartments 1 and 5 since those had larger capacities than the other three central compartments.

Table 21. Fuel-flowing Elapsed Time Distribution Parameters by Driver, Compartment ID, and Direction of Fuel Flow

Driver ID	Com-part-ment ID	Loading Number of Events	Loading Mean Time (sec)	Loading Standard Dev. of Time (sec)	Loading Mu	Loading Sigma	Off Loading Number of Events	Off Loading Mean Time (sec)	Off Loading Std. Dev. of Time (sec)	Off Loading Mu	Off Loading Sigma
Driver D84	1	103	509	170.4	6.18	0.33	119	369	191.6	5.79	0.49
	2	81	283	129.6	5.55	0.44	83	228	175.7	5.20	0.68
	3	101	275	106.1	5.55	0.37	111	189	81.8	5.16	0.41
	4	101	237	71.6	5.43	0.29	100	227	92.4	5.35	0.39
	5	85	463	162.3	6.08	0.34	74	502	158.0	6.17	0.31
Driver D12	1	100	549	219.7	6.23	0.39	104	450	149.3	6.06	0.32
	2	118	328	167.9	5.68	0.48	114	221	83.1	5.33	0.36
	3	100	276	160.7	5.47	0.54	93	179	64.2	5.13	0.35
	4	101	344	201.0	5.69	0.54	56	166	44.0	5.08	0.26
	5	131	495	188.1	6.14	0.37	133	408	129.6	5.96	0.31
Driver D19	1	108	616	217.9	6.36	0.34	113	452	119.1	6.08	0.26
	2	128	436	242.2	5.94	0.52	125	225	72.9	5.37	0.32
	3	103	334	181.7	5.68	0.51	107	213	78.9	5.30	0.36
	4	141	302	213.3	5.51	0.64	135	225	88.6	5.34	0.38
	5	139	595	250.8	6.31	0.40	137	491	96.1	6.18	0.19
Driver D42	1	108	423	135.5	6.00	0.31	106	482	156.7	6.13	0.32
	2	108	254	126.4	5.42	0.47	105	211	80.2	5.28	0.37
	3	101	200	96.6	5.20	0.46	98	158	41.1	5.03	0.26
	4	110	253	142.8	5.39	0.53	105	197	63.2	5.23	0.31
	5	107	437	198.4	5.99	0.43	100	455	180.0	6.05	0.38
All Drivers	1	531	541	200.3	6.23	0.36	537	434	157.7	6.01	0.35
	2	547	336	189.9	5.68	0.53	524	214	103.3	5.26	0.46
	3	517	283	167.0	5.50	0.55	507	180	73.5	5.12	0.39
	4	563	290	180.5	5.51	0.57	439	206	87.1	5.25	0.41
	5	576	512	213.0	6.16	0.40	542	444	148.9	6.04	0.33

Each driver operates the valves in a different way. These differences are captured by the means and standard deviations of the distributions. They can also be appreciated in Figure 28 to Figure 37, which show the distributions of elapsed time while fuel was flowing during loading and offloading activities. Consider, for example, Figure 28 which shows the distributions of fuel-flowing elapsed times for compartment 1 (the largest compartment in the tankers participating in the pilot test) for each of the four main drivers. The figure shows that on average, driver D42 is much "faster" than any of the other drivers at loading compartment 1. What the term "faster" implies here is that driver D42 operates the emergency and primary valves of compartment 1 in such a way that they remain open the least amount of time when compared to the other drivers (note: the actual time to load compartment 1 was the same, with minor variations depending on the equipment at the terminal, for all of the pilot test drivers since the three tankers were identical and had the same capacities). Figure 28 also shows that driver D42 is the most consistent of the four at loading compartment 1. This is shown by a tighter distribution.

The same figure shows that driver D19 presents the highest variability in terms of elapsed time when loading compartment 1. However, driver D19 is the most consistent of the four drivers when offloading compartment 1; although not the "fastest." That qualifier goes to driver D84, with driver D42 (the "fastest" at loading compartment 1) being one of the "slowest" at offloading that compartment.

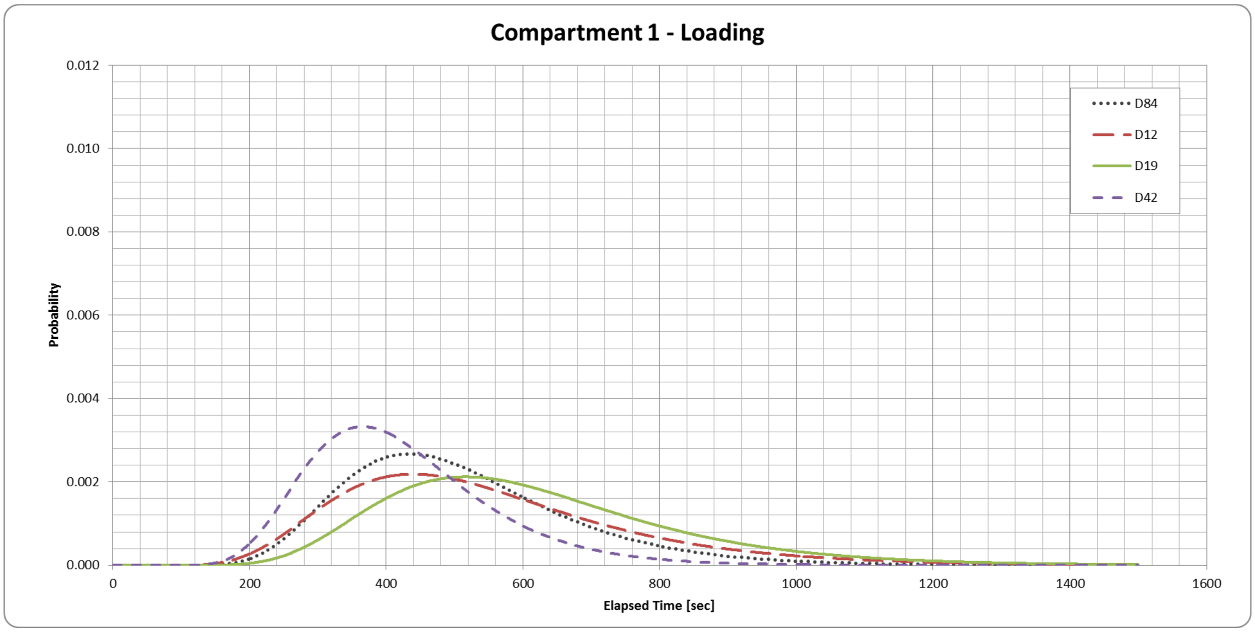

Figure 28. Fuel-flowing Elapsed Time Distributions by Driver – Compartment 1 Loading.

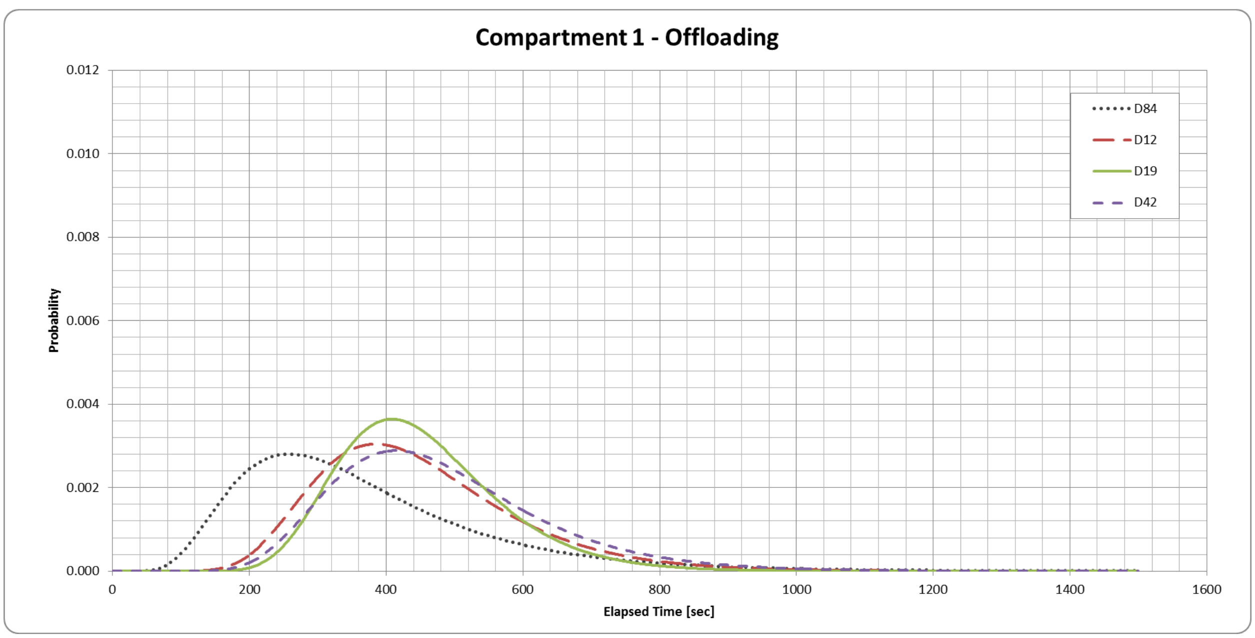

Figure 29. Fuel-flowing Elapsed Time Distributions by Driver – Compartment 1 Offloading.

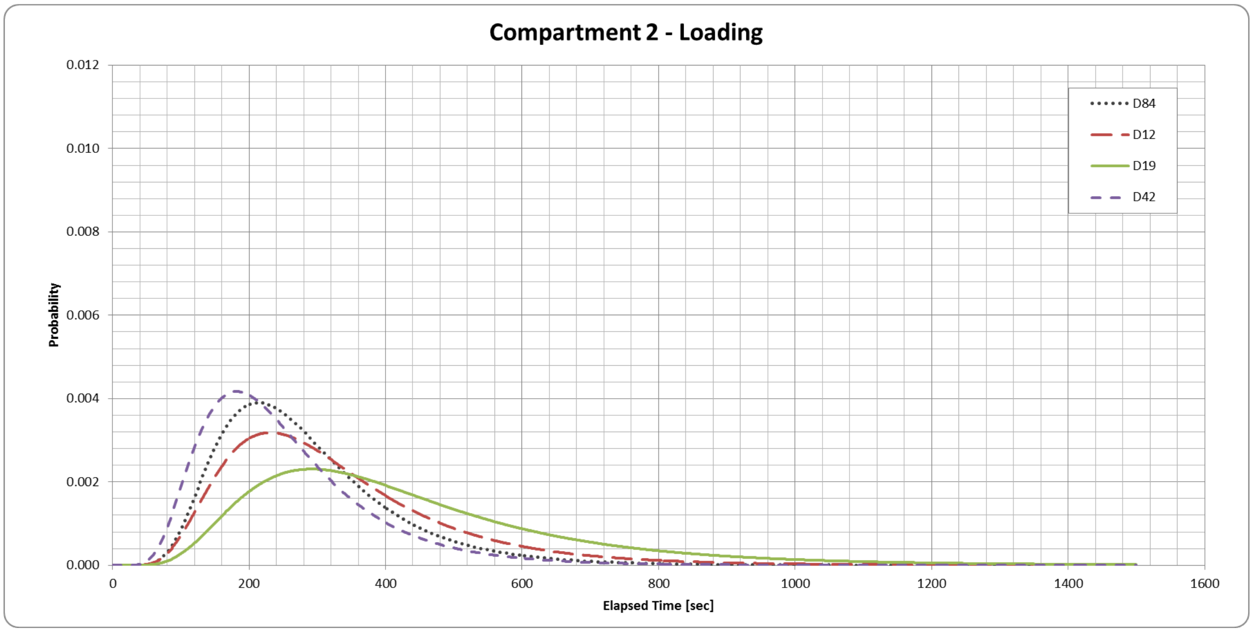

Figure 30. Fuel-flowing Elapsed Time Distributions by Driver – Compartment 2 Loading.

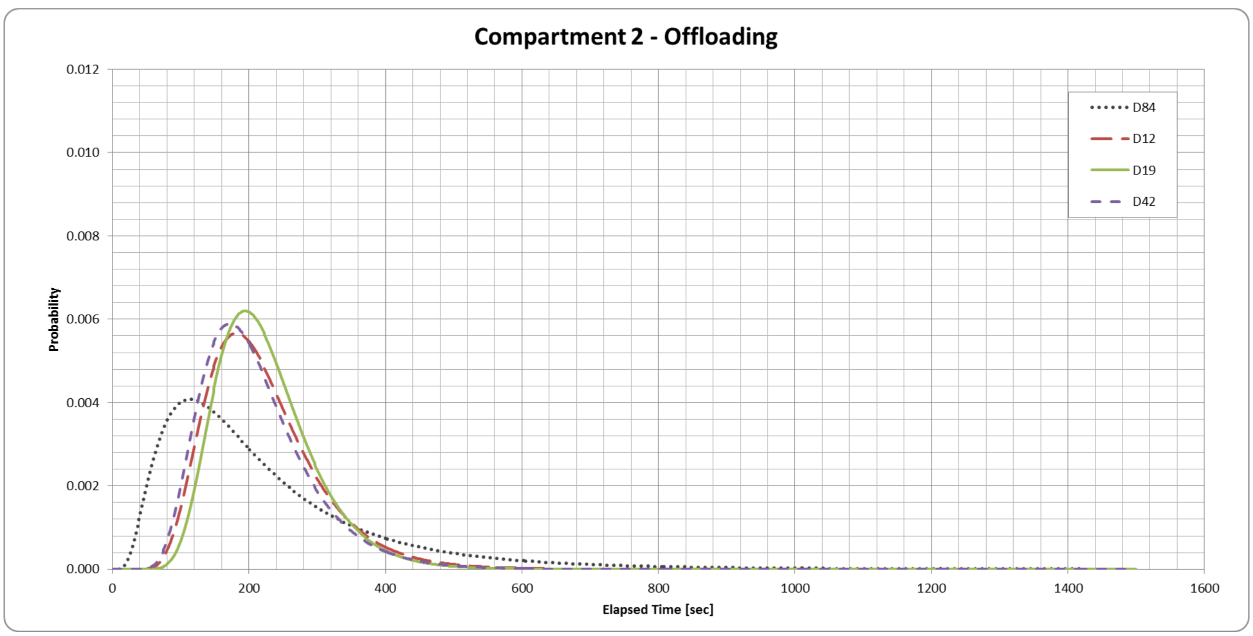

Figure 31. Fuel-flowing Elapsed Time Distributions by Driver – Compartment 2 Offloading.

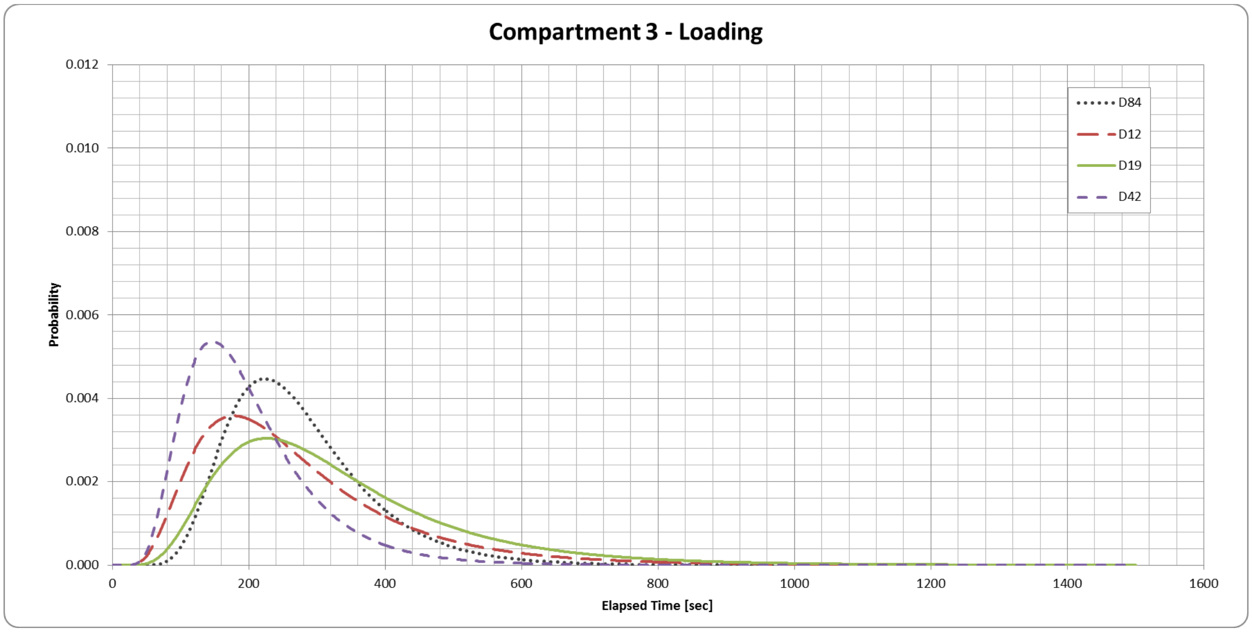

Figure 32. Fuel-flowing Elapsed Time Distributions by Driver – Compartment 3 Loading.

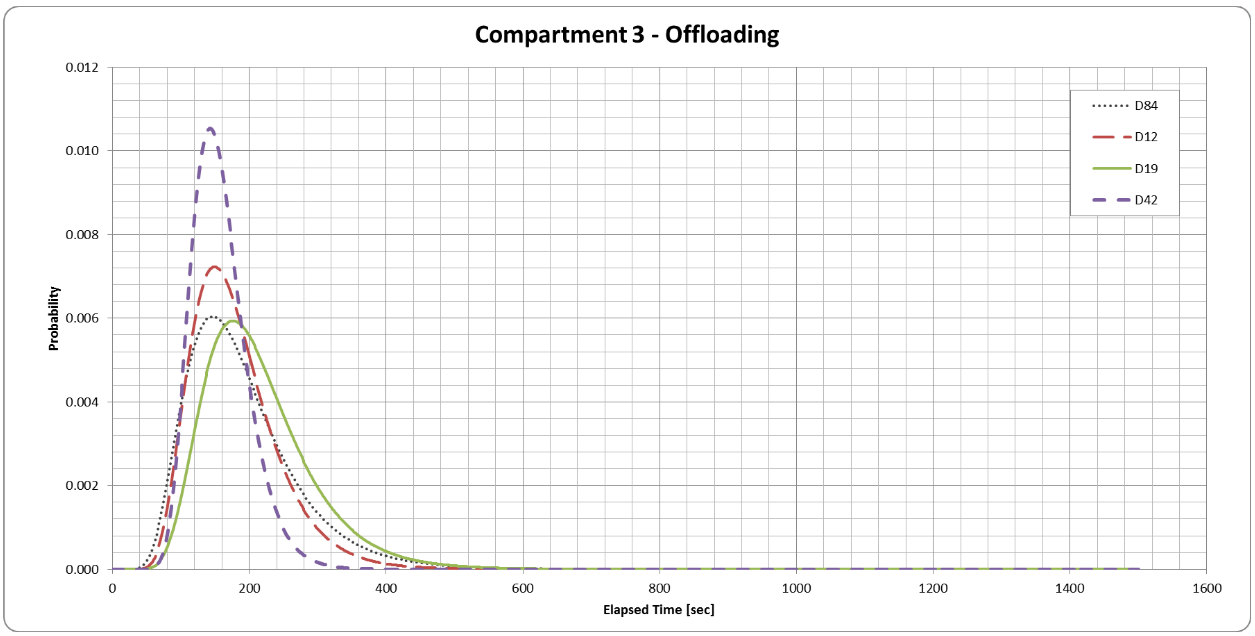

Figure 33. Fuel-flowing Elapsed Time Distributions by Driver – Compartment 3 Offloading.

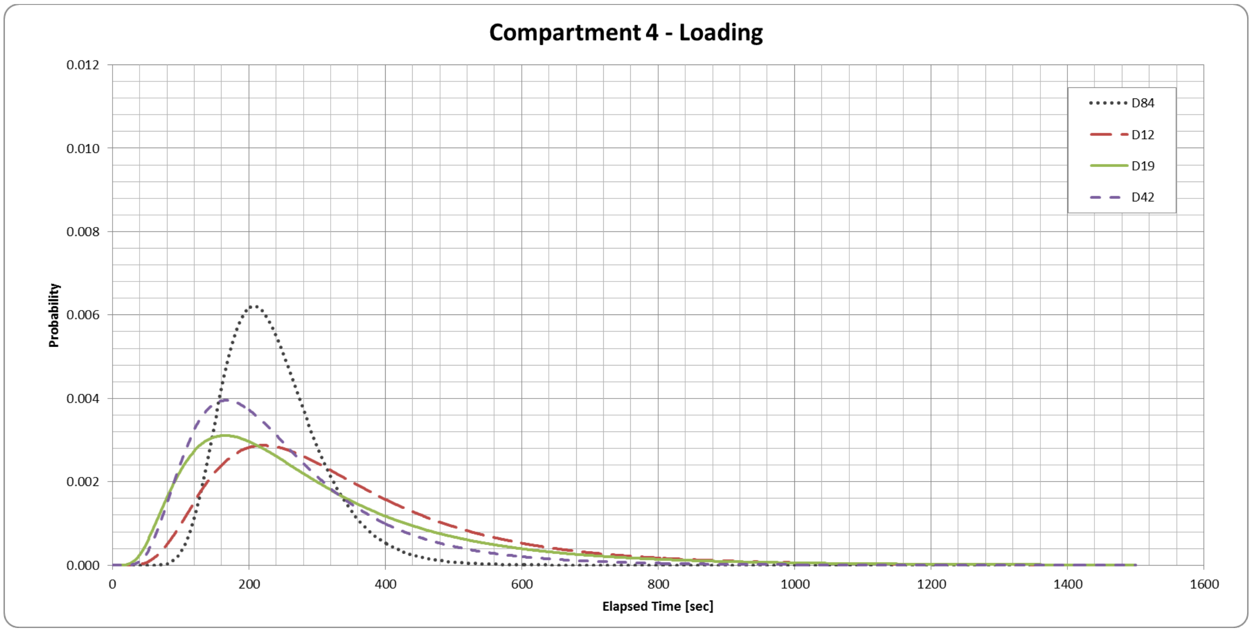

Figure 34. Fuel-flowing Elapsed Time Distributions by Driver – Compartment 4 Loading.

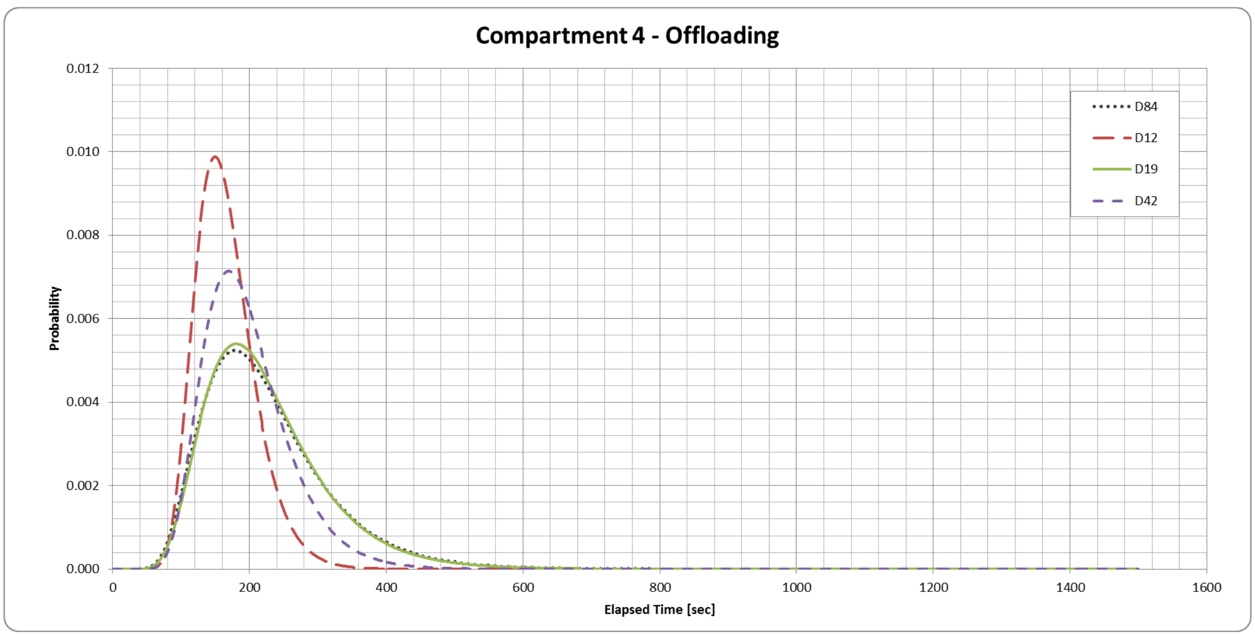

Figure 35. Fuel-flowing Elapsed Time Distributions by Driver – Compartment 4 Offloading.

Figure 36. Fuel-flowing Elapsed Time Distributions by Driver – Compartment 5 Loading.

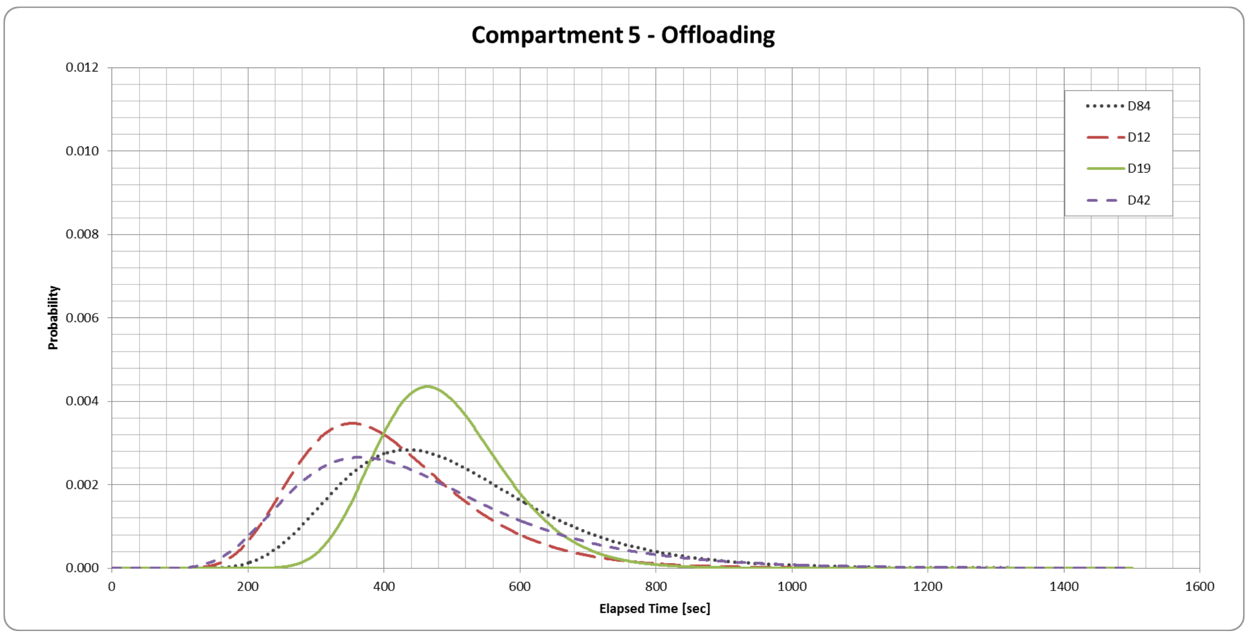

Figure 37. Fuel-flowing Elapsed Time Distributions by Driver – Compartment 5 Offloading.

Figure 38 and Figure 39 show dwell times (i.e., the amount of time to load or offload fuel) versus fuel amount for each compartment for loading and offloading, respectively.

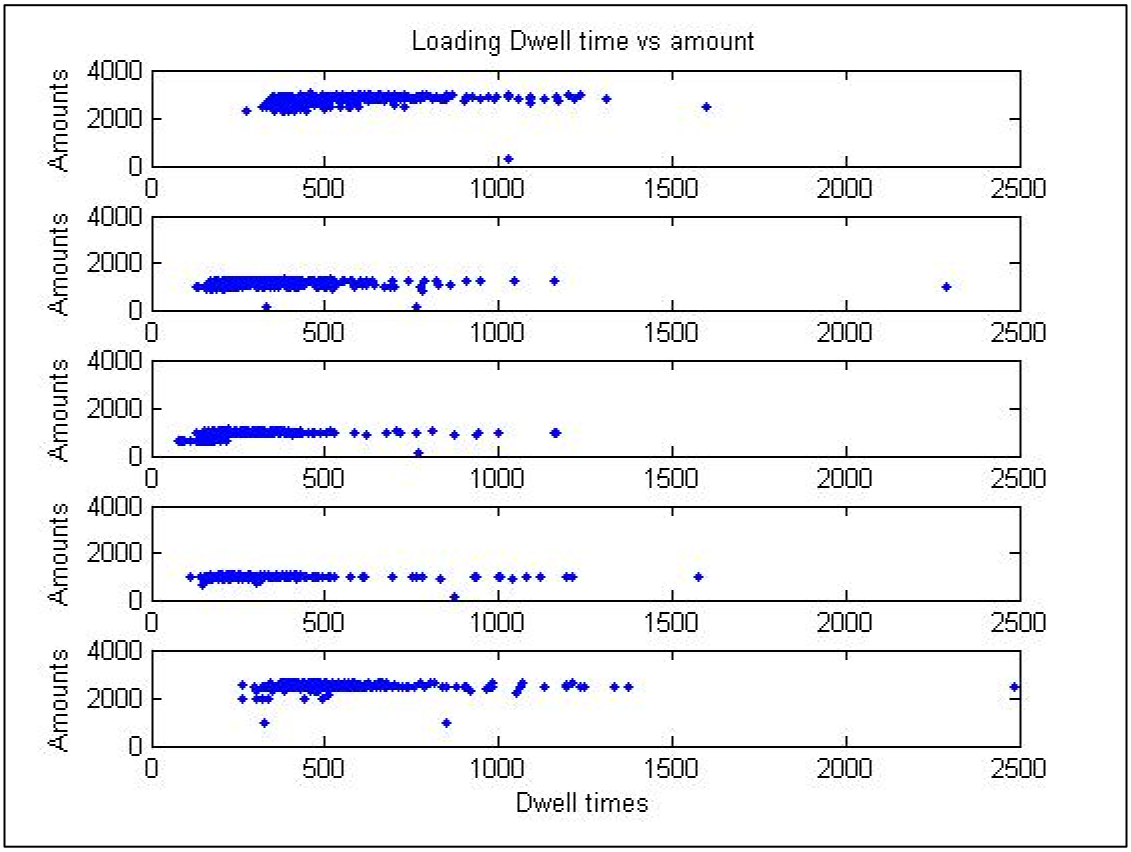

Figure 38. Dwell times in seconds versus fuel amount in gallons from compartments 1 (top) to 5 (bottom) - 340 loading events.

Notice that each compartment has different loading and offloading characteristics when compared to other compartments (see Figure 28 to Figure 39). And although the drivers present variations among themselves for a given compartment, these variations are, in general, smaller than the variations when compared across different compartments. This fact is made more evident when analyzing Figure 40 to Figure 49, which present the distribution of elapsed times when fuel is flowing by compartment for each of the four drivers D84, D12, D19, and D42 (Figure 40 to Figure 47), and all of the pilot test drivers combined (Figure 48 and Figure 49). As expected, in all of the cases it took a shorter elapsed time to load compartments 2, 3, and 4 than compartments 1 and 5 (the largest compartment). All of the drivers were "faster" in loading compartment 5 than compartment 1; the other three compartments were splash mixed and depended on the driver. Drivers D84 and D19 (and all drivers combined as well) offloaded compartment 1 "faster" than compartment 5, while the reverse was true for drivers D12 and D42.

Because of these significant variations among drivers, type of operation (loading versus offloading), and compartments, it was not possible to use just one general probability distribution of elapsed times to assess the likelihood of observing an event (fuel loading or offloading elapsed time). For this reason, the boERS maintained one distribution per driver, compartment, and type of operation. It used that distribution to assess the likelihood of observed events and to determine if an activity was "normal" or not.

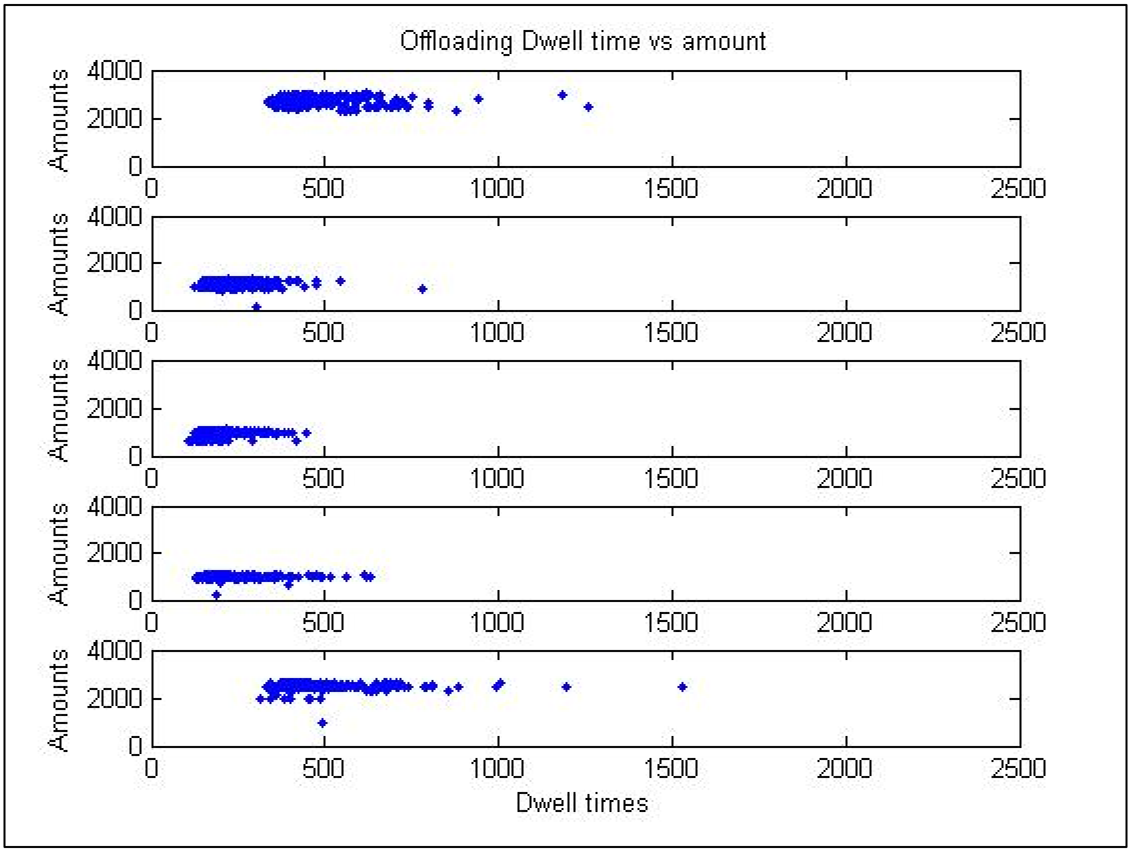

Figure 39. Dwell times in seconds versus fuel amount in gallons from compartments 1 (top) to 5 (bottom) - 340 offloading events.

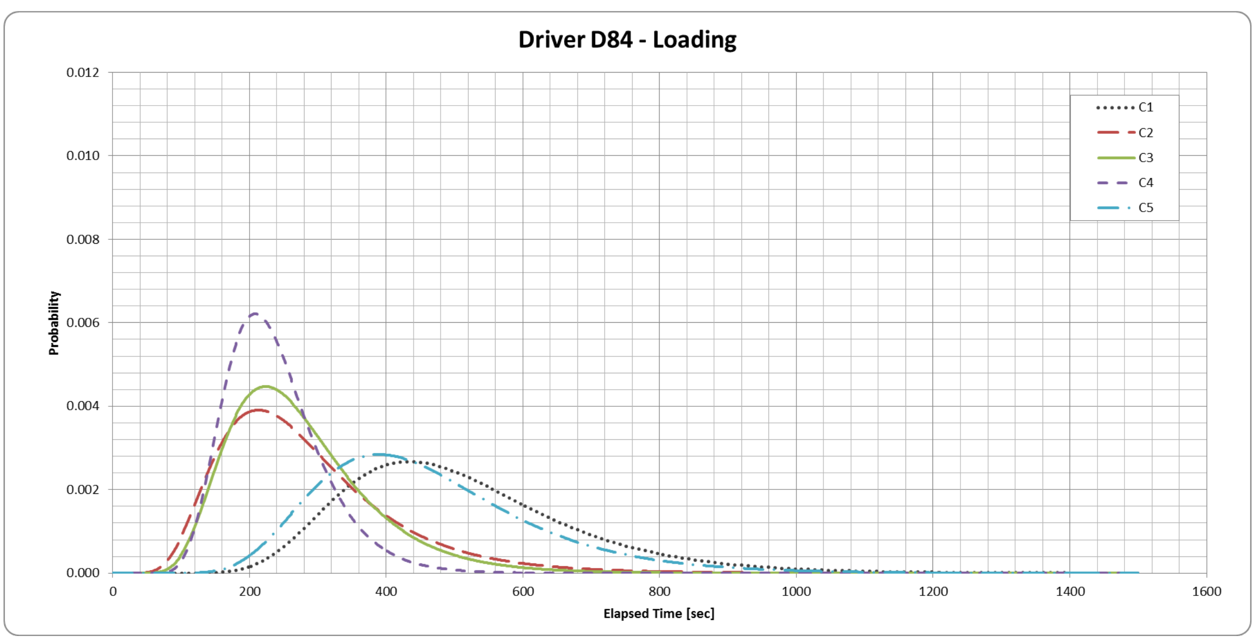

Figure 40. Fuel-flowing elapsed time distributions by compartment for driver D84 loading.

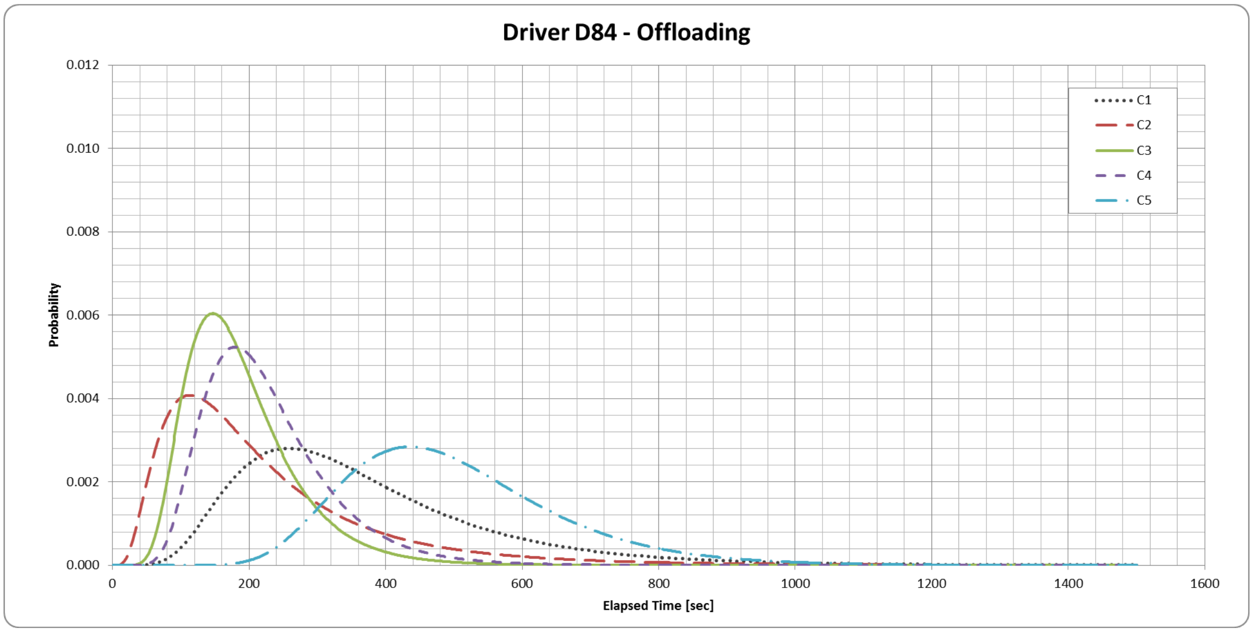

Figure 41. Fuel-flowing elapsed time distributions by compartment for driver D84 offloading.

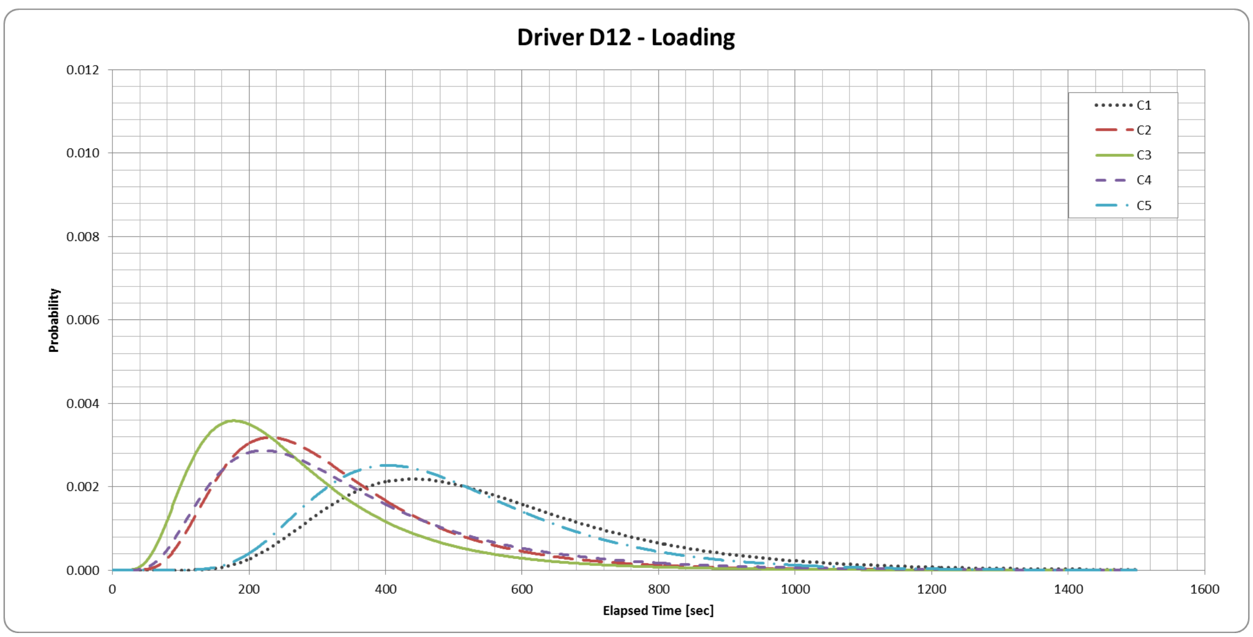

Figure 42. Fuel-flowing elapsed time distributions by compartment for driver D12 loading.

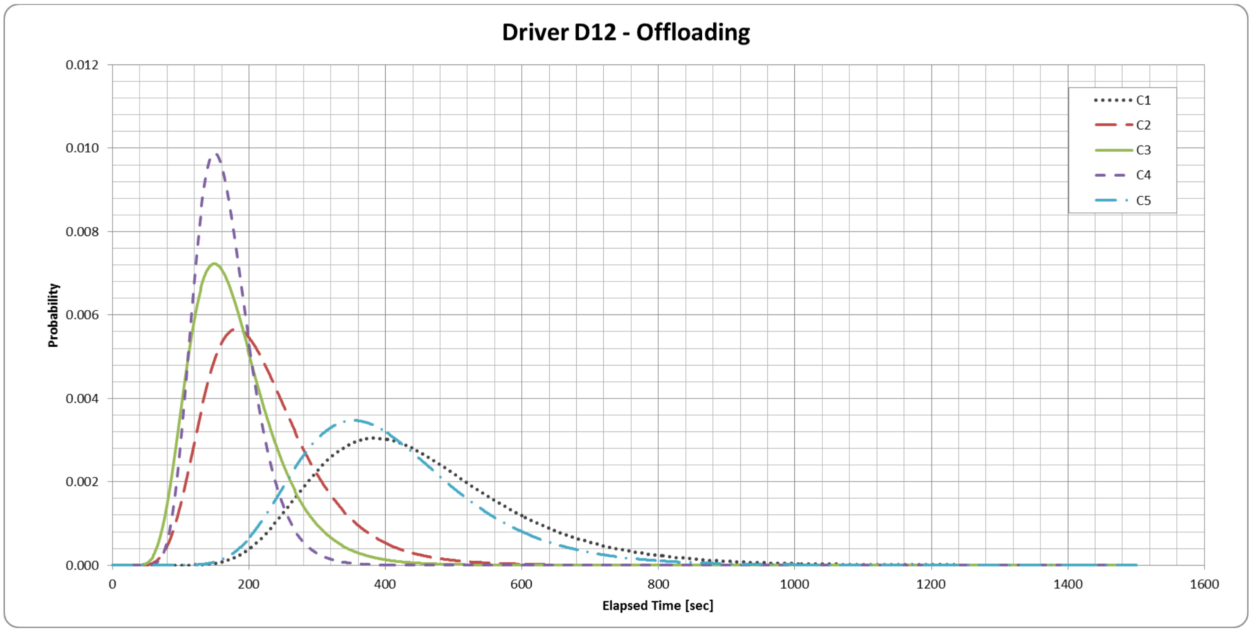

Figure 43. Fuel-flowing elapsed time distributions by compartment for driver D12 offloading.

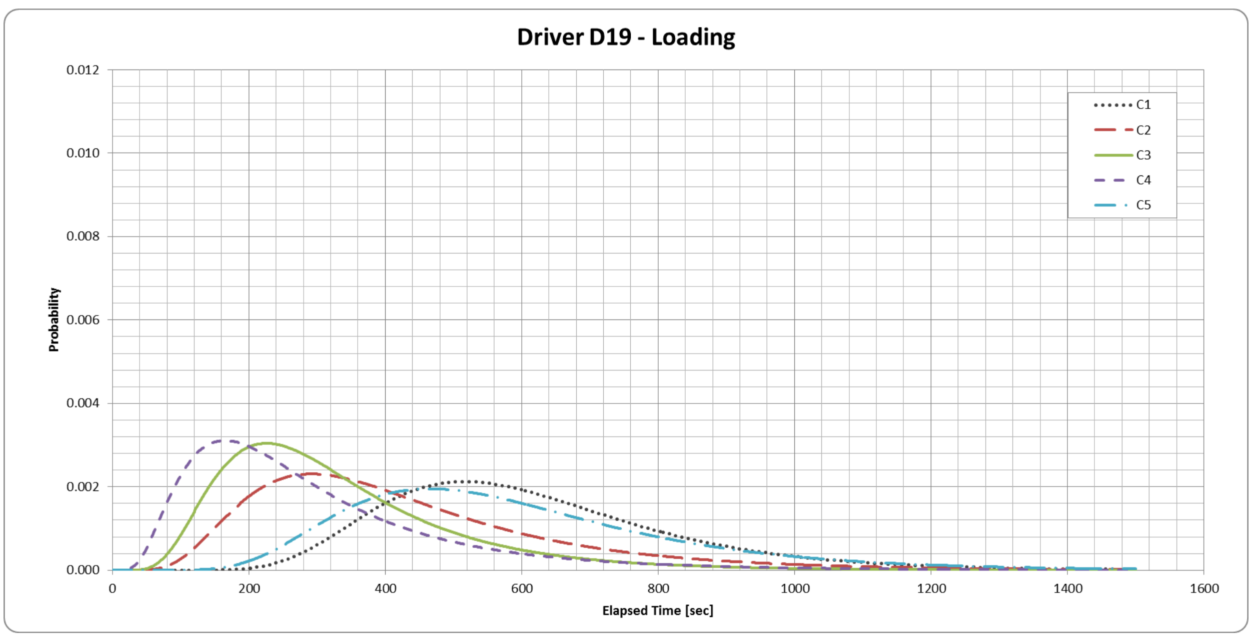

Figure 44. Fuel-flowing elapsed time distributions by compartment for driver D19 loading.

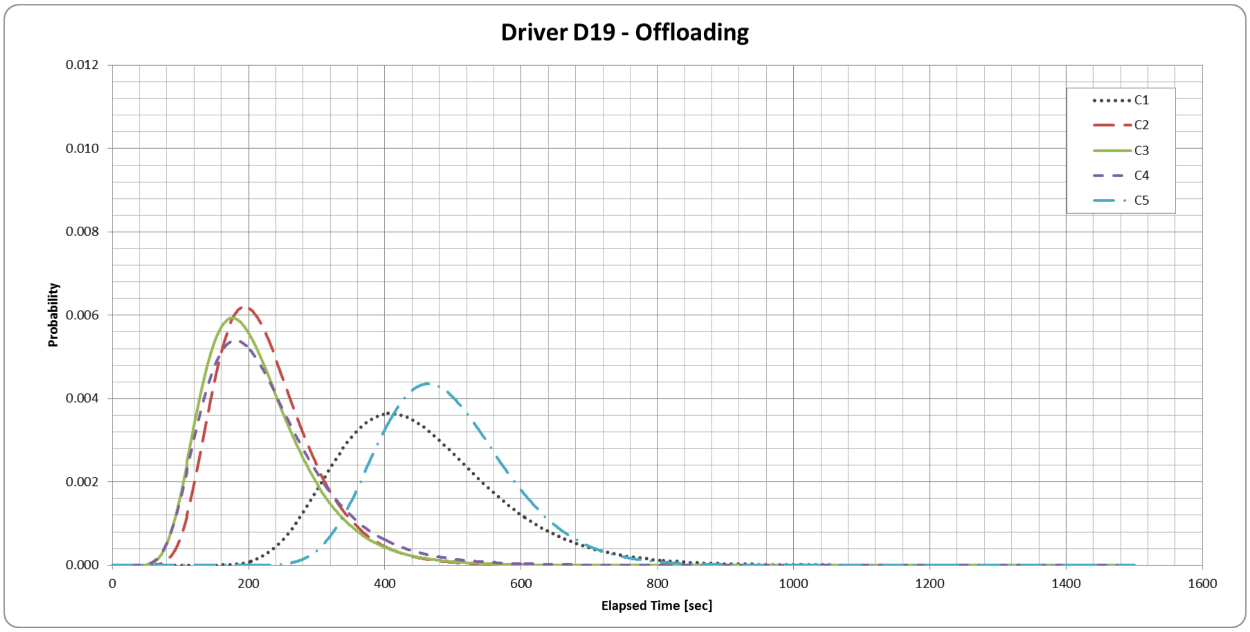

Figure 45. Fuel-flowing elapsed time distributions by compartment for driver D19 offloading.

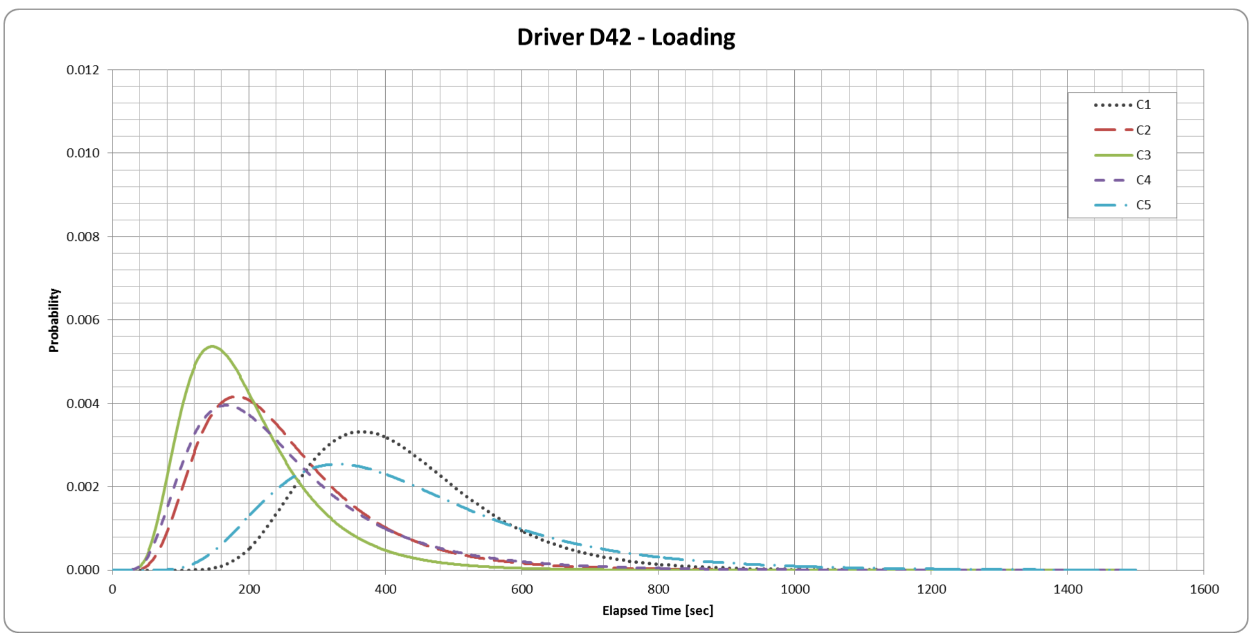

Figure 46. Fuel-flowing elapsed time distributions by compartment for driver D42 loading.

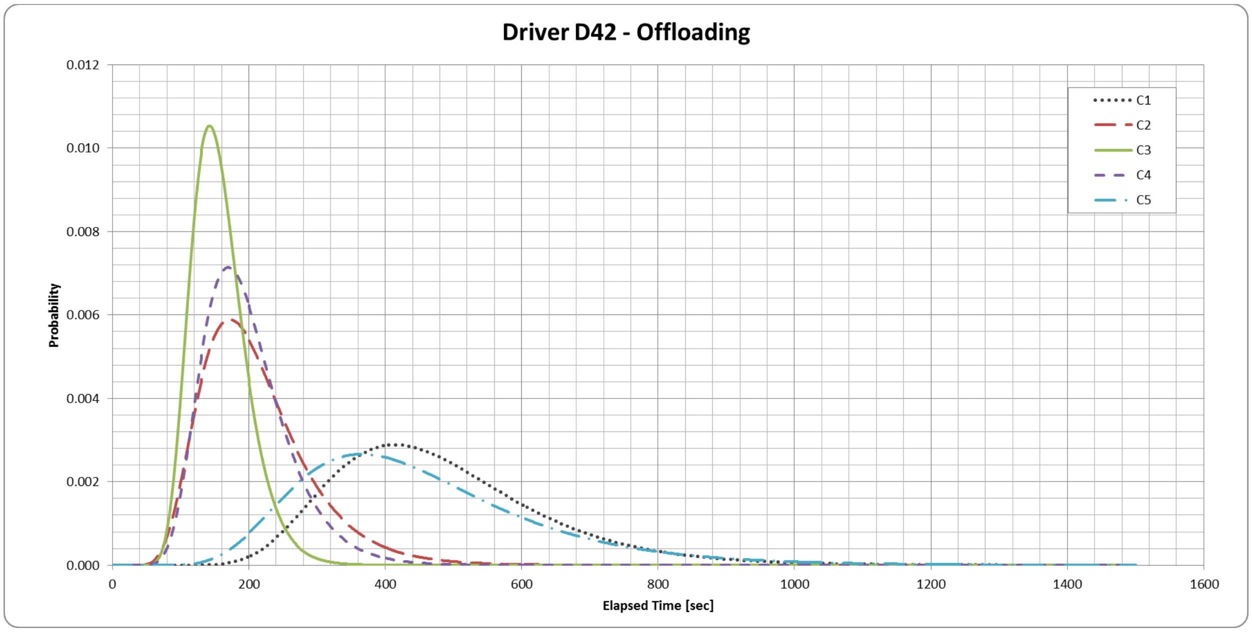

Figure 47. Fuel-flowing elapsed time distributions by compartment for driver D42 offloading.

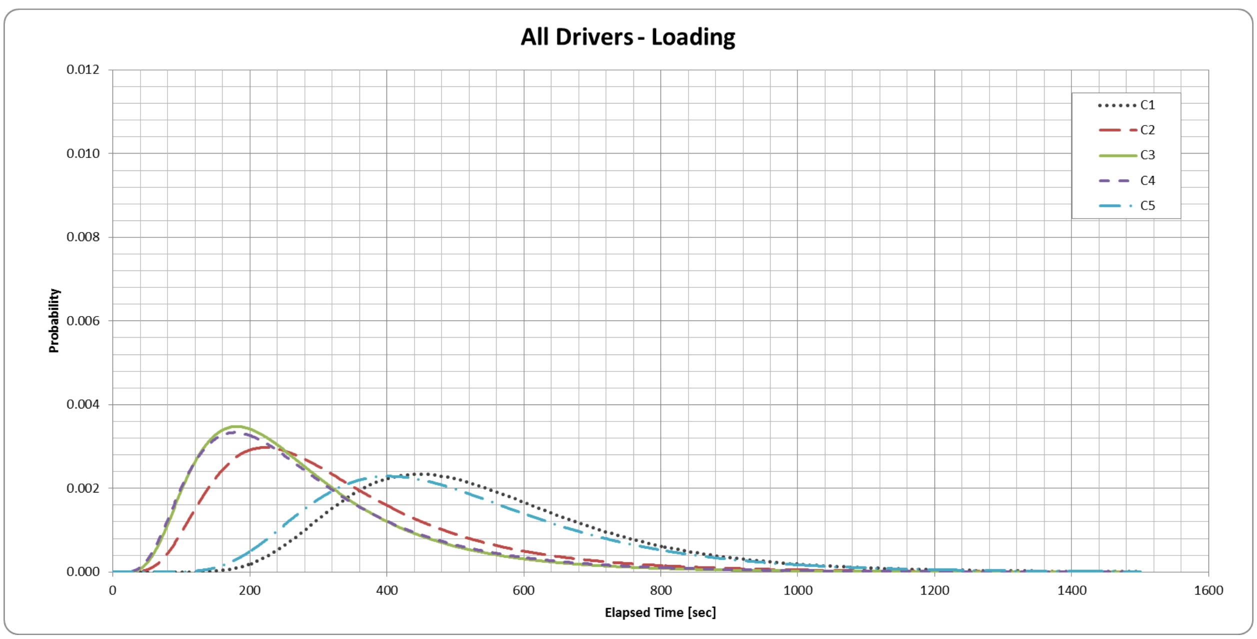

Figure 48. Fuel-flowing elapsed time distributions by compartment for all drivers loading.

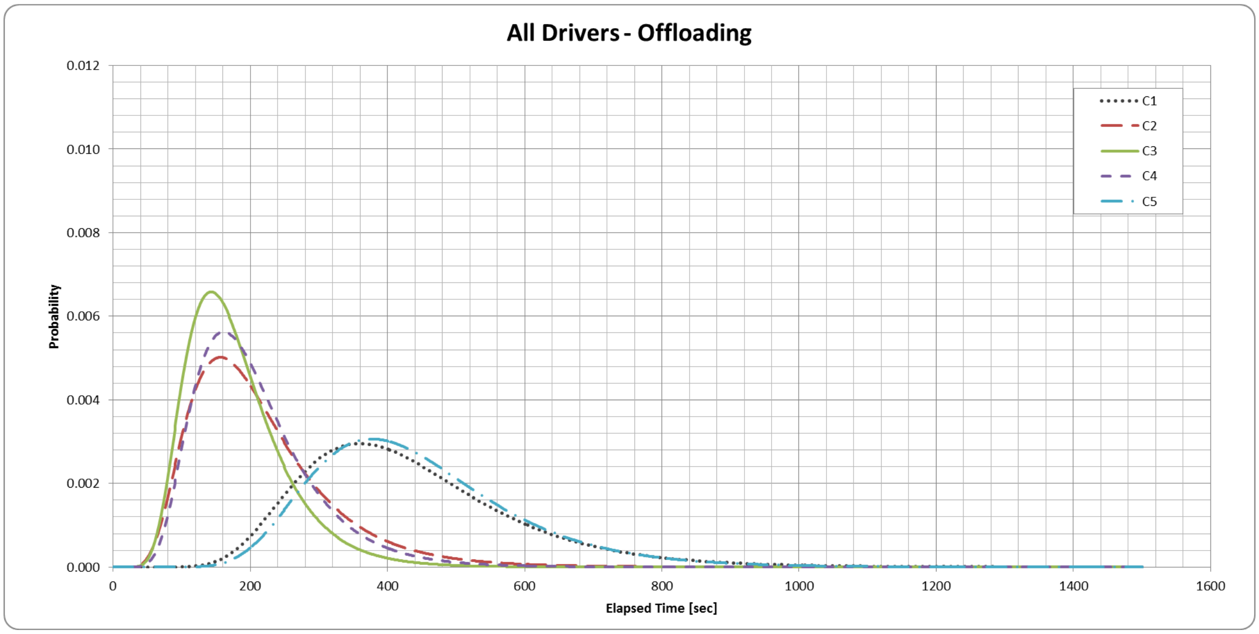

Figure 49. Fuel-flowing elapsed time distributions by compartment for all drivers offloading.

Using those probability distributions, each observation of a fuel-flowing event is assessed by the boERS. Consider, for example, an observed fuel-flowing elapsed time ***fft*** = 354 seconds for compartment 1. Assume also that the carrier has established the following probabilities thresholds: (1) normal event: probability of being observed is greater than or equal to 50 %; (2) unlikely event: probability of being observed is between 25% and 50%; and (3) rare event: probability of being observed is less than 25%. Table 22 presents the likelihood of observing a fuel-flowing elapsed time of 354 seconds (or less) by driver and tanker compartment. In this example, if the 354 seconds were observed for driver D84 for compartment 1, the event would be classified as normal (56.4 % is greater than 50 %, see Figure 50). The same observation by driver C would be classified as rare (21.0 % is less than 25 %, see Figure 51). These likelihoods would be added to the driver report, but in the second case the event would be flagged so the carrier/dispatcher could further investigate the event.

Table 22. Probability of Observing a Fuel-offloading Event Lasting 354 Seconds or Less by Driver and Compartment

Compartment ID	Driver D84	Driver D12	Driver D19	Driver D42	All Drivers
1	56.4%	28.2%	21.1%	21.0%	34.6%
2	83.8%	93.1%	94.4%	94.5%	90.8%
3	95.7%	98.4%	94.5%	99.9%	97.3%
4	91.0%	99.9%	91.8%	97.9%	93.8%
5	16.4%	38.4%	5.7%	32.2%	30.1%

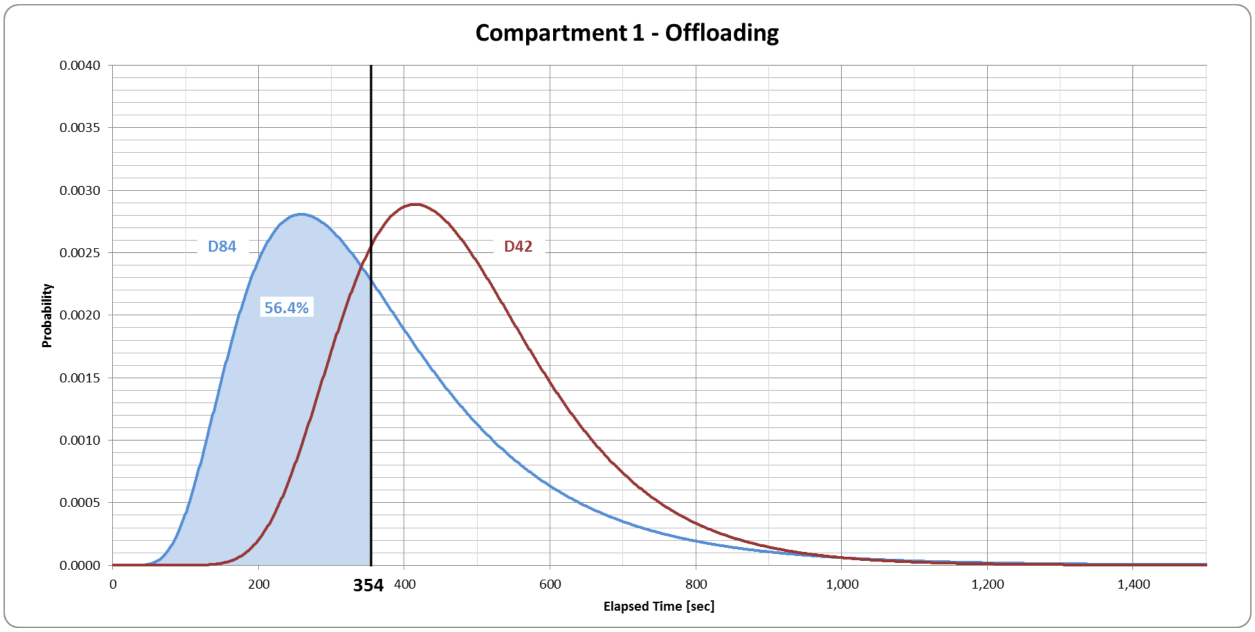

Figure 50. Likelihood of observing a 354 seconds or shorter fuel-offloading event for driver D84.

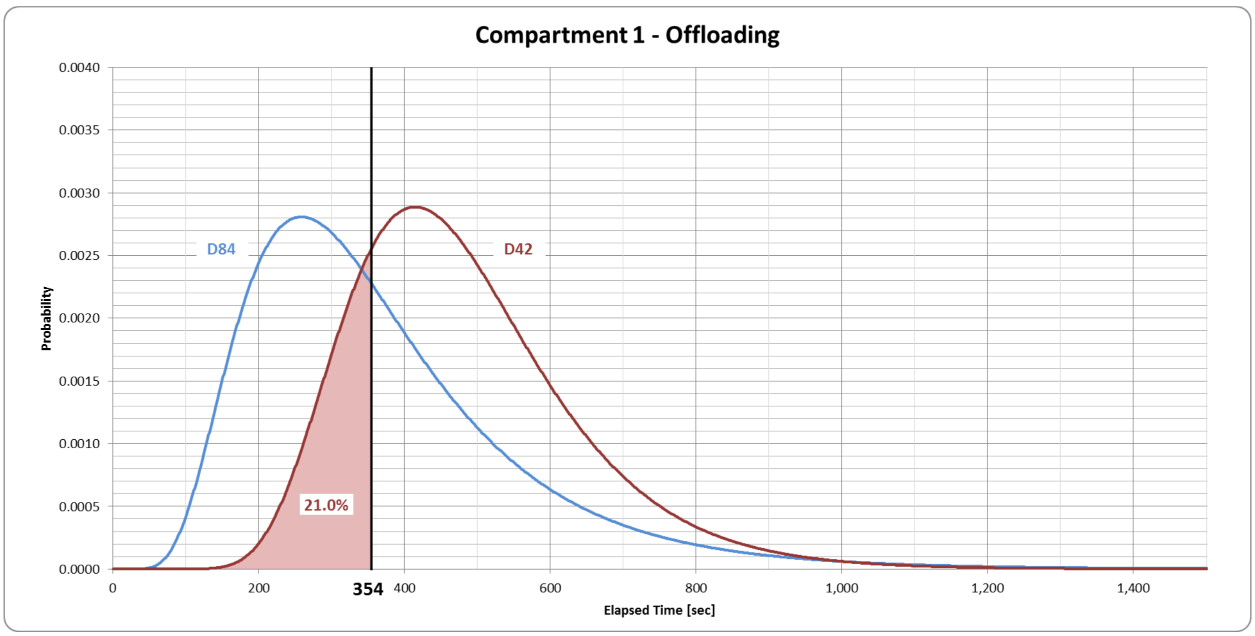

Figure 51. Likelihood of observing a 354 seconds or shorter fuel-offloading event for driver D42.

2.4.2 Valve Sequencing

The identification of suspicious activities requires the analysis of fuel-flowing events and their associated elapsed times as described earlier in this report. However, the analysis and evaluation of these observed parameters, under certain conditions, may not capture activities that are not normal. Certain valve sequencing may not trigger a fuel-flowing event (and therefore would not be analyzed by the boERS elapsed-time self-learning algorithms) but could be a part of a fuel-theft event. For instance, if the emergency valve for a given compartment is opened and closed with the primary valve closed, and subsequently (at the same or another location) the primary valve is opened and closed with the emergency valve closed, then the fuel contained in the segment of pipe going from the emergency valve to the primary valve will flow and could be subject to have been stolen.

The boERS keeps track of valve sequencing at a given location and analyzes these actuations. Figure 52 through Figure 56 present the frequency of each observed valve actuation sequence for each compartment by driver. The main valve actuation sequences are:

(1) Primary opens, Emergency opens, Emergency closes, Primary closes, represented in the figures as PEEP followed by the letter "S" if the sequence was performed only once at a location, or the letter "M" if the sequence was performed multiple times[7];
(2) Primary opens, Emergency opens, Primary closes, Emergency closes (PEPE_S or PEPE_M);
(3) Emergency opens, Primary opens, Emergency closes, Primary closes (EPEP_S or EPEP_M);
(4) Emergency opens, Primary opens, Primary closes, Emergency closes (EPPE_S or EPPE_M);
(5) Primary opens and closes with no Emergency actuation (POC_NoE or PP);
(6) Emergency opens and closes with no Primary actuation (EOC_NoP or EE); and
(7) Other valve actuation sequences.

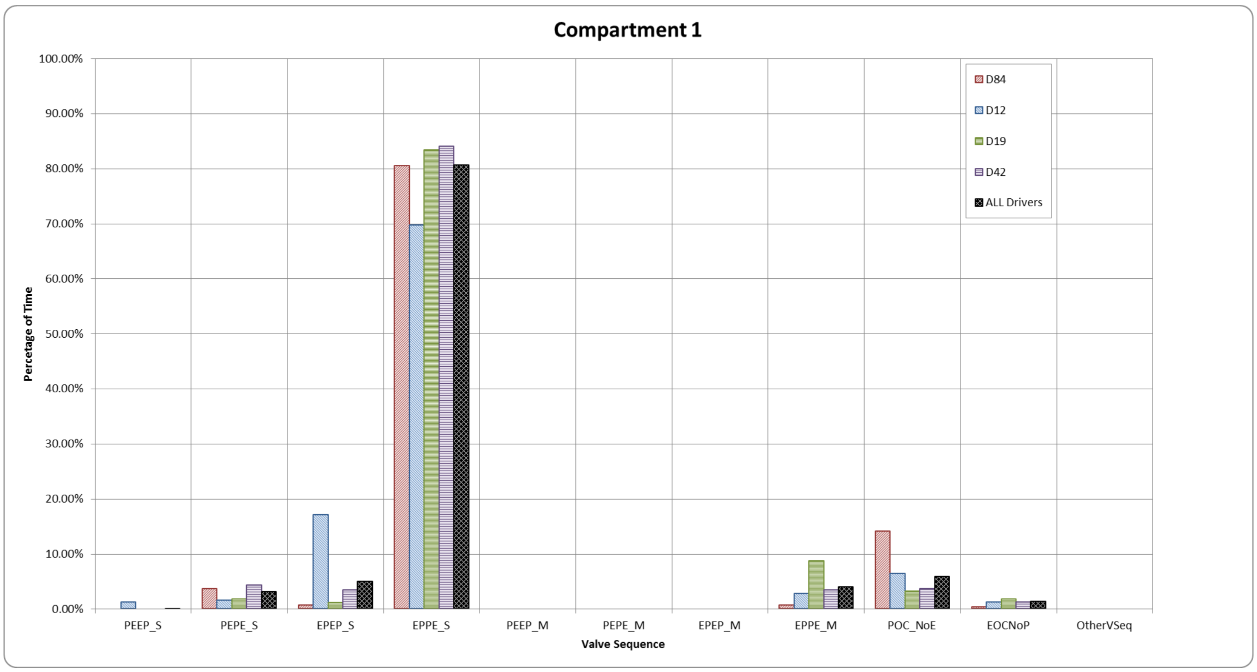

Figure 52. Valve actuation sequences loading and offloading by driver for compartment 1.

[7] Some examples of what would cause a multiple-time actuation could be a driver loading two different fuel types into the same compartment at the same location, or offloading the same compartment into two different reservoirs at the point of destination. Also, some drivers (either routinely or if on a slope) would operate the loading valve handle several times in quick succession to try to get all the remaining fuel out.

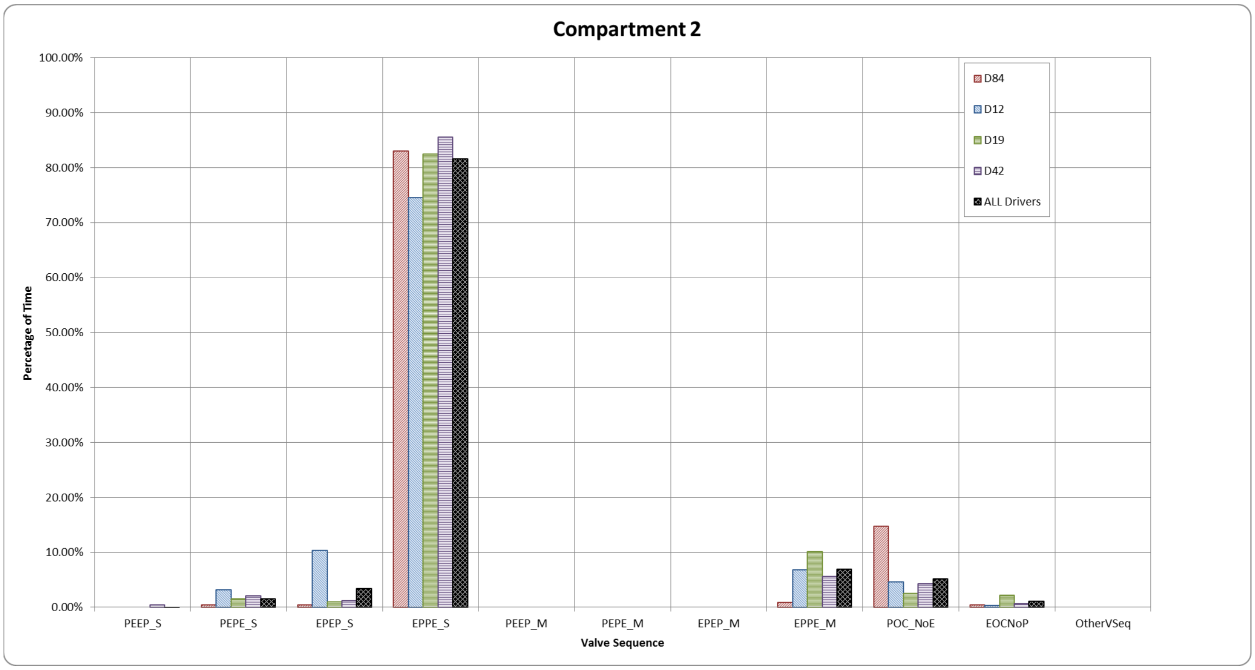

Figure 53. Valve actuation sequences loading and offloading by driver for compartment 2.

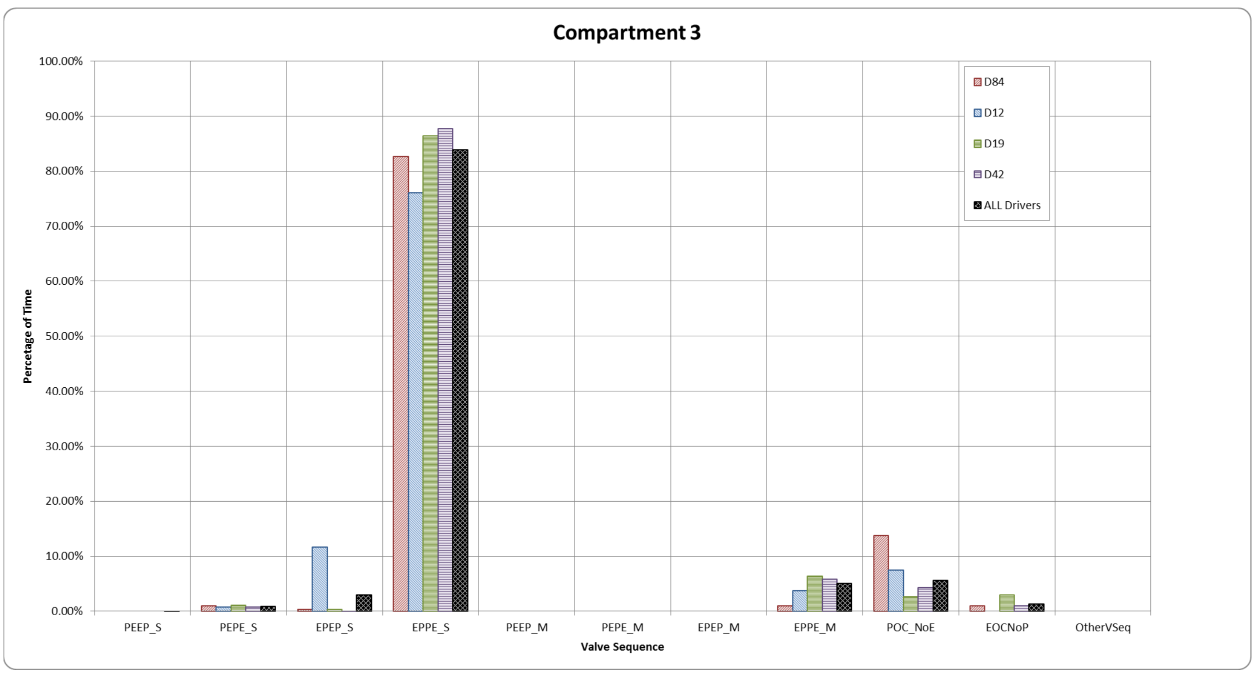

Figure 54. Valve actuation sequences loading and offloading by driver for compartment 3.

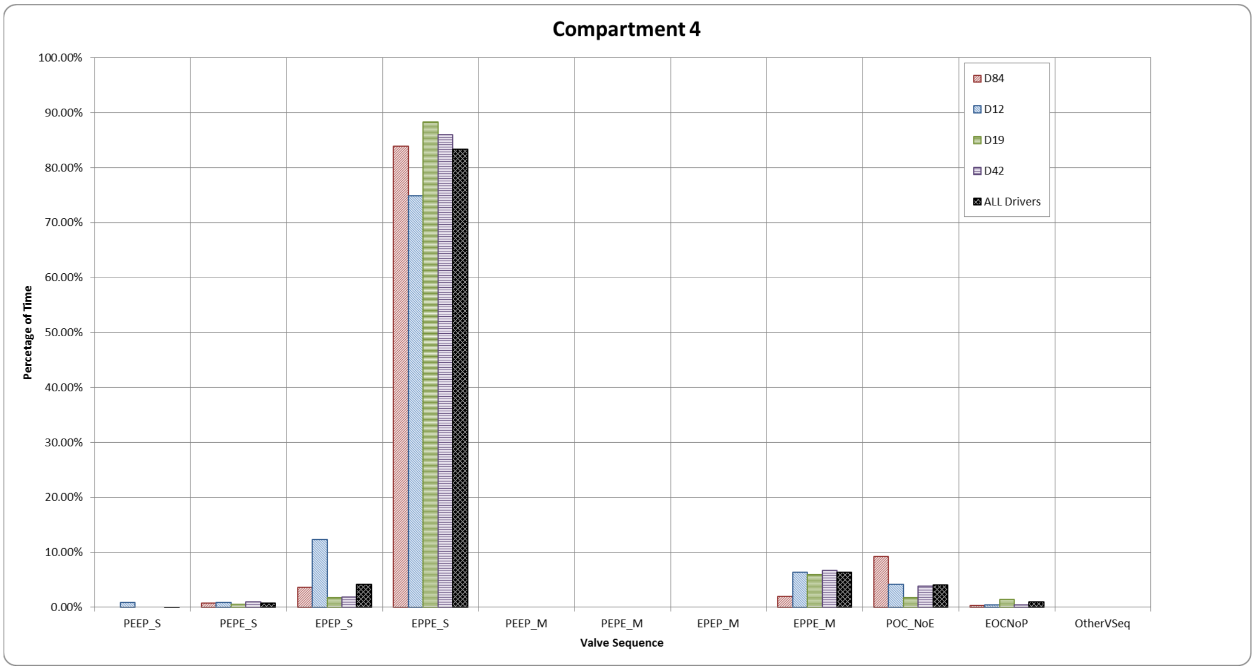

Figure 55. Valve actuation sequences loading and offloading by driver for compartment 4.

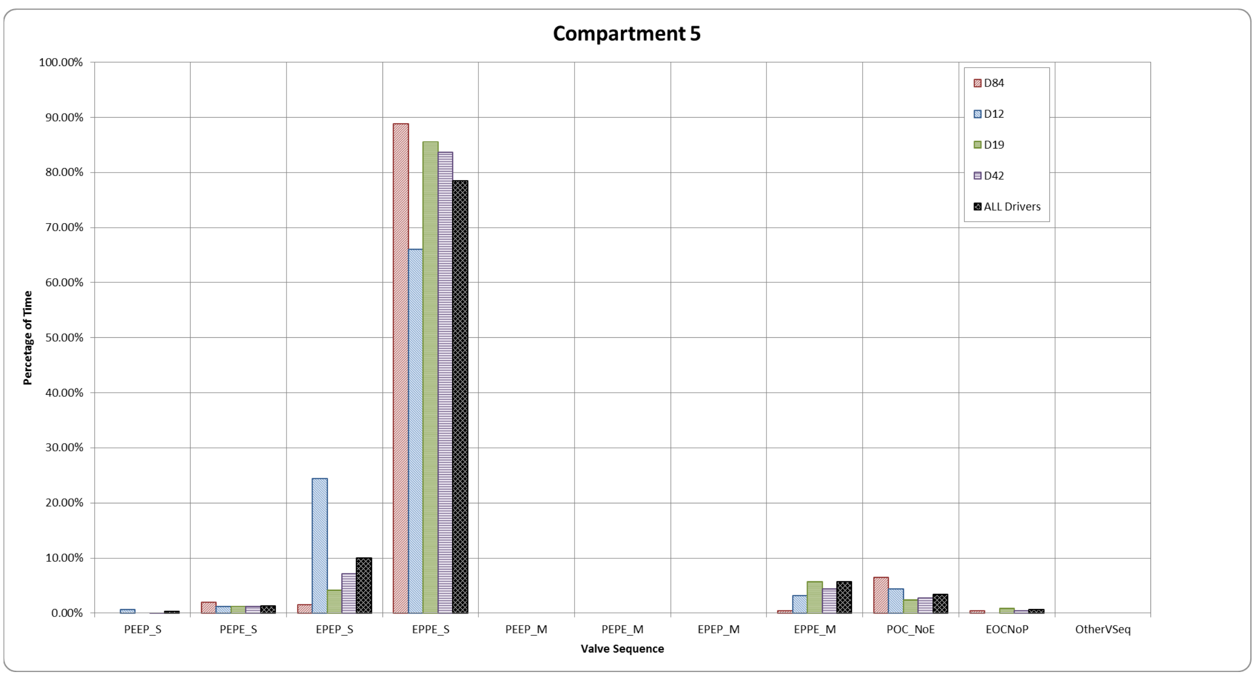

Figure 56. Valve actuation sequences loading and offloading by driver for compartment 5.

In the majority of the cases, the four drivers that were analyzed used the sequence EPPE either once (S) or multiple times (M) when actuating valves for loading and offloading fuel. The sequence EPEP was also used somewhat frequently by driver D12. Sequences PEEP_S and PEPE_S were used sometimes, but PEEP_M, PEPE_M, and EPEP_M were never observed during the pilot test.

Although the entire valve-sequence for any valve actuation event at a given location was tracked and evaluated, of particular interest were the first two-valve actuations. As explained earlier, this particular sub-sequence can indicate a suspicious event that may require further investigation by the carrier. For example, opening and closing the emergency valve would load fuel in the segment of pipe that runs between this valve and the primary valve. Also, opening the primary valve before the emergency valve or opening it after opening and closing the emergency valve at an offloading location could be an indication of fuel theft. If any of these events are observed, the boERS will flag those in the driver report for further investigation by the carrier.

Figure 52 through Figure 56 show that in a few cases there were actuations in which the primary (emergency) valve was opened and closed with the emergency (primary) valve closed. Those actuations would have triggered an alert. Some of these cases were attributed to malfunctions of the valve switches and/or sensors. As explained in Section 2.1, it was necessary to replace the hardware (wiring) about five months into the pilot test. Subsequently, the reliability of the valve switches was 100%. Table 23 shows the frequency of these single-valve actuations before and after the hardware was upgraded for the drivers that operated the vehicles both in the “before” and “after” periods. It can be seen that only a fraction of the cases were attributed to driver behavior. Only three drivers (i.e., D12, D19, and D84) showed “single valve” operations in the “after” period. Of the six single valve actuations of D12 (all “PP”), four were at three different gas stations and two at the same terminal. Driver D19 had 23 “single valve” actuations, ten (eight “PP” and two “EE”) at the same terminal, five (all “PP”) on a shoulder of an interstate highway, three (all “PP”) in a parking lot, two (one “PP” and one “EE”) at an inspection station and another two (both “PP”) at a company site, and one (“EE”) at a gas station. Driver D84 presented eight single valve actuations (seven “PP” and one “EE”) at the same terminal. All of these single valve actuations resulted in alerts.

Table 23. Single-Valve Actuations for Drivers D12, D19, D42, D70, and D84 Before and After Hardware Upgrade

Valve Type Actuation and Hardware Repair Status	Number of Actuations	Percent of Actuations
Emergency Valve Actuations Before Repair	59	1.3%
Emergency Valve Actuations After Repair	5	0.3%
Total Emergency Valve Actuations	64	1.0%
Total Valve Actuations Before Upgrade	4,524	72.5%
Primary Valve Actuations Before Repair	524	11.6%
Primary Valve Actuations After Repair	32	1.9%
Total Primary Valve Actuations	556	8.9%
Total Actuations After Upgrade	1,713	27.5%
Total Actuations Before and After	6,237	100.0%

The boERS kept track of the first two-valve actuations of any valve sequencing and compiled probability distributions of the elapsed times between the opening of the first valve and the opening the second valve for any compartment. This feature was implemented during the pilot test once the research team realized it could be very important in helping the carriers identify suspicious activities.

Table 24 presents the first two-valve actuations elapsed time distribution parameters, while Figure 57 through Figure 61 show a graphical representation of these elapsed time distributions. In general, the first two-valve actuations for compartment 1 present the shortest elapsed time, followed by those of compartment 2. The other three compartments do not follow a clear pattern in terms of the elapsed time between the first two-valve actuations, indicating differences in the style with which drivers operate the valves.

Table 24. First Two-Valve Actuations Elapsed Time Distribution Parameters by Driver and Compartment ID for Loading and Offloading

Driver ID	Compartment ID	Number of Events	Mean (sec)	Standard Deviation (sec)	Mu (sec)	Sigma (sec)
Driver D84	1	53	183	419.9	4.30	1.35
	2	55	471	320.9	5.96	0.62
	3	54	493	423.8	5.92	0.74
	4	55	665	410.2	6.34	0.57
	5	55	731	569.9	6.36	0.69
Driver D12	1	75	547	510.5	5.99	0.79
	2	75	486	592.0	5.73	0.95
	3	64	667	496.2	6.28	0.66
	4	69	460	485.2	5.76	0.86
	5	77	489	370.6	5.97	0.67
Driver D19	1	70	155	450.4	3.92	1.50
	2	66	462	442.9	5.81	0.81
	3	69	594	352.1	6.24	0.55
	4	63	771	481.4	6.48	0.57
	5	69	867	609.9	6.56	0.63
Driver D42	1	96	183	351.2	4.44	1.24
	2	96	488	412.9	5.92	0.73
	3	99	518	369.3	6.05	0.64
	4	109	661	551.3	6.23	0.73
	5	102	483	407.7	5.91	0.73
All Drivers	1	438	364	432.2	5.46	0.94
	2	436	509	456.2	5.94	0.77
	3	437	550	395.6	6.10	0.65
	4	444	622	478.1	6.20	0.68
	5	444	563	485.9	6.05	0.75

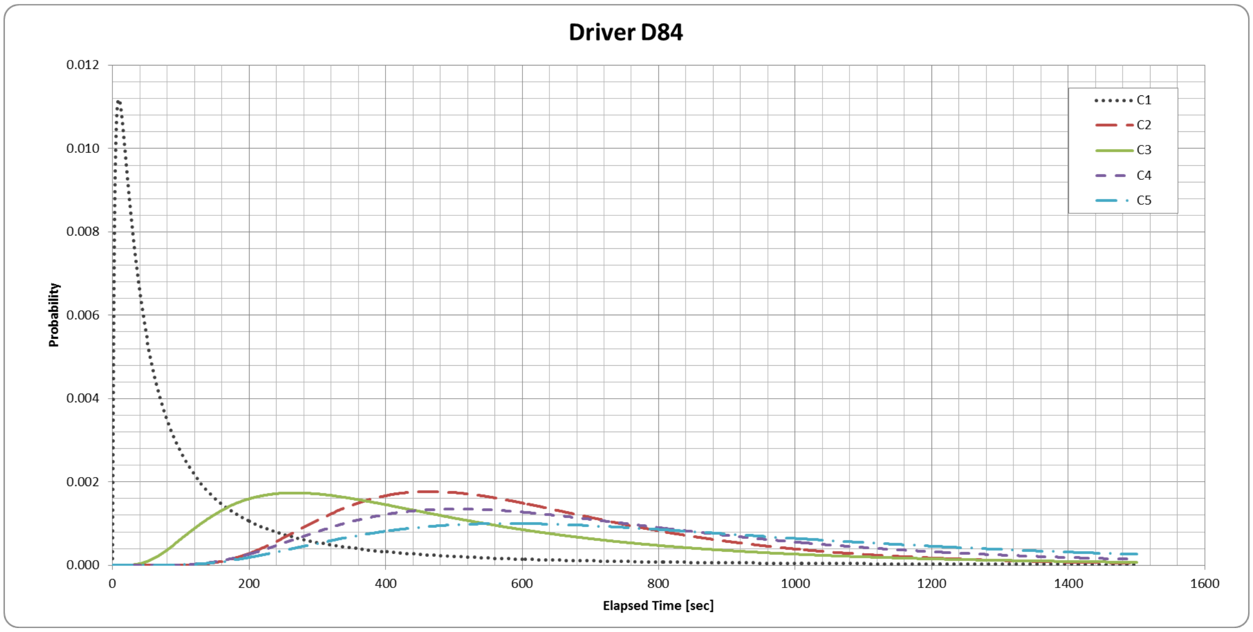

Figure 57. First two-valve actuations elapsed time distributions by compartment for driver D84.

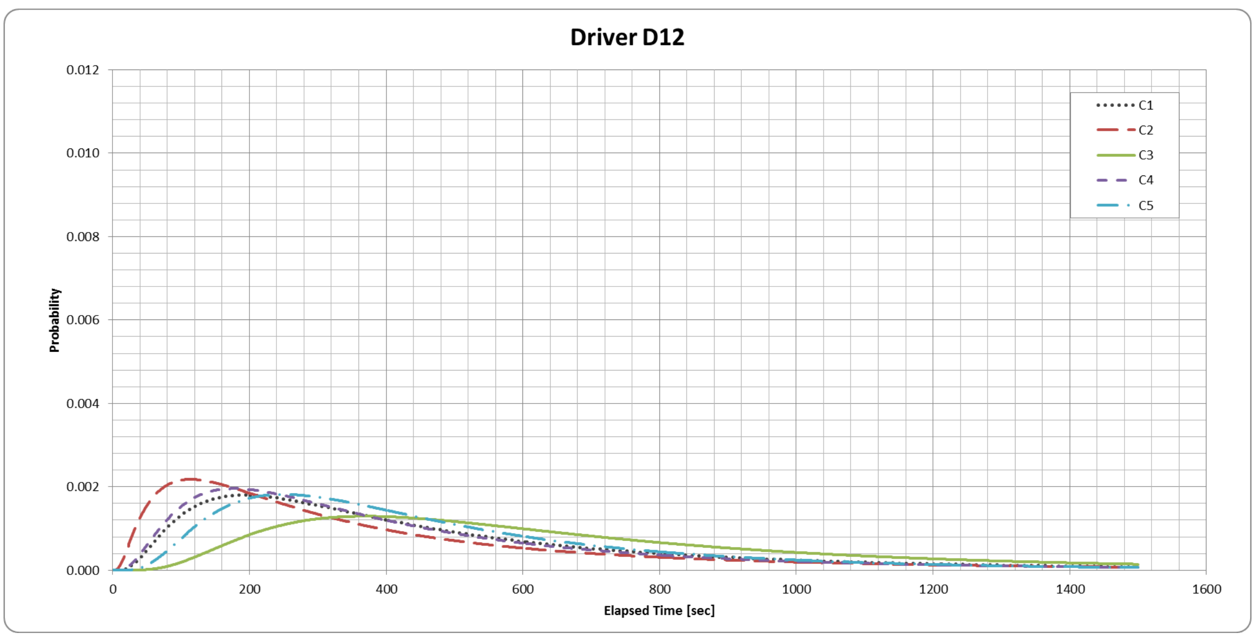

Figure 58. First two-valve actuations elapsed time distributions by compartment for driver D12.

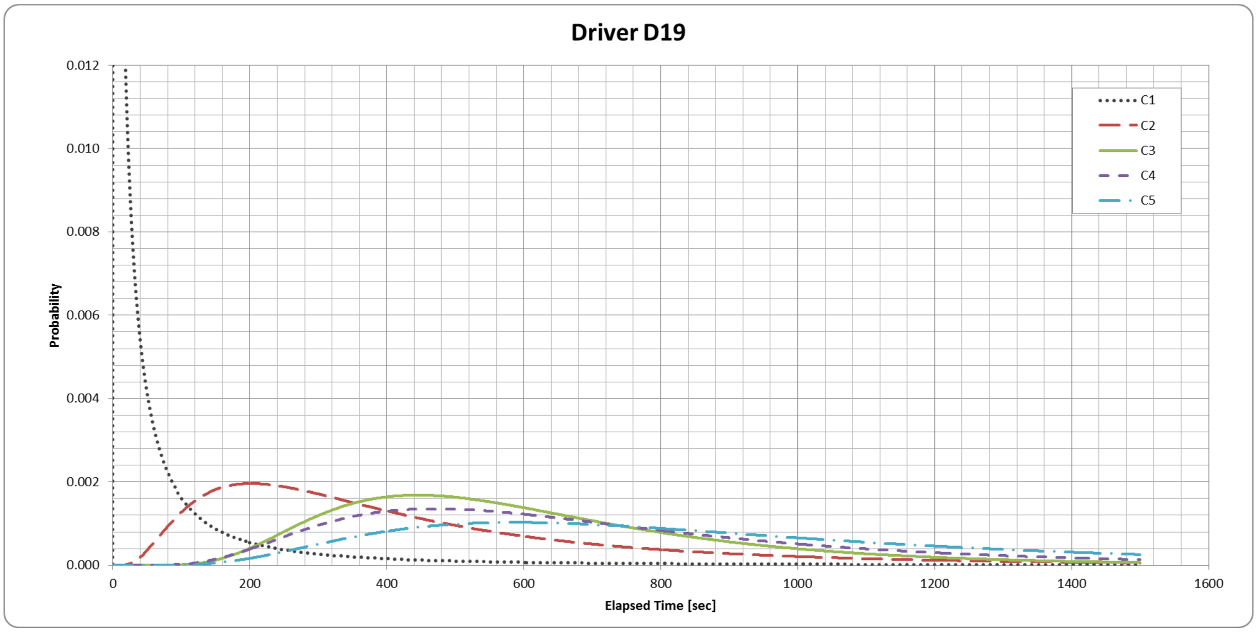

Figure 59. First two-valve actuations elapsed time distributions by compartment for driver D19.

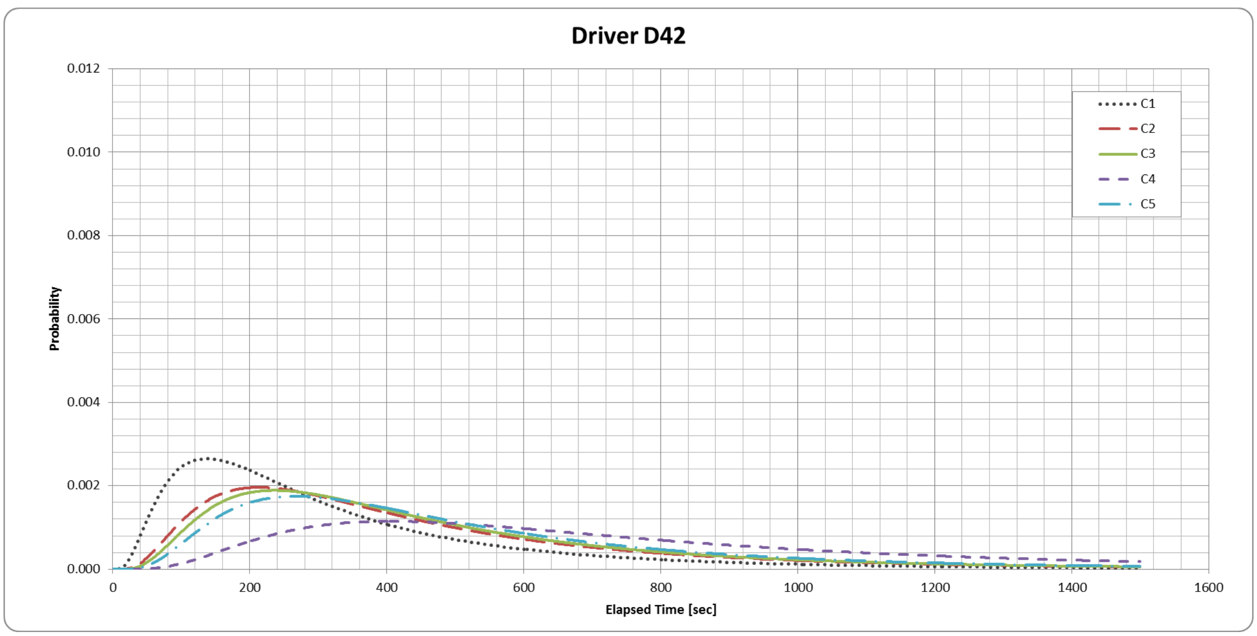

Figure 60. First two-valve actuations elapsed time distributions by compartment for driver D42.

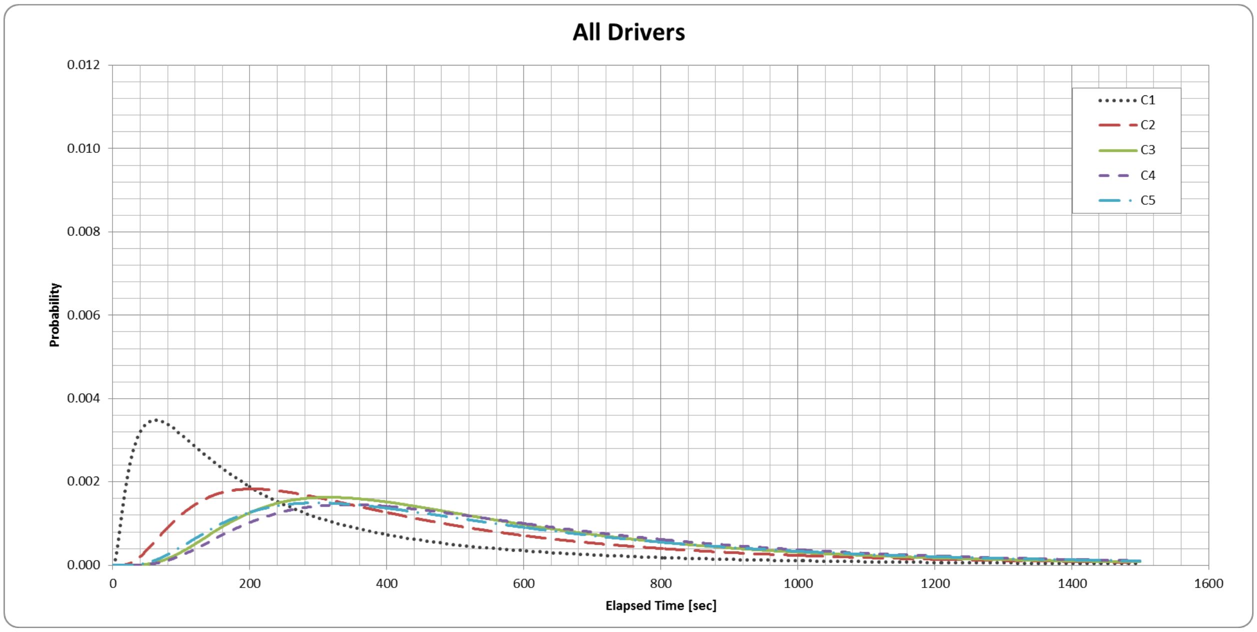

Figure 61. First two-valve actuations elapsed time distributions by compartment for all drivers.

The information presented in Table 24 and Figure 57 through Figure 61 was used by the boERS in the same way as the information presented in Table 21. That is, observed events (i.e., first two-valve actuations elapsed times) where used to determine the likelihood of being observed based on the past history for the driver, vehicle, and compartment. If these likelihoods were below a certain established threshold, then the boERS would flag that event for further investigation by the carrier/dispatcher. For example, if an event of 30 seconds were to be observed for driver D84 and compartment 1, that event would be labeled "unlikely" based on the thresholds discussed on page 51 (see Table 25 below for the likelihoods of observing an event of this type lasting 30 seconds or less). However, the same event would be labeled "rare" and flagged if the driver had been D12.

Table 25. Probability of Observing a First two-valve Actuation Event of 30 Seconds or Less by Driver and Compartment ID

Compartment ID	Driver D84	Driver D12	Driver D19	Driver D42	All Drivers
1	25.8%	0.1%	36.8%	20.6%	1.5%
2	0.0%	0.8%	0.2%	0.0%	0.1%
3	0.0%	0.0%	0.0%	0.0%	0.0%
4	0.0%	0.3%	0.0%	0.0%	0.0%
5	0.0%	0.0%	0.0%	0.0%	0.0%

3. TECHNICAL ISSUES AND LESSONS LEARNED

This section describes the significant technical issues that were encountered during the pilot test and the lessons learned that can be leveraged to mitigate the impacts to data collection and quality in the future.

3.1 SYSTEM DESIGN AND OPERATION ISSUES

The T2TCU was occasionally confused by more than one device on the databus reporting the time. Care should be taken to use only the time information from the telematics device in future efforts.

Oftentimes, at offloading, the tanker air suspension bags are deflated to lower the back of the tanker a few inches. This lowering helps in draining all of the fuel out of a given compartment. The tanker weight during the pilot test is derived from sensors monitoring the tanker air-bags. As a result, there is no weight sensing when the suspension air bags are deflated. With this type of weight sensor, and the fact that in most offloading events the air bags are dumped, it is not possible to view the change in weight as the fuel is flowing out of a compartment. A workaround would be to get a weight reading every time the vehicle starts or stops moving. This would allow the change in weight to be calculated (i.e., delta weight).

In order to prevent the draining of the tractor engine starting batteries during long periods of inactivity or extremely cold temperatures, the tanker system was equipped with an auto-shutoff feature that was triggered when the battery voltage dropped to a certain voltage below normal. This led to frequent low-power shutdown events of the tanker-borne equipment and loss of data during troubleshooting and testing activities. An internal T2TCU battery system would have prevented these disruptions and allowed for data collection over extended periods of tractor downtime, or periods of separation from the tractor.

A very small percentage data files got “stuck” on the telematics device due to communication difficulties. With only 3 trucks, the files were able to be retrieved with physical access to the telematics device. In a larger deployment that would not be feasible, so the logic to attempt to resend files would need to be strengthened in a production system.

3.2 FLEET AND OPERATIONAL ISSUES

Access to vehicles for system repairs, updates, and pointed testing was very difficult. Such access was typically accomplished from 10:00 pm to 4:00 am when the vehicles were available at their domicile. As a result, some issue correction efforts were delayed which ultimately impacted data quality and quantity. This is always an issue with real-world testing in this type of vocation. Petroleum distribution tanker-trucks typically do not have a large window of inactivity and some operations are 24/7. There is no tangible work-around to this issue.

Access to drivers for training and general communications was also very difficult. During the pilot test, the lack of access to the drivers impacted data quality and quantity. It is expected that in a commercial deployment, where the carrier management adopts the technology, such driver issues would not be present because the carrier would act as the liaison to the driver as is done in the dispatching of loads and general safety training.

Driver adoption and data entry quality were persistent issues despite the fact that the drivers were being paid a marginal stipend to input data during the pilot test. For a commercial deployment situation it is believed that this issue would be mitigated.

Driver turnover (or churn) had a large impact on the quantity and quality of the data captured. Driver churn is an issue in the trucking industry, but was not expected to the degree that was seen in this effort relative to the petroleum hauling industry. The driver churn experienced during the pilot test was due to reassignment of the majority of the initial set of drivers to new equipment as it was procured by the fleet partner. Abatement to this issue would be to have an agreement in place at the beginning of the testing to retain drivers with their equipment for the life of the testing.

3.3 INSTITUTIONAL ISSUES

Delays in implementing software and hardware changes in the field had a large impact on the quantity and quality of the data captured. Because much of the software and hardware changes were required to be done in the field, the scheduling of technicians, travel time, and access to the vehicles negatively impacted the implementation of these changes. Additionally, hardware changes were delayed by the production schedules for new hardware (cables and boards) to be fabricated. Cabling and circuit board failures were not expected and are addressed in the next section.

3.4 QUALITY ISSUES

There were systemic failures of the wiring connections within the tanker harnesses. A low-temperature solder connector was used that produced a "cold solder joint" or a non-conducting/high-failure joint (see Figure 62). This problem was not identified until after the cables were installed and the pilot test was underway. As a result, data corruption, data loss and increased downtime were experienced. The cables were remanufactured using mechanical butt-splice connectors that solved this issue.

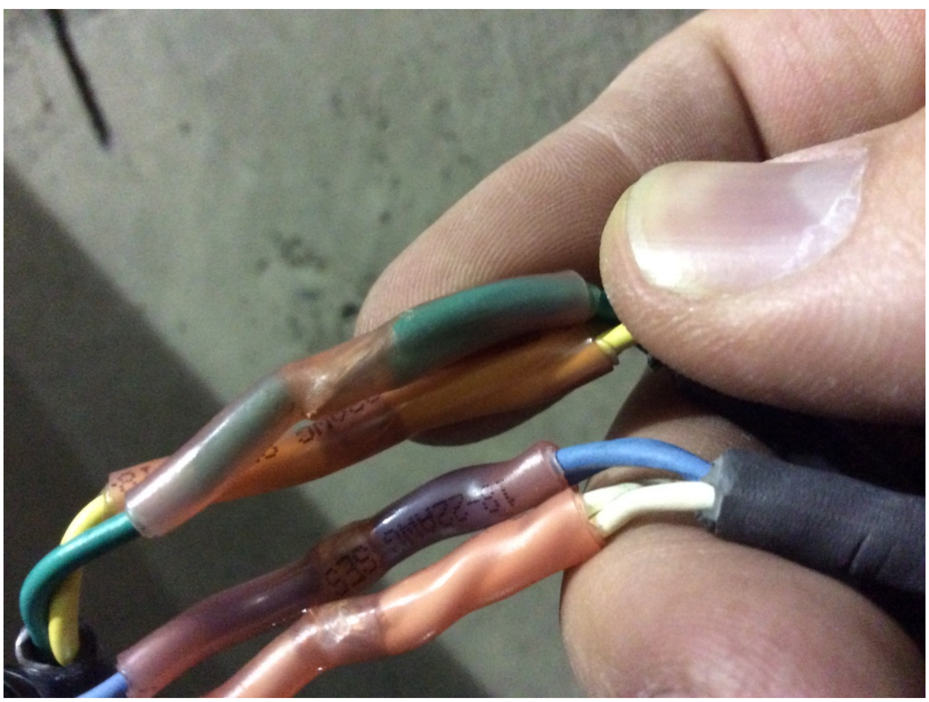

Figure 62. Failed tanker harness low-temperature solder connectors.

The pilot test required production quality or near-production quality components from vendor partners. However, pre-field testing of vendor components to identify environmental, communication, and fabrication issues was not a part of the vendor partner contracts that were put into place in advance of the pilot testing conducted by ORNL. Many of the component failure issues were not expected and could have been identified with pre-testing certification by the industry partners.

Moisture invasion was an issue with the T2TCU enclosure due to their size, location, and the wiring penetration compression grommets that were used. The failure of the circuit board within the T2TCUs (see Figure 63) necessitated that new boards be built and the T2TCU enclosures redesigned (see Figure 64). This issue caused substantial gaps in the data collection during the pilot test. Improved sealing of the tanker enclosure and avoidance of putting connections on the top of the enclosure would provide greater robustness to these elements. Pre-certification testing in an environmental chamber would have identified this issue.

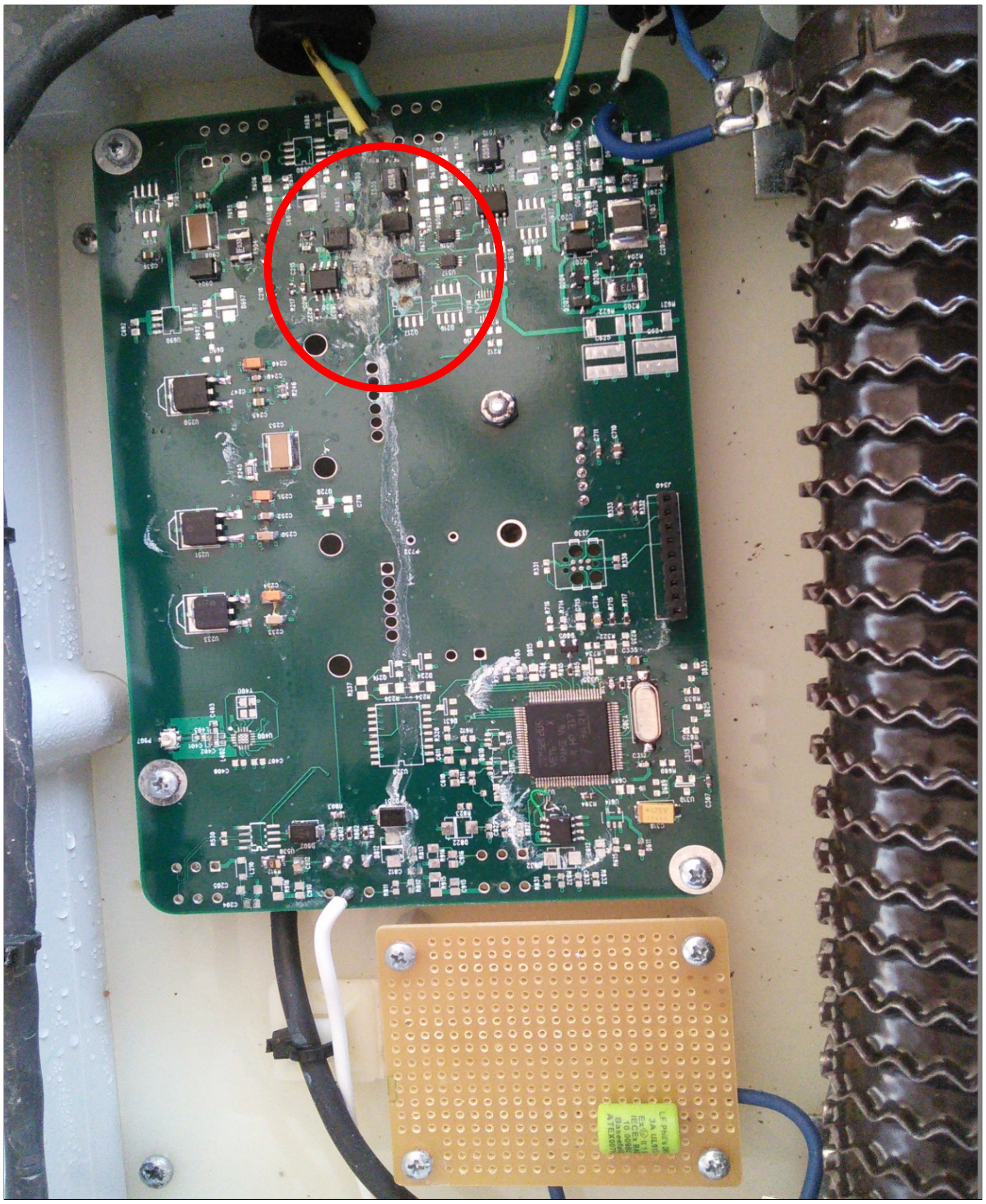

Figure 63. Corrosion damage to the T2TCU main circuit board from moisture intrusion.

Figure 64. Newly installed T2TCU main circuit board.

Custom enclosures and cable lengths for each tanker would also be desirable to prevent water infiltration into the enclosures and to prevent ice buildup on excess cabling (which could lead to cables being torn away from the tanker).

3.5 ADDITIONAL IMPROVEMENTS

Another area of improvement for future efforts is increased sensor implementation. In order to better assess potential tampering and safety issues, sensors for the hatch manholes as well as fill caps could be added – albeit at an increased cost. If magnetic targets could be attached, less expensive Hall Effect sensors could be used instead of proximity switches. Switches and targets could also be integrated into the valves by the valve manufacturer mitigating the possibility of tampering with the switches.

Other improvements for consideration are:

- For simplicity, the Air-Weigh tanker database components used fixed addresses. In the future, they should be able to negotiate an address as laid out in the J1939 address claim.
- Although both the obERS and boERS have exception handling mechanisms, those exceptions can be more detailed to better identify and help solve software problems.
- The boERS processing time could be optimized in a wider deployment.

- Since the tractor ignition is typically off when fuel is being loaded or offloaded, the tractor receives time-stamped fuel events later in time. The buffered information does not currently have an independent location, so the tractor assumes that the information it receives has happened at the location it receives it. Normally this works, but if something disturbs or delays the tractor and tanker communication, such as a disconnected or bad cable, the buffered data location information could be wrong. One way to address this could be to add an additional GPS unit for the tanker system. The use of an additional GPS unit and its associated information could also ease issues related to timestamp synchronization between the tractor and tanker.
- Information to the carrier is currently displayed on a webpage. Communication methods could be expanded to include text messaging and email, especially for alerts.
- Remote diagnostics, such as changing the logging level detail, would be helpful for a more widespread deployed system.

4. CONCLUSIONS

The pilot test conducted by ORNL showed that the proposed supply-chain based solution to prevent fuel-tax evasion is technologically feasible. The technology was deployed and tested on a real-world fuel-hauling fleet during day-to-day operations and minimally affected these operations. For example, the drivers needed only to go through a 45-minute, one-time training course on how to enter information on the obTD. The loading and offloading of fuel and other related operations were not affected by the deployed system.

The harsh environment to which the hardware was subjected during the pilot test (ice, road snow removal chemical substances, etc.) had a negative effect on the first generation of wiring and connectors deployed. These had to be hardened and re-deployed during the pilot test and provided much improved results. Some adjustments had to be made to the software that was deployed, but in general, the applications that were developed for the project functioned as expected and allowed the collection of the necessary information to conduct the tests.

The system was easy to operate for the drivers. The valve operations were not impeded by the deployed sensors, so no new skills were needed to operate the tanker. Fuel information (i.e., quantity, type, BOL number, destination, etc.) had to be entered manually by the drivers at the terminal and at the offloading location (although at the latter location nothing had to be reentered since the interface "remembered" what was entered at the terminal). Some errors were made by some drivers who entered the information incorrectly, especially in some low-occurrence cases (e.g., buying fuel at two different terminals for the same customer and shipment). The boERS identified those cases and noted those in the driver reports so the carrier was able to correct the information before it was uploaded to the FDAS. Even when the information was not corrected, the FDAS users could apply filters to find cases that were abnormal. Furthermore, in cases where the technology is completely disconnected for a period of time and the carrier does not submit any information from that vehicle, the FDAS would be able to identify these gaps since the odometer reading is one of the information elements submitted in the reports to this system.

The solution developed in this project balances the needs of tax auditors and those of the fuel-hauling companies and their customers. For the former, it provides a quick way to find anomalies in the tax information submitted to the system. It also allows tax auditors to conduct quick data analyses to better assess what is considered to be "normal operation" for a given carrier. For example, in the discussion above, a distribution of fuel-shipment distance traveled is presented for the carrier and vehicles participating in the pilot test. The average distance traveled was much higher than what some fuel-tax auditors would consider regular. Therefore, for this particular carrier, long distances are not an indication of illicit activities and it may be a waste of resources to audit that company simply based on that fact.

The cost of the deployment of the technology (except for the FDAS), regardless of whether the technology is mandated by the Federal Government, will likely be borne by the carrier. The technology therefore has to provide incentives to the fuel hauling carriers in order for it to be adopted. The addition of carrier incentives was one of the main considerations in the development of the solution investigated during the pilot test. Two of the most relevant issues for a fuel transportation company were addressed: fuel theft and fuel cocktailing. For these issues, the technology provides sufficient information to the carrier to help identify events that are likely indicators of illegal activities.

Other tangible benefits include:

(a) supports the reduction and possible complete elimination of fuel miss-delivery,
(b) monitoring and reporting of safety issues (e.g., hatches or valves open during transit, or hatches or valves open while entering a fuel terminal),

(c) corroborating of the fuel deliveries for tax filings,
(d) providing evidence to customers that all of the fuel that was supposed to have been delivered, was delivered.
(e) providing information related to driver behavior for training purposes,
(f) providing information relevant for improving the efficiency of fuel hauling activities, and
(g) providing an opportunity to reduce human transcription error in reported data and information.

The technology is also factory or field installable and it is backwards compatible with currently deployed fuel-hauling equipment.

It is concluded that the ORNL-developed technology was successful in demonstrating its effectiveness in the FTE environment, and was shown to be able to provide benefits to the carriers in identifying events that may be related to fuel theft or cocktailing. As such, future efforts in the development of this technology are recommended (see Section 6.8). These recommended future efforts include further integration of the technology into the tractor-tankers, development of an expert system of human behavior to enrich the ERS, definition and conduct of a Field Operational Test augmented with technology demonstrations and workshops, and partnering with industries sharing similar issues to that in the highway-based FTE environment.

5. LESSONS LEARNED

5.1 TECHNOLOGICAL SOLUTIONS, ADOPTION, AND INVESTMENT

This project has shown that applying an integration of sensor, communication and tracking technologies toward solving the FTE problem in the US is feasible, and holds the promise of significantly reducing tax revenue loss in the US petroleum trucking industry. Unresolved issues associated with this, however, are: 1) defining more specifically how such technologies are to be deployed, 2) identifying what technological mix is optimal to balance the needs of the federal government, the tax auditing community and the petroleum hauling community, and 3) determining the optimal investment by the federal government and private industry in this technology given the relatively dynamic nature of the transportation fuels industry in the US. This project has demonstrated that a technological solution toward reducing the FTE problem while at the same time providing benefits to tax auditors and carriers is feasible. Future efforts should address aspects of the unresolved issues.

5.2 THE HUMAN ELEMENT

Although numerous FTE scenarios have been identified, and although there are some well-defined events that make up these scenarios, there still remains considerable uncertainty in determining whether certain sets of events constitute legal or illegal scenarios. One of the primary differences between these two is the characteristics of the human elements which are involved with the fuel hauling scenarios. This project has demonstrated that human patterns of behavior can be identified and utilized to flag events which may potentially be illegal in nature. The ERS developed in his project is a unique integration of the characteristics of: 1) the tasks associated with petroleum hauling and delivery, 2) the equipment and location in the petroleum hauling and delivery tasks, and 3) the characteristics of the drivers of petroleum tankers. Together, within the ERS, these characteristics and patterns represent a much stronger evidential base for determining legal and illegal activities. It should be noted that the human patterns of behavior must be developed for, and is unique to each carrier that utilizes this technology. As such, this requires an investment on the part of the carrier in the development of such human patterns of behavior for their company. Such an investment, however, can be leveraged by the carrier for other purposes. These include a better understanding of its fuel handling and delivery operations, identification of areas for enhanced training, identification of areas in the fuel handling process in which the efficiency of its operations can be improved, and identifying potential safety hazards associated with their driver's behavior. These are all benefits that are available in addition to minimizing or eliminating fuel theft and other illegal activities within their firm. An additional benefit is that the use of such technology makes a firm much more transparent with respect to their involvement in any federal audit involving FTE. In effect, any company that uses such technology might be viewed as a more trusted carrier, possibly minimizing their involvement in a future FTE audit.

This project has demonstrated that driver behavior patterns can be utilized within an evidential reasoning framework to support the identification of legal and potentially illegal activities in a fuel delivery scenario. For this project, such patterns were generated by project team members through observation and the collection of data and information related to the operations of the carrier. Because carrier operations vary from carrier to carrier, the development of human behavior patterns must be done for each carrier that will use this technology. Such efforts, although valuable, represent a substantial investment to generate the unique human behavior patterns for each carrier. On the other hand, carrier operations, although different in the details of their operation, are similar in a broader sense. All have similar major tasks that must be performed. Variances in performance and behavior patterns may occur with regard to the order of task execution, the omission of tasks, task duration, as well as other factors.

For this project data and information related to task execution and the associated variances were gathered by the project team to support the development of the ERS. Currently, such efforts must be accomplished for each carrier wanting to adopt this technology, and could involve a considerable investment of time and effort if accomplished for each of the carrier drivers.

Future efforts could be focused on the development of a more comprehensive list of tasks conducted by each carrier driver and the factors that influence task performance. Such data and information can be compiled by conducting a human factors task analysis across the fuel delivery industry. The library of tasks and influencing factors can be utilized by each carrier to build driver specific behavioral profiles that are specific to the carrier. These profiles can subsequently be used within the ERS.

The behavioral profiles for each carrier could be generated through a manual process in which the tasks, influencing factors and task timing are noted. Such a process could also be more automated if accomplished through a computer-based application. Over a period of time, a driver-specific behavioral profile could be generated that could be utilized to support the development of the ERS. The ability to generate driver-specific behavioral profiles more automatically would reduce the cost of implementing the technology, and reduce the need to involve personnel outside of the carrier's organization to add profiles for new drivers and to recalibrate profiles for existing drivers over time.

5.3 TECHNOLOGY-PUSH

Another lesson learned from this project was that despite the significant tax losses associated with FTE and associated audits, and the financial losses due to fuel theft, etc., there does not seem to be a strong willingness on the part of industry to make changes from the current status quo. This might also suggest that there is a general belief that a cost-effective solution to these problems cannot be effectively developed. As such, the industry is not expected to seek-out such technology. Rather, the validity and utility of the technology must be demonstrated to the industry in order to generate greater interest by them in the technology. This will require a hardened and field-ready version of the technology for demonstration to the industry. This version may not be the same version that is ultimately deployed, but will suffice for the efforts of demonstrating the technology to the industry, and providing a cost-point.

The technology must have a multiplicity of benefits to a variety of clients including the federal government, auditors and fuel handling and delivery carriers that must be demonstrated. Such demonstrations will require: a) physical demonstrations of the technology, including an ERS, in a technology transfer type of environment, b) a Field Operational Test (FOT) that includes data collected from a real-world carrier before the test begins (to establish a baseline), and after the technology is on-board, and c) workshops that clearly promote the value and benefits of the technology, including the ERS, to the carriers; and will seek input from potential clients regarding the functionality of the technology. Future efforts should define a limited deployment FOT that includes a shared investment by the federal government and by private industry in a multi-year effort to validate the benefits to the federal government, auditors and private industry. This FOT can be augmented by demonstration technology venues as well as technology workshops.

5.4 OTHER TRANSPORTATION MODES

Although the focus of this project has been on highway fuel transport and delivery, there are many other industries and other federal agencies that have similar issues associated with the transport of petroleum, hazmat, high-value bulk commodities, etc. It is likely that the technology solution being addressed in this project will have applicability in other industries as well. That is, it is believed that the current technology can be easily adapted to support industries involved with: (a) home heating oil, dyed diesel and other straight tanker-truck applications, (b) other tanker-truck borne commodities (e.g., liquid or other), (c) other non-tanker borne commodities that have high value or are hazardous in nature, (d) rail commodities, (e) ship-borne/barge commodities including high value, sensitive, or hazardous intermodal containers, and (f) military commodity transport. Technologies to support the needs of these industries can help to leverage future technology enhancements in the over-the-road fuel handling and delivery industry, and could facilitate an earlier and wider adoption of the technology.

6. RECOMMENDATIONS

This project has demonstrated that a technological solution to the FTE issue while simultaneously providing benefits to auditors and the petroleum carriers is feasible. The previous section suggested several recommendations based on the lessons learned in this project. Other recommendations stemmed from interactions with project partners, and with organizations involved in the technical working group associated with this project. This section of the report highlights these recommendations.

Regarding the project's technical working group, a final meeting of the group was held on November 5, 2015. The technical working group consisted of state and former federal auditors, and was held at the NTRC building in Knoxville, Tennessee. The purposes of this meeting were: (1) to brief the group on the results of the analysis of the pilot test data, (2) to discuss lessons learned, and (3) to compile ideas for future directions of the technology. The outcome from this meeting is highlighted in the subsections below. Additional detail about this meeting is included in Appendix J.

6.1 RECOMMENDATIONS FROM THE LESSONS LEARNED

The following recommendations were suggested in the Lessons Learned Section of this report, and are summarized here for completeness.

Recommendation is made to resolve the following:

(1) greater specificity on how best to deploy FTE technologies,
(2) determination of what technological mix is optimal to balance the needs of the tax auditing community and the petroleum hauling community, and
(3) determination of the optimal investment in this technology given the relatively dynamic nature of the transportation fuels industry in the US.

Recommendation is made to enhance the ERS through the development of expert systems of behavior that characterizes: (1) the fuel hauling and delivery tasks, (2) the equipment and location associated with such tasks, and (3) the human patterns of behavior of the carrier drivers. Furthermore, efforts are recommended for the development of a computer-based tool that can more automatically generate driver behavior patterns in order to minimize the cost of the custom development of such patterns by human experts.

Recommendation is made to define and conduct a limited deployment FOT that includes a shared investment by the federal government and by private industry in a multi-year effort to validate the benefits of the technology to the federal government, auditors and private industry. This FOT can be augmented by demonstration technology venues as well as technology workshops.

In order to facilitate an earlier and wider adoption of the technology recommendation is made to seek to leverage the FTE technology with other industries such as: (a) home heating oil, dyed diesel and other straight tanker-truck applications, (b) other tanker-truck borne commodities (e.g., liquid or other), (c) other non-tanker borne commodities that have high value or are hazardous in nature, (d) rail commodities, (e) ship-borne/barge commodities including high value, sensitive, or hazardous intermodal containers, and (f) military commodity transport. The basis for this leveraging would be security and safety issues that are common across these industries. If common issues can be addressed by the technology, costs could be reduced, and adoption of the technology could be expedited.

6.2 TECHNOLOGY DEPLOYMENT IN OTHER ENVIRONMENTS

The obERS and boERS are applications that can be ported and deployed in other environments that are similar to the ones in which they were tested (i.e., Microsoft Windows or Android environments). Similarly, the hardware (valve and hatch switches and sensors) and associated infrastructure and software can be installed and deployed on any tractor-tanker combination tanker. The FDAS (database and auditor's interfaces) can be deployed anywhere FHWA chooses with minimal changes.

The telematics-provided interfaces, both on-board and back-office, are proprietary and are tightly integrated into their system. Technology transfer would be necessary if the solution developed in this project is to be deployed elsewhere using the business models adopted for the pilot test (i.e., a telematics provider system), or a more open environment (e.g., using tablets or smart-phone technology). New interfaces dealing with the collection of sensor information, and driver and carrier inputs will have to be developed.

6.3 DRIVER DATA-ENTRY TASKS

The fuel terminals that were accessed during the pilot test are partially automated. That is, the driver, after entering and parking the tanker in one of the fuel-loading bays, accesses a kiosk (i.e., a computer) to indicate the type and quantity of fuel being bought. After loading the fuel in each of the compartments (a process that is fully controlled by the kiosk computer [except for the hose connections]) the driver obtains a hardcopy of the BOL which contains the information entered at the kiosk by the driver plus some additional data. At that point, the driver enters fuel-related information such as type, quantity, BOL number, and destination into the obTD. This step could be eliminated (and human transcription errors minimized or eliminated) by getting an electronic copy of the BOL. Recommendation is made for the development of a Bluetooth interface that would allow the obTD to handle electronic data transfer at the terminal. This would simplify the driver's data entry task, making the system that was tested in this project almost transparent to the driver. It may still be necessary for the driver to indicate at the delivery destination that the fuel was indeed delivered; but this could be further developed to the point where the driver is required to merely press a button on the obTD indicating that the fuel was delivered at the intended location.

6.4 DEPLOYMENT COSTS

The cost of the technology can be greatly reduced by eliminating some sensors that provide information which can be obtained by other means. During the pilot test the researchers learned that fuel-hauling vehicles operate in one of two loading states: empty or fully loaded. Information provided by the weight sensors, which are a costly component of the system, can be provided by analyzing data from other readily available on-board technologies (i.e., torque or engine loading signals on the vehicle databus) that can provide information relevant for the assessment of the vehicle weight. ORNL has conducted other projects [9] [10] where this technology has been used for similar analyses, and has demonstrated that it can provide information on the loading state of the tanker. See Appendix K for a short study with a fuel tanker during the pilot test. Recommendation is made that the ORNL approach be further investigated for use within future efforts of this project.

6.5 INDUSTRY ADOPTION APPEAL

The technology that was deployed and tested in the pilot test addressed the issue of cargo integrity, one of the main concerns of fuel transportation companies and their customers. The technology also offers a first and necessary step towards the reduction, or complete elimination, of fuel miss-delivery (or cross-contamination); a very costly problem for fuel-hauling companies. Capturing information about valve actuations per tanker compartment, and the type of fuel in that compartment (both addressed by the technology developed in this project), together with some new technology to be developed to identify the type of fuel in an underground tank at the fuel-delivery destination would solve the cross-contamination problem. Such a concept could provide alerts if the wrong type of fuel is attempted to be offloaded. The addition of this feature to the system (at a reasonable cost) would expedite its adoption by the industry since it can provide significant cost savings. Recommendation is made to further investigate such enhancements to support increased industry appeal.

6.6 AUDITING SYSTEM CAPABILITIES

The carrier side of the system developed in this project uses self-learning algorithms that can identify activities that are outside of the normal operations of a company. These algorithms use driver and location-specific information to determine if an action taken by that driver at that location is expected (normal) or not. The same type of algorithms can be deployed to the FDAS to help auditors identify when certain actions of a fuel-hauling company are not normal and may need further investigation. This would optimize the use of scarce auditing resources by allowing a focus on companies that may not be operating according to the law. Recommendation is made to further investigate such enhancements to support increased appeal of the technology to the auditing community.

6.7 MOVING TOWARDS COMMERCIALIZATION

The ORNL staff along with the FHWA COTR attended the National Tank Truck Carriers (NTTC) Tank Truck Week in Houston, Texas on November 12, 2015, in order to gauge the interest in the technology that has been developed in this project for possible use by carriers for fuel-theft mitigation, tampering alerts, and safety warning. Discussions were held with 19 companies. More information about this meeting is available in Appendix M.

The following steps are recommended as part of the process of moving toward commercialization of the technology developed in this project:

1. Identification of a company willing to further develop, test, and certify a hardened system with a price point that the market will bear;
2. Further enhancement of the ERS to include a richer set of patterns associated with the fuel handling tasks, equipment and drivers;
3. Development of an expert system that can automatically generate driver behavior patterns for use within the ERS as well as other applications of benefit to the carriers;
4. Transfer the ERS software to a licensee;
5. Establish partnerships with a fleet or fleets who want this technology for carrier benefits, or tanker manufacturers who want to offer it as optional technology;
6. Define and conduct a FOT to clearly demonstrate the benefits of the technology to the federal government, the auditing community and the fuel carriers;
7. Development of technology venues capable of easily and clearly demonstrating the technology to potential interested clients;

8. Conducting technology workshops to raise awareness of the technology and its benefits; and
9. Identification of a server location for the deployment of the FDAS.

6.8 NEXT GENERATION SYSTEM

For the next-generation system, the components that are required for the deployment of this technology should be integrated during tanker manufacturing; with the valve and hatch sensors integrated during the original equipment manufacturers (OEM) process. These should be OEM offered as additional features. For economic feasibility, the system should only add $300-$500 per tanker to the total cost of the equipment. The electronics components should be hardened and certified for hazardous environments, and should have a life expectancy of more than 10 years.

One of the specific enhancements and improvements of the system that was suggested by Air-Weigh was the simplification of their system to improve its reliability for FTE applications. Figure 65 shows the vehicle-borne system deployed in the pilot test. It is composed of two main sub-systems: the tanker sub-system and the tractor sub-system. To simplify the configuration of the system, Air-Weigh proposed to confine all components to the tanker as shown in Figure 66. Besides eliminating the tractor-tanker data cables and the tractor T2TCU component of the system (note: the tanker T2TCU would become the Tanker Control Unit), this approach would also allow such a tanker to be independent of the tractor that it may be connected to. In effect, such a tanker could be considered a "smart" tanker. A disadvantage of this concept is that the smart tanker would have to have its own means of communications, either to the obTD or smart-phone device, or to a back-office system. A smart tanker concept would also need a GPS device to associate the registered events (opening and closing of valves and hatches) to a spatial location. The simplified system would also provide weight measurements for the tanker only.

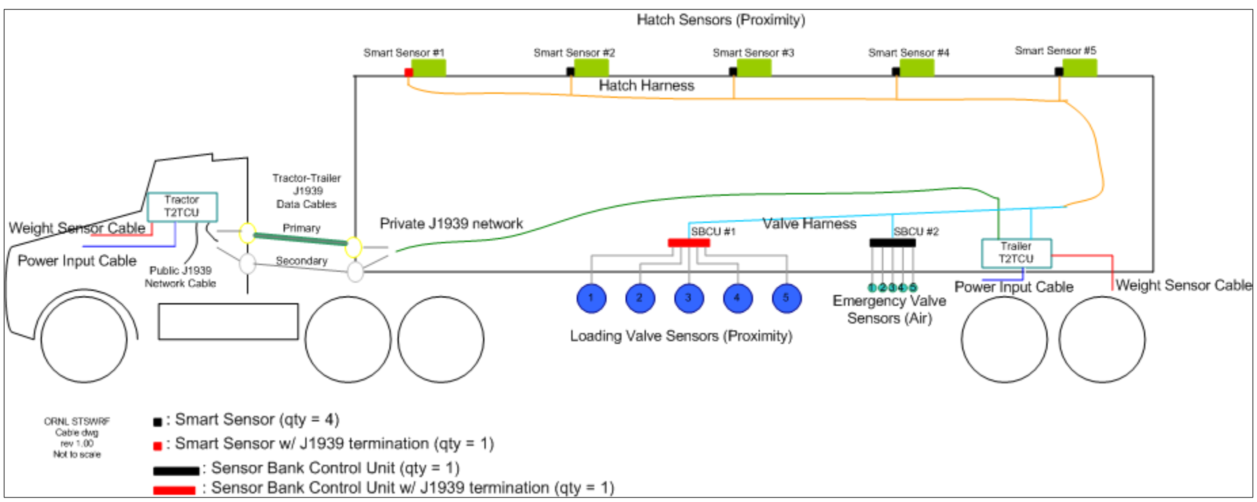

Figure 65. Air-Weigh pilot test deployed system.

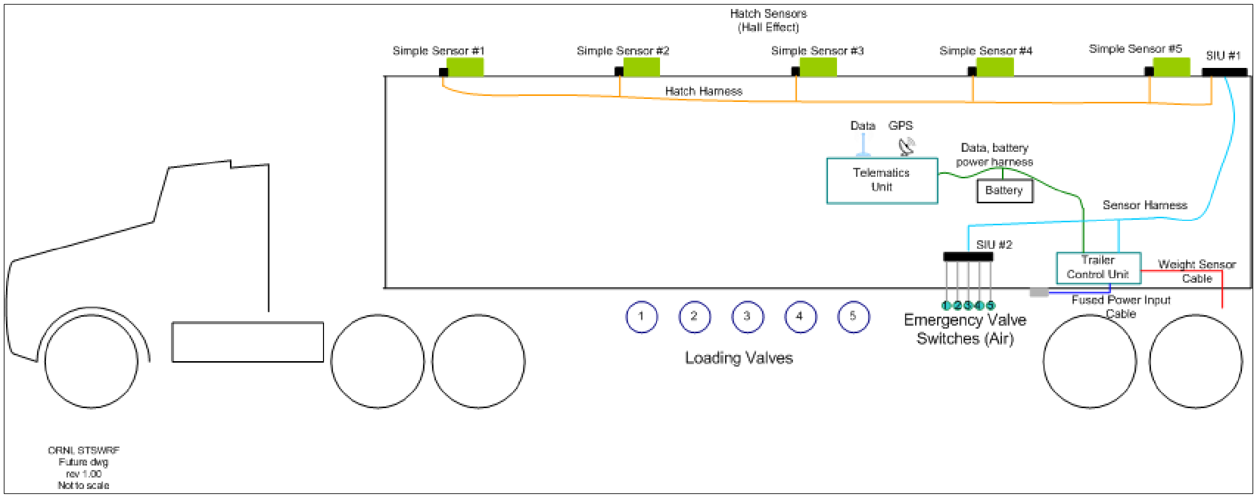

Figure 66. Air-Weigh simplified system.

Other proposed improvements include sensor interface units (one for the valves and one for the hatches), the use of pressure sensing switches and simplified hatch valve proximity switches, the hidden and inaccessible deployment of hatch sensors and targets in order to minimize tampering, the use of metal cable conduit (also to inhibit tampering), improvements in battery power, and the use of low power sensors.

Regarding the telematics sub-system, ISE proposed system improvements in three areas: (1) on-board and the back-office ERS, (2) on-board device/tanker system interaction, and (3) system security. With regard to the on-board and the back-office ERS, the use of automated tests would help to thoroughly and systematically debug the on-board and back-office software components. Also, the software applications developed for the pilot test should be enhanced to improve their robustness and efficiency. Similarly, the interactions between the on-board device and the Air-Weigh system should be made more robust. This could be done, for example, through the development of stricter communications protocols. Regarding system security, the sensors, as well as the communication among all the sub-systems should be made more difficult to defeat. The "commercial value" of systems that are more difficult to defeat should be evaluated to determine what levels of security should be implemented.

Other potential improvements include:

a. integration of the system developed in the pilot test with electronic BOL data in order to simplify the driver's data entry task;
b. more robust and expanded sets of error handling procedures; and
c. development of real-time carrier alerts through e-mail and/or text messages.

ISE also provided some additional recommendations including: (1) development of enhanced system trouble-shooting capabilities by integrating the ERS automated tests, (2) development of more documentation; and (3) increasing cross-discipline team integration through meetings and reviews for better information flows and more integrated problem-solving procedures.

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APPENDIX A: FUEL DISTRIBUTION AND OWNERSHIP

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BACKGROUND

During the review of the Safeguarding Truck-Shipped Wholesale and Retail Fuels (STSWRF) project, led by Oak Ridge National Laboratory, the topic arose as to entities who would be interested in the data collected during a vehicle's transport of motor fuel. Participants suggested that there would be a number of different scenarios that would involve several different entities and thus may affect what information is collected for the event.

In this paper, I would like to attempt to describe the various entities that may have ownership of the fuel, and/or have some reporting requirement on the State or Federal level reflecting the activity. While there may be some variances in the treatment of special events, such as waterborne movement of fuel, or the taxation of certain alternative fuels and/or blendstocks, I am going to concentrate on gasoline and special fuels (diesel, kerosene, and fuel oil). For the balance of this paper, I will use the term diesel to generically refer to special fuels. Based on the audience, I think it would just be more familiar. What is sold as fuel oil is not going to be taxed at the federal level, and the rules for kerosene are much like diesel.

We will start the different points of taxation on motor fuel. At the Federal level, the tax is imposed when the product leaves the bulk transfer/terminal system. This is referred to as tax at the rack. For our purposes here, we will consider that is when product leaves a bulk terminal. While there are other situations where the tax is imposed, I will keep it germane to our project. Thus, when the fuel is loaded into a vehicle at the bulk terminal, the federal tax is imposed. This applies to gasoline and diesel. When the diesel is to be used for off-road applications (agriculture, construction, etc.) a red dye is added and no tax is imposed. There are significant fines if the fuel is found in the propulsion tank of a vehicle on a highway.

A little more than half the States apply their fuel taxes at the rack. The other States have various points of taxation and are generally referred to as Distributor States. Depending on the fuel type, the taxes are imposed based on the license laws of that State. For Maryland, who is a distributor State, gasoline is taxed on the first sale in the State. For diesel, multiple transactions may be made by distributors (also called Sellers, Jobbers, and other names) before the tax is to be imposed. Most other distributor States have similar points of taxation.

ENTITIES

There are a number of parties involved in the sale and delivery of motor fuel and to complicate matters, there are different names used to describe entities with similar roles and responsibilities. The following is a partial list of entities that may have some interest in the data from this project. Later, I will explain in more detail the roles of the different entities. The definitions are taken from the Federation of Tax Administrators (FTA), Motor Fuel Tax Section Uniformity Guide.

Distributor

A person who transports motor fuel into a state (imports) or exports motor fuel out-of-state; or who is engaged in distribution of motor fuel primarily by tank car or tank truck, or both; and who operates a bulk plant where he has active motor fuel bulk storage (capacity may be specified by individual state). May also include a person who produces, refines, blends, compounds, or manufactures motor fuel. It does not, however, include a person who receives or transports into this state and sells or uses motor fuel under such circumstances as preclude the collection of the tax herein imposed, by reason of the provisions of the Constitution and Statutes of the United States. However, a person operating a motor vehicle into the state, may transport motor fuel in the ordinary fuel tank attached to the motor fuel vehicle, and use the fuel for the operation of the motor vehicle, without being considered a distributor.

Elective Supplier
A supplier that is required to be licensed in the destination state and agrees/elects to collect and remit motor fuel tax to the destination state on accountable product/motor fuel imported to the destination state.

Permissive Supplier
An out-of-state supplier, who is not an importer or exporter, that elects to collect and remit motor fuel tax to the destination state, but is not required to have a supplier's license in the destination state.

Position Holder
With respect to motor fuel in a terminal, the person that holds the inventory position of the motor fuel, as reflected on the records of the terminal operator. A person holds the inventory position when that person has a contractual agreement with the terminal operator for the use of storage facilities or terminaling services at a terminal with respect to the motor fuel. This also includes a terminal operator who owns motor fuel in their terminal.

Supplier
Any person required to collect and remit tax on accountable product/motor fuel removed from a terminal/refinery rack.

Terminal Operator
Any person that owns, operates, or otherwise controls a terminal.

That list was included to give an idea of the different parties involved in the transactions and while there may not be that many in every transaction, there could be several who would be interested in the movement of the product from the terminal to the final destination.

In short, fuel is introduced into a terminal (depending on the location, it may be by pipeline, vessel, train, or even truck) and the owner of the fuel is the position holder. There may be transactions (exchanges) that take place while the product has never moved. In the simple sales out of the terminal, the IRS (Internal Revenue Service Publication 510) provides an easy-to-understand definition:

> ***Removal from terminal***. *All removals of gasoline at a terminal rack are taxable. The position holder for that gasoline is liable for the tax.*

In the simplest case, the position holder is also the distributor. They will pay taxes (if a rack tax State, or at the Federal level) when the product leaves the terminal. However, you may have the position holder selling the product to another entity (such as a distributor) where the tax is still charged at the same place, but you have additional parties interested in the data that this project can produce. The entities might be the same in a distributor State, but the tax is paid in a later transaction (such as when the fuel is delivered to a retail service station).

Another entity may be the carrier. There are a shrinking number of companies who own their own transport vehicles and in many (I am thinking the vast majority now) cases, the carrier is just a common carrier who is contracted to move the fuel.

As for the bills of lading, they are not subject to any defined layout or inclusion of information. The FTA has struggled with trying to define what a bill of lading is and attempts have been made to try and make them uniform, but those efforts have not been successful to date. Ultimately, the shipping documents have some useful information, including the control number of the document itself. While the auditors would like to have this number along with the names of the shipper and customer we would likely have to select the information for the driver to capture in the tracking system with consideration of the amount of work involved.

INTERESTED PARTIES

With what I hope was an adequate description of the events and participants, I will try and list who would be interested in information that would be collected in the research project:

Table 26. Project Collected Information and Interested Parties

Entity	Information	Used For
Terminal Operator	Shipping documentation (Bill of Lading) control number	I can't imagine this happening much if ever, but this could be essentially a third-party resource in cases of questionable transactions.
Position Holder	Shipping Documentation Delivery Information Route Information Event Log	This would depend on the position holder's actions after the product leaves the terminal. If they are the distributor, they would want the delivery and route information along with the event log (valve opening and closing). If they simply are selling the product as it leaves the terminal, their role may be similar to the terminal operator.
Distributor	Shipping Documentation Delivery Information Route Information Event Log	This would probably be the entity with the biggest potential use of the information collected. It would help with information to verify terminal transactions and deliveries. If a customer states they have not received what was on the invoice, the distributor can examine the collected data for information on the transport of the fuel.
Customer	Delivery Information	If a customer is billed for an amount that they think is incorrect, this can be a way to track what was delivered.
Carrier	Shipping Documentation Delivery Information Route Information Event Log	At the Federal and State level, the carriers may have to file information returns on their activity. Also, there may be contractual language that places liability on product loss while under the control of the carrier, although another party owns the fuel.
Auditor	Shipping Documentation Delivery Information Route Information Event Log	Depending on which entity the auditor is looking at, they may be able to use the captured information to clarify points of sale, points of delivery and unreported transactions.

I am not sure if any of this would be considered an exhaustive list of the parties who are involved in any fuel sale/delivery transaction, or who could use the information produced by the on-board operations logging. Again, the purpose here was to try and give an explanation of the transaction flows, and to name some of the parties involved. Your input would be appreciated.

Michael Dougherty
May 6th, 2014

APPENDIX B: TELEMATICS DEVICE SCREENS

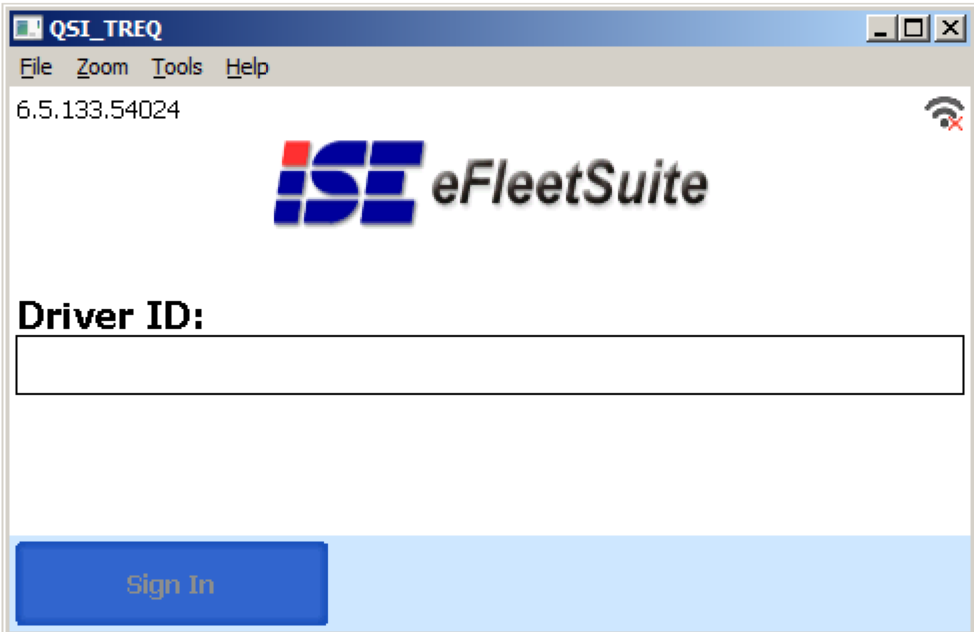

Figure 67. Telematics log on screen.

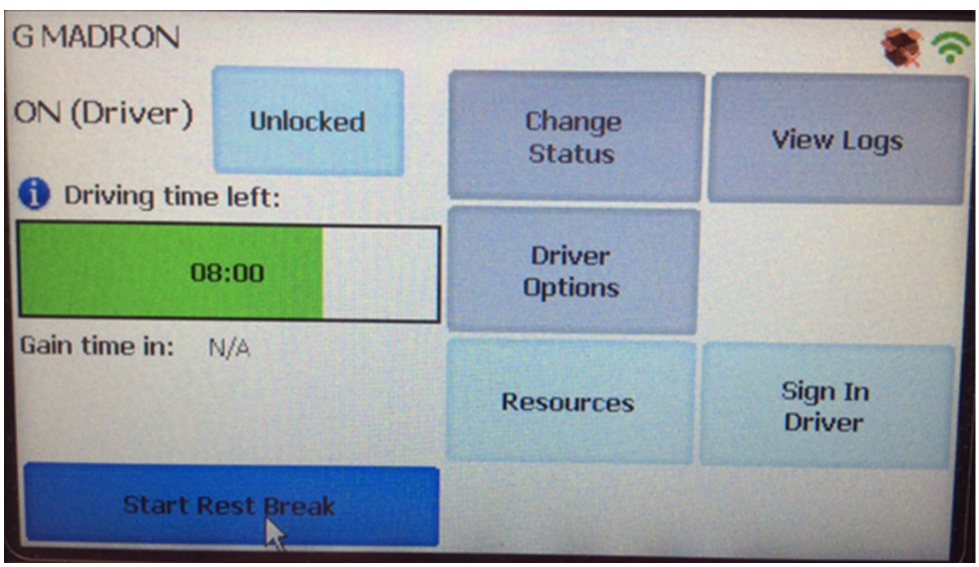

Figure 68. Telematics home page.

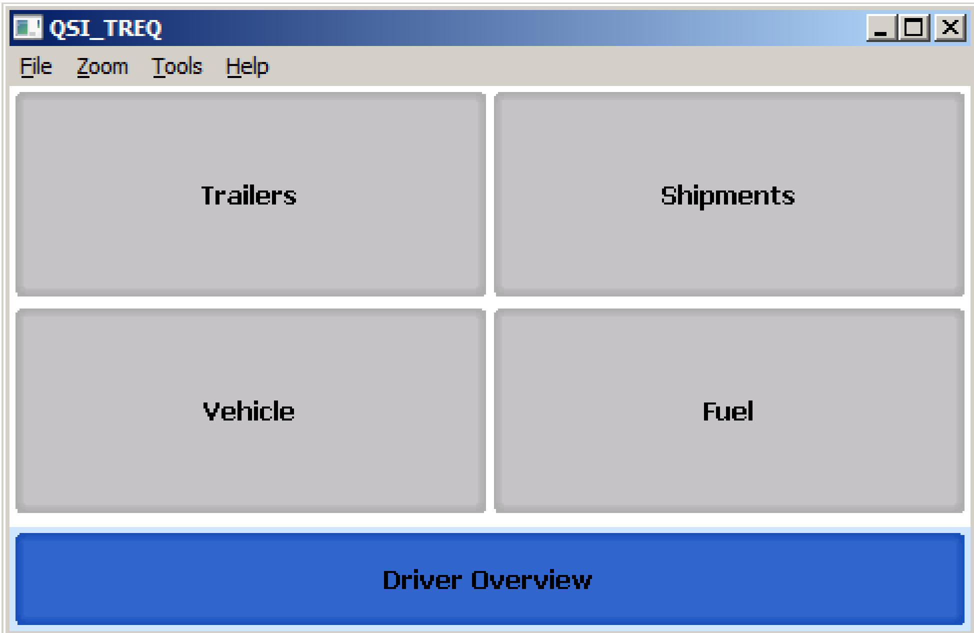

Figure 69. Telematics resources page, where fuel-type can be selected.

The majority of the telematics software used in this project was of commercial grade and already in existence. The Fuel tracking specific information was added for this project.

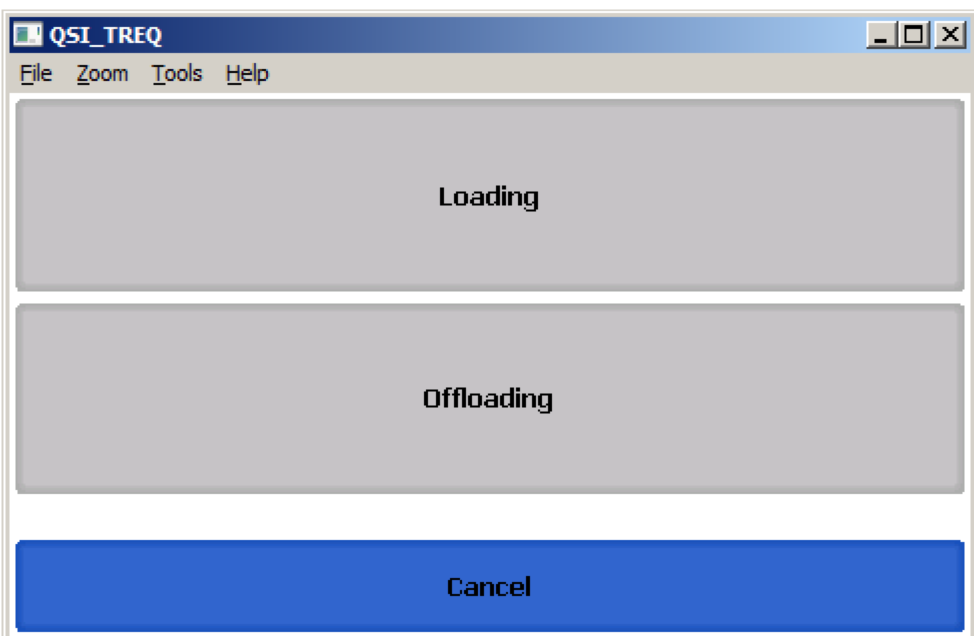

Figure 70. Telematics fuel page, where loading or offloading can be selected.

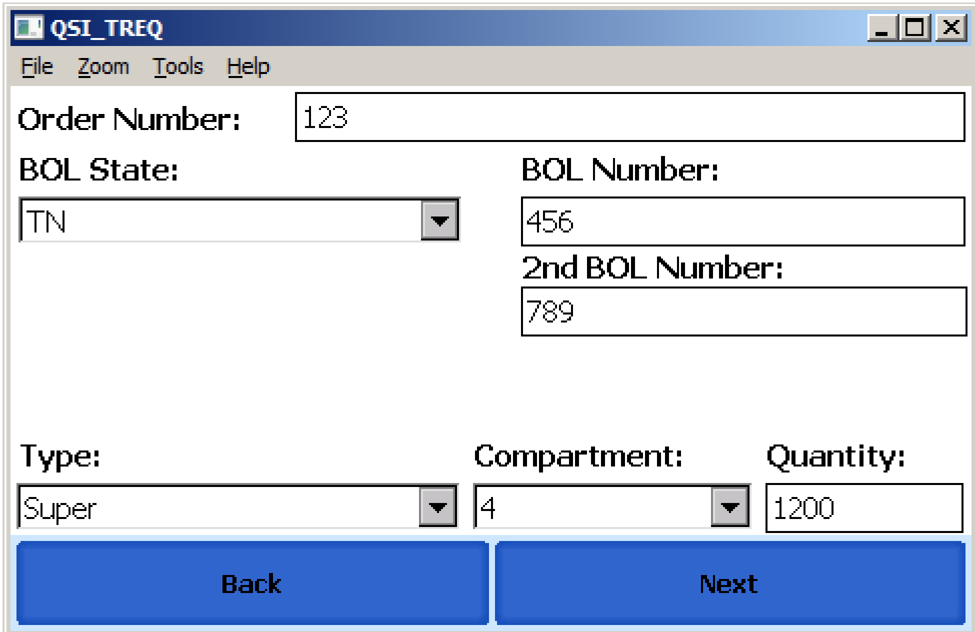

Figure 71. Telematics loading fuel screen.

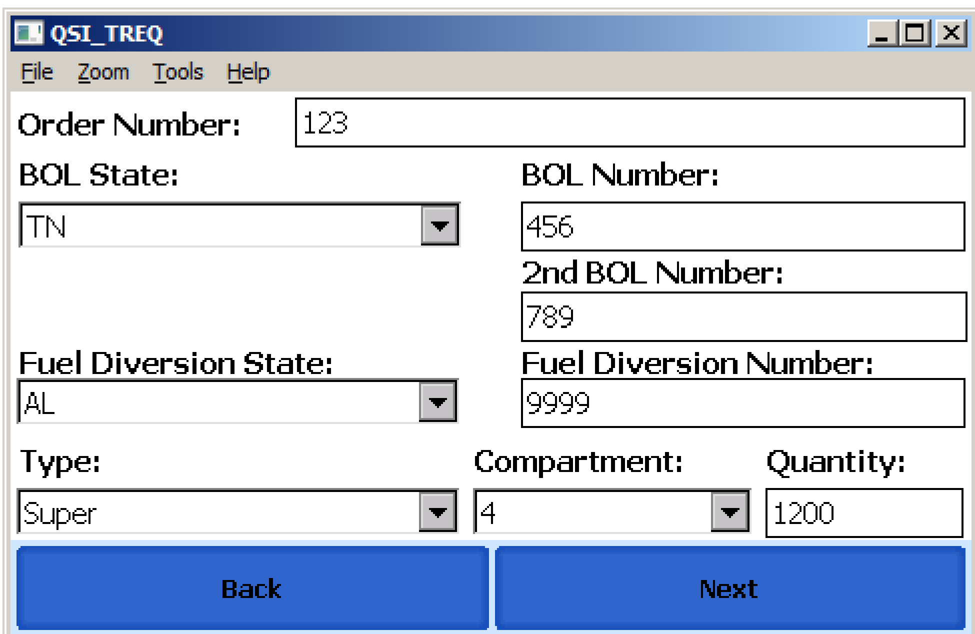

Figure 72. Telematics offloading fuel screen.

If the actual destination state is different from the state declared at loading, a driver can enter a fuel diversion state and number.

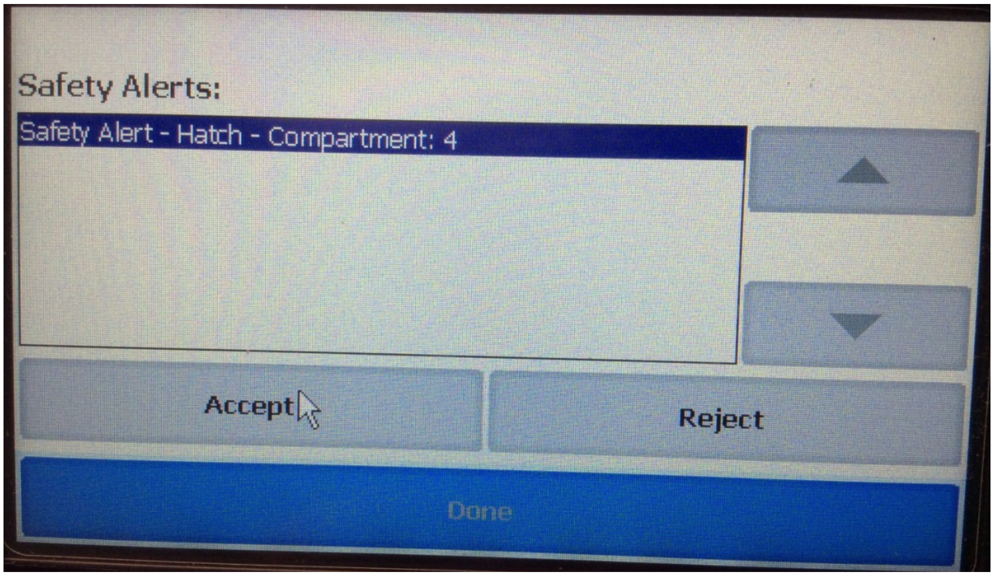

Figure 73. Telematics safety alert screen.

The driver cannot interact with the telematics device while the vehicle is in motion, but a safety alert can be conveyed via an audible beep and a red light on the display. When the vehicle comes to a stop, the driver can view more details about the safety alert. Figure 72 shows that the hatch for compartment 4 was open while the vehicle was moving.

APPENDIX C: OBERS APPLICATION PROGRAMMING INTERFACE (OBERS API)

Class Name: *Vehicle (Temporary Folder Name as String)*

Class Parameter			String	Name of the temporary file folder
Initialization Properties:	*OO_DD_DeltaTimeThreshold*	Public	Double	11: Open-Open or Disconnected-Disconnected Delta time threshold. Default 2.5 seconds.
	CC_CC_DeltaTimeThreshold	Public	Double	00: Close-Close or Connected-Connected Delta time threshold. Default 2.5 seconds.
	OC_DC_DeltaTimeThreshold	Public	Double	10: Open-Close or Disconnected-Connected Delta time threshold. Default 2.5 seconds.
	OO_DD_MaxNumberThreshold	Public	Integer	11: Open-Open or Disconnected-Disconnected Maximum number of occurrence threshold. Default 3 times and then the element is reported as malfunctioning.
	CC_CC_MaxNumberThreshold	Public	Integer	00: Close-Close or Connected-Connected Maximum number of occurrence threshold. Default 3 times and then the element is reported as malfunctioning.
	MaxFuelLogFileSize	Public	Integer	Maximum file size. Default = 16 KB.
	FuelLogFileFolder	Public	String	Fuel Log File Folder (on-board device). Default: \Storage Card\FuelLogs\
Properties:	*InMotion*	Public	Boolean	True if vehicle is in motion (vehicle speed > 5 mph)
	DateTime	Public	DateTime	Date and time of state change, in UTC
	Latitude	Public	Double	Latitude of state change (North: Positive). In decimal degrees.
	Longitude	Public	Double	Longitude of state change (West: Negative). In decimal degrees.
	GPSStatus	Public	Enum	0 = Valid GPS Reading; -1 = Bad Position Fix; -2 = Bad Horizontal Dilution of Precision (HDOP); -4 = Unknown Error
	Odometer	Public	Double	Odometer reading
	EquipmentCheck	Public	Boolean	Set to True at driver login and while initial check is on-going. Set to False after driver login and initial check has been concluded.
Methods:	*InitialCheck*	Public		Initial checking of valves and hatches
	VehicleMoves	Public		Triggered only if vehicle starts moving (speed > 5 mph)
Events:	*OnAlert*	Public		Event raised when an alarm is detected. It passes the Alarm object (Vehicle.Alarm)

Note: The Initialization Properties should be set before any other properties and before any method is called. Once a driver logs out, the initialization parameters can be changed and the changes will take effect from that time forward. If they are not changed, the current settings will be implemented.
Note 2: All the Initialization Properties have default values as indicated above. At driver logout, the initialization parameters will NOT reset to the default values, but will retain their current values.

SubClass: *Driver (Vehicle.Driver)*

Properties:	*ID*	Public	String	1 to 20 characters identifying the driver of the vehicle
	Notes	Public	String	1 to 250 characters with notes entered by driver

Methods:	*Login*	Public		Triggered when a driver logs in
	Logout	Public		Triggered when a driver logs out. Generates Fuel logs and sends a message to the telematics on-board device (TOBD) system so that log can be retrieved and upload to the TBOS

Events:	*OnLogFilesReady*	Public		Event raised when after driver has logged out. It passes the number of fuel log files as a short (may be more than one if the maximum file size as defined by the initialization parameters has been exceeded) and a string vector with the file(s) folder and name(s). **Note**: the file in position 0 in this vector should be discarded; it contains either a null or the name of a test file.

SubClass: *Tractor (Vehicle.Tractor)*

Properties:	*USDOTNo*	Public	Integer	US DOT Number (1 to 8 numbers)
	ID	Public	String	1 to 20 characters identifying the tractor of the vehicle
	SteerAxWt	Public	Integer	Steer axle weight at time of state change (-1 if NA)
	DriveAxWt	Public	Integer	Drive axle weight at time of state change (-1 if NA)

Methods:	*N/A*			

SubClass: *TractorDB (Vehicle.Tractor.TractorDB)*

Properties:	*State*	Public	Enum	0 or 1 (0= Connected, 1= Disconnected). If State = 1 (disconnected), then use last readings for Vehicle. Latitude, Vehicle.Longitude, Vehicle.Odometer

Methods:	*StateChange*	Public		The object has changed its state from connected to disconnected or from disconnected to connected.

SubClass: *Trailer (Vehicle.Trailer)*

Properties:

ID	Public	String	1 to 20 characters identifying the trailer of the vehicle
NumberofCompartments	Public	Short	1 to 5
TrailerAxWt	Public	Integer	Trailer axle weight at time of state change (-1 if NA)

Methods:

NewTrailer	Public		Triggered when a new trailer is connected to the tractor.

SubClass: *TrailerDB (Vehicle.Trailer.TrailerDB)*

Properties:

State	Public	Enum	0 or 1 (0= Connected, 1= Disconnected). If State = 1 (disconnected), then use last readings for Vehicle. Latitude, Vehicle.Longitude, Vehicle.Odometer

Methods:

StateChange	Public		The object has changed its state from connected to disconnected or from disconnected to connected.

SubClass: *Compartment (Vehicle.Trailer.Compartment)*

Properties:

ID	Public	SByte	Compartment ID 1 to n
FuelType	Public	Enum	Type of fuel: 0=Super, 1=Regular, 2=Midgrade, 3=Ethanol, 4=Propane, 5=ULSD, 6=DyedULSD, 7=Biodiesel, 8=Kerosene, 9=1ULD, 10=DEF, 11=Regular_Ethanol, 12=Premium_Ethanol, 13=Plus_Ethanol, 14=Regular_Premium..
FuelAmount	Public	Single	Amount of fuel in this compartment
FuelFlowDirection	Public	Enum	0=Loading; 1=Unloading
OrderNumber	Public	String	Order Number associated to this compartment if applicable. (1 to 20 Characters)
FirstBOLNumber	Public	String	Bill-of-Lading Number for the first BOL associated to this compartment if applicable. If only one BOL, associate it to Vehicle.Trailer.Compartment.ID=1. (1 to 20 Characters)
SecondBOLNumber	Public	String	Bill of Laden Number for the second BOLID associated to this compartment if applicable. (1 to 20 Characters)
ThirdBOLNumber	Public	String	Bill of Laden Number for the third BOLID associated to this compartment if applicable. (1 to 20 Characters)
BOLDestination	Public	Enum	Destination for BOLID = First (it is assumed that if there are BOLID = Second and Third, they will have the same destination as First). State Code = State two characters 0=AL (Alabama)… . 50=WY (Wyoming), 99=Undefined.
FuelDiversionNumber	Public	Integer	Fuel diversion number associated to this compartment (if any): 1 to 6 digit number. If only one BOL for the entire vehicle, associate it to Vehicle.Trailer.Compartment.ID=1
FuelDiversionDestination	Public	Enum	Fuel diversion destination associated to this compartment (if any). If only one BOL for the entire vehicle, associate it to Vehicle.Trailer.Compartment.ID=1. State Code = State two characters 0=AL (Alabama)… . 50=WY (Wyoming), 99=Undefined.

Methods:

FuelFlowing	Public		Triggered when driver enters information in the telematics on-board device regarding fuel being loaded to this compartment. All properties have to be set before calling this method.
FuelDiverted	Public		Triggered when driver enters information in TOBD indicating that fuel is being diverted away from its original destination.

SubClass: *Valve (Vehicle.Trailer.Compartment.Valve)*

Properties:

ID	Public	Enum	-1=secondary valve, 0=emergency valve, 1=primary valve
State	Public	Enum	0 or 1 (0=Closed, 1= Open)

Methods:

StateChange	Public		The object has changed its state.

SubClass: *Sensor (Vehicle.Trailer.Compartment.Valve.Sensor)*

Properties:

State	Public	Enum	0 or 1 (0= Connected, 1= Disconnected).

Methods:

StateChange	Public		The object has changed its state from connected to disconnected or from disconnected to connected.

SubClass: *Hatch (Vehicle.Trailer.Compartment.Hatch)*

Properties:

State	Public	Enum	0 or 1 (0=Closed, 1= Open)

Methods:

StateChange	Public		The object has changed its state.

SubClass: *Sensor (Vehicle.Trailer.Compartment.Hatch.Sensor)*

Properties:

State	Public	Enum	0 or 1 (0= Connected, 1= Disconnected).

Methods:

StateChange	Public		The object has changed its state from connected to disconnected or from disconnected to connected.

SubClass: *Alarm (Vehicle.Alarm)*

Properties:

Type	Public	Enum	-1=NA, 0="Safety", 1="Sensor", 2="Tampering", 3="Notification"
Trigger	Public	Enum	-1=NA, 0="Valve", 1="Valve Sensor", 2="Hatch", 3="Hatch Sensor", 4= "TractorDB", 5="TrailerDB"
TriggerID	Public	Short	Compartment Number * 10 + Element ID: 0 for emergency valves, emergency valve sensors, hatches, hatch sensors, tractor DB and trailer DB, 1 for primary valves and primary valve sensors, 2 for secondary valves and secondary valve sensors.
TriggerDate	Public	DateTime	Date and time when alarm was triggered, in UTC.
ResetDate	Public	DateTime	Date and time when alarm was reset, in UTC
ID	Public	Integer	A sequential number that is assigned by the ERS to identify a particular alarm.
AcknowledgedBy	Public	Enum	0=Driver, 1=Co-Driver, 2=Dispatcher, 3=Mechanic, 4=Other

Methods:

AlarmReset	Public		This event is triggered when the driver resets the alarm through the TOBD.

Table 27. Property-Method Dependencies

			METHODS														
			Vehicle			Driver		TractorDB	Trailer	TrailerDB	Compartment		Valve	ValveSensor	Hatch	HatchSensor	Alarms
				InitialCheck	VehicleMoves	Login	Logout	StateChange	NewTrailer	StateChange	FuelFlowing	FuelDiverted	StateChange	StateChange	StateChange	StateChange	AlarmReset
OBJECTS	**Vehicle**	OO_DD_DeltaTimeThreshold	✓														
		CC_CC_DeltaTimeThreshold	✓														
		OC_DC_DeltaTimeThreshold	✓														
		OO_DD_MaxNumberThreshold	✓														
		CC_CC_MaxNumberThreshold	✓														
		MaxFuelLogFileSize	✓														
		FuelLogFileFolder	✓														
	Vehicle	InMotion		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Date		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Latitude		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Longitude		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		GPSStatus		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Odometer		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		EquipmentCheck		✓													
	Driver	ID				✓											
		Notes				✓											
	Tractor	USDOTNo				✓											
		ID				✓											
		SteerAxWt				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		DriveAxWt				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	TractorDB	State						✓									
	Trailer	ID				✓			✓								
		NumberofCompartments				✓			✓								
		TrailerAxWt				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	TrailerDB	State								✓							
	Compartment	ID									✓	✓					
		FuelType									✓						
		FuelAmount									✓						
		FuelFlowDirection									✓						
		OrderNumber									✓	✓					
		FirstBOLNumber									✓	✓					
		SecondBOLNumber									✓	✓					
		ThirdBOLNumber									✓	✓					
		BOLDestination									✓	✓					
		FuelDiversionNumber										✓					
		FuelDiversionDestination										✓					
	Valve	ID											✓				
		State											✓				
	Valve.Sensor	ID												✓			
		State												✓			
	Hatch	State													✓		
	Hatch.Sensor	State														✓	
	Alarms	ResetDate															✓
		ID															✓
		AcknowledgedBy															✓

Note 1: All of the Initialization Properties have default values.
Note 2: Driver properties may be set at the time of driver logout, but it is not a requirement.

SETTING OBERS PROPERTIES AND CALLING OBERS METHODS

This section presents examples that illustrate the procedures to set the properties of the obERS dll and call its methods when different events occur. Each property should be set using the data type indicated in the previous section. The Class declaration should include as a parameter the complete path of the folder where the application expects the temporary files to be stored.

Initial Check

For the initial check the following assumptions are made:

1. All of the valves are closed at driver log in. The telematics on-board device (TOBD) system checks that this is true. If not, then
    a. It sets the vehicle, compartment, and valve properties. For example:
       Vehicle.InMotion = False
       Vehicle.Date = 13112013 183455
       Vehicle.Laitude = 36.4589
       Vehicle.Longitude = -87.0589
       Vehicle.GPSStatus = ValidReading
       Vehicle.Odometer = 346013
       Vehicle.EquipmentCheck = True
    b. For each valve i that is open
       Vehicle.Trailer.Compartment.ID = i
       Vehicle.Trailer.Compartment.Valve.ID = Emergency
       Vehicle.Trailer.Compartment.Valve.State = Open
       Calls the Vehicle.InitialCheck method

2. All of the hatches are closed at driver log in. The TOBD system checks that this is true. If not, then
    a. For each hatch i that is open
       Vehicle.Trailer.Compartment.ID = i
       Vehicle.Trailer.Compartment.Hatch.State = Open
       Calls the Vehicle.InitialCheck method

3. All of the valve sensors are connected at driver log in. The TOBD system checks that this is true. If not, then
    a. For each valve sensor i that is disconnected
       Vehicle.Trailer.Compartment.ID = i
       Vehicle.Trailer.Compartment.Valve.ID = Primary
       Vehicle.Trailer.Compartment.Valve.Sensor.State = Disconnected
       Calls the Vehicle.InitialCheck method

4. All of the hatch sensors are connected at driver log in. The TOBD system checks that this is true. If not, then
    a. For each hatch sensor i that is disconnected
       Vehicle.Trailer.Compartment.ID = i
       Vehicle.Trailer.Compartment.Hatch.Sensor.State = Disconnected
       Calls the Vehicle.InitialCheck method

5. The tractor databus is connected and available at driver log in. The TOBD system checks that this is true. If not,
    Vehicle.Tractor.TractorDB.State = Disconnected
    Calls the Vehicle.InitialCheck method

6. The trailer databus is connected and available at driver log in. The TOBD system checks that this is true. If not, then
    Vehicle.Trailer.TrailerDB.State = Disconnected
    Calls the Vehicle.InitialCheck method

Note: It is not necessary to set one property at a time and call the Vehicle.InitialCheck method. For example, if compartment *j* hatch is open and the sensor for the primary valve of compartment *j* is disconnected, then both State properties for these elements can be set at the same time, and only one call to the Vehicle.InitialCheck method is made (i.e., the Vehicle.InitialCheck method checks all of the elements that can have a state change). However, if the primary and emergency valves for compartment *j* are open, then two calls must be made to the Vehicle.InitialCheck method since only one Vehicle.Trailer.Compartment.Valve.ID property can be set each time the method is called.

Driver Login

At Driver Login the TOBD system should set the following properties (Note: after the initial checking, events such as Driver Login, valve and hatch change state, sensor disconnect, and other events should have the Vehicle.EquipmentCheck property set to false):

Vehicle.InMotion = False
Vehicle.Date = 13112013 183456
Vehicle.Laitude = 36.4589
Vehicle.Longitude = -87.0589
Vehicle.GPSStatus = ValidReading
Vehicle.Odometer = 346013
Vehicle.EquipmentCheck = False
Vehicle.Driver.ID = JDOE5534
Vehicle.Driver.Notes = "Some text entered by the driver to describe some fuel loading/unloading situation"
Vehicle.Tractor.USDOTNo = 5679002
Vehicle.Tractor.ID = 14235
Vehicle.Tractor.SteerAxWt = 9240
Vehicle.Tractor.DriveAxWt = 10237
Vehicle.Trailer.ID = T02
Vehicle.Trailer.NumberofCompartments = 4
Vehicle.Trailer.TrailerAxWt = 9871
Calls the Vehicle.Driver.Login method

Note: highlighted properties above need only be set at driver login. For Vehicle.EquipmentCheck, please refer to **Initial Check** above.

Fuel loaded to a compartment (Assumes trailer databus information is available while loading)

This example assumes the opening of the emergency valve of compartment 2 after the driver has indicated to the TOBD system that he/she is loading 2,100 gallons of diesel (i.e., ULSD) fuel to compartment 2, with a 4589-JFLY BOL number and a destination to Tennessee. The TOBD system will provide the following information:

Vehicle.InMotion = False
Vehicle.Date = 13112013 204511
Vehicle.Laitude = 36.5590
Vehicle.Longitude = -87.4452
Vehicle.GPSStatus = ValidReading
Vehicle.Odometer = 346102

Vehicle.Tractor.SteerAxWt = 9242
Vehicle.Tractor.DriveAxWt = 10239
Vehicle.Trailer.TrailerAxWt = 9869

Vehicle.Trailer.Compartment.ID = 2
Vehicle.Trailer.Compartment.FuelType = ULSD
Vehicle.Trailer.Compartment.FuelAmount = 2100
Vehicle.Trailer.Compartment.FuelFlowDirection = Loading
Vehicle.Trailer.Compartment.BOL = 4589-JFLY
Vehicle.Trailer.Compartment.BOLDestination = TN

Vehicle.Trailer.Compartment.Valve.ID = Emergency
Vehicle.Trailer.Compartment.Valve.State = Open

Calls the Vehicle.Trailer.Compartment.FuelFlowing method
Calls the Vehicle.Trailer.Compartment.Valve.StateChange method

Note: highlighted properties above need only to be set (and the method called) when the driver indicates that fuel is being loaded (or unloaded).

Opening of the primary valve for compartment 2 at the same location and 3 seconds later (slight change in axle-weight readings):

Vehicle.InMotion = False
Vehicle.Date = 13112013 204514
Vehicle.Laitude = 36.5590
Vehicle.Longitude = -87.4452
Vehicle.GPSStatus = ValidReading
Vehicle.Odometer = 346102

Vehicle.Tractor.SteerAxWt = 9241
Vehicle.Tractor.DriveAxWt = 10238
Vehicle.Trailer.TrailerAxWt = 9871

Vehicle.Trailer.Compartment.ID = 2

Vehicle.Trailer.Compartment.Valve.ID = Primary
Vehicle.Trailer.Compartment.Valve.State = Open

Calls the Vehicle.Trailer.Compartment.Valve.StateChange method

Closing of the primary valve for compartment 2 at the same location and 9 minutes 22 seconds later (significant change in axle-weight readings):

Vehicle.InMotion = False
Vehicle.Date = 13112013 205436
Vehicle.Laitude = 36.5590
Vehicle.Longitude = -87.4452
Vehicle.GPSStatus = ValidReading
Vehicle.Odometer = 346102

Vehicle.Tractor.SteerAxWt = 10699
Vehicle.Tractor.DriveAxWt = 18986
Vehicle.Trailer.TrailerAxWt = 14245

Vehicle.Trailer.Compartment.ID = 2

Vehicle.Trailer.Compartment.Valve.ID = Primary
Vehicle.Trailer.Compartment.Valve.State = Closed

Calls the Vehicle.Trailer.Compartment.Valve.StateChange method

Fuel unloaded at a drop location (Assumes the trailer databus information is available while unloading)

This example assumes the opening of the primary valve of compartment 3 after the driver has indicated to the TOBD system that he/she is unloading 1,900 gallons of regular gasoline from compartment 3. The TOBD system will provide the following information:

Vehicle.InMotion = False
Vehicle.Date = 13112013 215109
Vehicle.Laitude = 36.0902
Vehicle.Longitude = -87.1423
Vehicle.GPSStatus = ValidReading
Vehicle.Odometer = 346159

Vehicle.Tractor.SteerAxWt = 11242
Vehicle.Tractor.DriveAxWt = 30291
Vehicle.Trailer.TrailerAxWt = 29069

Vehicle.Trailer.Compartment.ID = 3
Vehicle.Trailer.Compartment.FuelType = Regular

Vehicle.Trailer.Compartment.FuelAmount = 1900
Vehicle.Trailer.Compartment.FuelFlowDirection = Unloading

Vehicle.Trailer.Compartment.Valve.ID = Primary
Vehicle.Trailer.Compartment.Valve.State = Open

Calls the Vehicle.Trailer.Compartment.FuelFlowing method
Calls the Vehicle.Trailer.Compartment.Valve.StateChange method

Note: Highlighted properties above need to be set (and the method called) when the driver indicates that fuel is being loaded (or unloaded). The FuelType and FuelAmount may not be specified if it is the same as when it was loaded (to be discussed, in relationship to additives and other added products).

Opening of the emergency valve for compartment 3 at the same location and 10 seconds later (slight change in axle-weight readings):

Vehicle.InMotion = False
Vehicle.Date = 13112013 215119
Vehicle.Laitude = 36.0902
Vehicle.Longitude = -87.1423
Vehicle.GPSStatus = ValidReading
Vehicle.Odometer = 346159

Vehicle.Tractor.SteerAxWt = 11240
Vehicle.Tractor.DriveAxWt = 30294
Vehicle.Trailer.TrailerAxWt = 29064

Vehicle.Trailer.Compartment.ID = 3

Vehicle.Trailer.Compartment.Valve.ID = Emergency
Vehicle.Trailer.Compartment.Valve.State = Open

Calls the Vehicle.Trailer.Compartment.Valve.StateChange method

Opening of a hatch (Assumes the trailer databus information is available while the hatch is being opened)

The vehicle is parked and the hatch for compartment 1 is opened. The TOBD system will provide the following information:

Vehicle.InMotion = False
Vehicle.Date = 14112013 060923
Vehicle.Laitude = 35.3932
Vehicle.Longitude = -87.4113
Vehicle.GPSStatus = ValidReading
Vehicle.Odometer = 346492

Vehicle.Tractor.SteerAxWt = 10432
Vehicle.Tractor.DriveAxWt = 23911
Vehicle.Trailer.TrailerAxWt = 22193

Vehicle.Trailer.Compartment.ID = 1

Vehicle.Trailer.Compartment.Hatch.State = Open

Calls the Vehicle.Trailer.Compartment.Hatch.StateChange method

When the Vehicle.Trailer.Compartment.Hatch.StateChange method is called, this method will determine that an alarm has been triggered and it will set the following properties:

Vehicle.Alarm.Type = Tampering
Vehicle.Alarm.Trigger = Hatch
Vehicle.Alarm.TriggerID = 10
Vehicle.Alarm.TriggerDate = 14112013 060923
Vehicle.Alarm.ID = 23

Following this, the Vehicle.OnAlert event will be raised and the alarm object passed as parameter. The TOBD system will then access the properties of the alarm object to determine how to proceed (in this case, it will find that it was a tampering alarm due to the opening of the compartment 1 hatch). Once the dispatcher or driver or another actor has taken some action regarding this alarm, the TOBD system will provide the following information:

Vehicle.Alarm.ID = 23
Vehicle.Alarm.ResetDate = 14112013 061639
Vehicle.Alarm.AcknowledgedBy = Dispatcher
Calls the Vehicle.Alarm.AlarmReset method

Fuel loaded to a compartment (Assumes the trailer databus information is NOT available while loading)

This example assumes that the opening of the emergency valve of compartment 2 occurred while the engine was turned off, and the message is received by the OBTD when the ignition key is in the on position again.

Vehicle.InMotion = False
Vehicle.Date = 13112013 204511 (Information passed by AirWeigh or computed by ISE)
Vehicle.Laitude = 36.5590 (First reading after ignition key is turned on)
Vehicle.Longitude = -87.4452 (First reading after ignition key is turned on)
Vehicle.GPSStatus = ValidReading (First reading after ignition key is turned on)
Vehicle.Odometer = 346102 (First reading after ignition key is turned on)

Vehicle.Tractor.SteerAxWt = 9242 (Information passed by AirWeigh to ISE[8])
Vehicle.Tractor.DriveAxWt = 10239 (Information passed by AirWeigh to ISE[1])
Vehicle.Trailer.TrailerAxWt = 9869 (Information passed by AirWeigh to ISE)
Vehicle.Trailer.Compartment.ID = 2 (Information passed by AirWeigh or computed by ISE)
Vehicle.Trailer.Compartment.Valve.ID = Emergency (Information passed by AirWeigh)
Vehicle.Trailer.Compartment.Valve.State = Open (Information passed by AirWeigh)
Calls the Vehicle.Trailer.Compartment.Valve.StateChange method
Vehicle.InMotion = False
Vehicle.Date = 13112013 204514 (Information passed by AirWeigh)
Vehicle.Laitude = 36.5590 (First reading after ignition key is turned on)
Vehicle.Longitude = -87.4452 (First reading after ignition key is turned on)
Vehicle.GPSStatus = ValidReading (First reading after ignition key is turned on)
Vehicle.Odometer = 346102 (First reading after ignition key is turned on)

Vehicle.Tractor.SteerAxWt = 10699 (Information passed by AirWeigh to ISE[9])
Vehicle.Tractor.DriveAxWt = 18986 (Information passed by AirWeigh to ISE[2])
Vehicle.Trailer.TrailerAxWt = 14245 (Information passed by AirWeigh to ISE)

Vehicle.Trailer.Compartment.ID = 2 (Information passed by AirWeigh)
Vehicle.Trailer.Compartment.Valve.ID = Primary (Information passed by AirWeigh)
Vehicle.Trailer.Compartment.Valve.State = Open (Information passed by AirWeigh)

Calls the Vehicle.Trailer.Compartment.Valve.StateChange method

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[8] Need to determine if AirWeigh will be providing tractor weight information while engine is off.
[9] Need to determine if AirWeigh will be providing tractor weight information while engine is off.

And for the valve closing messages:

Vehicle.Date = 13112013 205436 (Information passed by AirWeigh)
Vehicle.Tractor.SteerAxWt = 10699 (Information passed by AirWeigh to ISE[2])
Vehicle.Tractor.DriveAxWt = 18986 (Information passed by AirWeigh to ISE[2])
Vehicle.Trailer.TrailerAxWt = 14245 (Information passed by AirWeigh to ISE)

Vehicle.Trailer.Compartment.ID = 2 (Information passed by AirWeigh)
Vehicle.Trailer.Compartment.Valve.ID = Primary (Information passed by AirWeigh)
Vehicle.Trailer.Compartment.Valve.State = Closed (Information passed by AirWeigh)
Calls the Vehicle.Trailer.Compartment.Valve.StateChange method

Vehicle.Date = 13112013 205503 (Information passed by AirWeigh)
Vehicle.Tractor.SteerAxWt = 10699 (Information passed by AirWeigh to ISE[2])
Vehicle.Tractor.DriveAxWt = 18986 (Information passed by AirWeigh to ISE[2])
Vehicle.Trailer.TrailerAxWt = 14245 (Information passed by AirWeigh to ISE)
Vehicle.Trailer.Compartment.ID = 2 (Information passed by AirWeigh)
Vehicle.Trailer.Compartment.Valve.ID = Emergency (Information passed by AirWeigh)
Vehicle.Trailer.Compartment.Valve.State = Closed (Information passed by AirWeigh)

Calls the Vehicle.Trailer.Compartment.Valve.StateChange method

Subsequently, when the driver enters information using the obTD regarding this fuel loading event (e.g., the driver indicates that he/she has loaded 2,100 gallons of diesel fuel, i.e., ULSD, to compartment 2, with a 4589-JFLY BOL number and a destination to Tennessee), the TOBD system will provide the following information to the obERS:

Vehicle.InMotion = False
Vehicle.Date = 13112013 205738
Vehicle.Laitude = 36.5590
Vehicle.Longitude = -87.4452
Vehicle.GPSStatus = ValidReading
Vehicle.Odometer = 346102

Vehicle.Trailer.Compartment.ID = 2
Vehicle.Trailer.Compartment.FuelType = ULSD
Vehicle.Trailer.Compartment.FuelAmount = 2100
Vehicle.Trailer.Compartment.FuelFlowDirection = Loading
Vehicle.Trailer.Compartment.BOL = 4589-JFLY
Vehicle.Trailer.Compartment.BOLDestination = TN

Calls the Vehicle.Trailer.Compartment.FuelFlowing method

Note 1: highlighted properties above need only to be set (and the method called) when the driver indicates that fuel is being loaded (or unloaded).
Note 2: The same procedure described here will be implemented for fuel unloading and hatch opening as well as any other event that may occur while the engine is off and the trailer databus is not available.

Driver Logout

When the driver logs out, the TOBD system should set the following properties:

Vehicle.InMotion = False
Vehicle.Date = 14112013 183026
Vehicle.Laitude = 36.4588
Vehicle.Longitude = -87.0587
Vehicle.GPSStatus = ValidReading
Vehicle.Odometer = 346593

Vehicle.Driver.ID = JDOE5534

Vehicle.Tractor.USDOTNo = 5679002

Vehicle.Tractor.ID = 14235
Vehicle.Tractor.SteerAxWt = 9267
Vehicle.Tractor.DriveAxWt = 10270
Vehicle.Trailer.ID = T02
Vehicle.Trailer.TrailerAxWt = 9791
Calls the Vehicle.Driver.Logout method

Note: highlighted properties above were set at the time of driver login; however, at driver logout the TOBD system should set them again as a way of crosschecking.

The Vehicle.Driver.Logout method will generate the fuel-log file(s). Depending on the size of the fuel-log information collected, one or more files will be created by the obERS. After these files are created, the Vehicle.Driver.OnLogFilesReady event will be raised and the number of available fuel-log files for this driver, as well as a vector with the names of these files, will be passed as parameters to the TOBD system for uploading to the TBOS. Once the TOBD system determines that the fuel-log file(s) has (have) been uploaded, it will delete the file(s).

Note: all methods return a Boolean = True if successful and = False if unsuccessful.

Fuel-log File

The Fuel-log file will contain the following information:

File Name:
Starts with “FL”, then Driver ID, Carrier ID (US DOT Number), Tractor ID, and Log in Date and Time.

Format:

The fuel-log file will be a comma separated values file, with a first record containing the header with the names of the different fields, followed with a number of records containing data. Data types, units and field names are shown in Table 28:

Table 28. Fuel-log File Fields

Field Name	Units	Type
Record No	N/A	Int
Event Type	N/A	Int
In Motion?	N/A	Boolean
Date	ddmmyyy-hhmmss	DateTime
Latitude	deg	Int
Longitude	deg	Int
GPS Status	N/A	Int
Odometer	miles	Single
Driver ID	N/A	Char
Driver Notes	N/A	Char
US DOT No	N/A	Int
Tractor ID	N/A	Char
Steer Ax Wt	lb	Long
Drive Ax Wt	lb	Long
TrkDBState	N/A	Int
Trailer ID	N/A	Char
No Cmprtmnts	N/A	Int
Trailer Ax Wt	lb	Long
TrlDBState	N/A	Int
Comp ID	N/A	Int
FType	N/A	Char
FAmount	gal	Single
FFlow Dir	N/A	Int
Order No	N/A	Char
1st BOL No	N/A	Char
2nd BOL No	N/A	Char
3rd BOL No	N/A	Char
BOL Dest	N/A	Char
F Diver No	N/A	Char
F Diver Dest	N/A	Int
V State V0	N/A	Int
VS State V0	N/A	Int
V State V1	N/A	Int
VS State V1	N/A	Int
V State V2	N/A	Int
VS State V2	N/A	Int
H State	N/A	Int
HS State	N/A	Int

Field Name	Units	Type
Rec Has Alarm?	N/A	Boolean
Alarm Count	N/A	Int
Alarm ID1	N/A	Int
A Type A1	N/A	Int
A Trigger A1	N/A	Int
A Trigger ID A1	N/A	Int
A Trigger Date A1	ddmmyyy-hhmmss	DateTime
A Reset Date A1	ddmmyyy-hhmmss	DateTime
A Acknowledged By A1	N/A	Int
A Submitted 2OBD A1	N/A	Boolean
Alarm ID2	N/A	Int
A Type A2	N/A	Int
A Trigger A2	N/A	Int
A Trigger ID A2	N/A	Int
A Trigger Date A2	ddmmyyy-hhmmss	DateTime
A Reset Date A2	ddmmyyy-hhmmss	DateTime
A Acknowledged By A2	N/A	Int
A Submitted 2OBD A2	N/A	Boolean
Alarm ID3	N/A	Int
A Type A3	N/A	Int
A Trigger A3	N/A	Int
A Trigger ID A3	N/A	Int
A Trigger Date A3	ddmmyyy-hhmmss	DateTime
A Reset Date A3	ddmmyyy-hhmmss	DateTime
A Acknowledged By A3	N/A	Int
A Submitted 2OBD A3	N/A	Boolean
Alarm ID4	N/A	Int
A Type A4	N/A	Int
A Trigger A4	N/A	Int
A Trigger ID A4	N/A	Int
A Trigger Date A4	ddmmyyy-hhmmss	DateTime
A Reset Date A4	ddmmyyy-hhmmss	DateTime
A Acknowledged By A4	N/A	Int
A Submitted 2OBD A4	N/A	Boolean
Alarm ID5	N/A	Int
A Type A5	N/A	Int
A Trigger A5	N/A	Int
A Trigger ID A5	N/A	Int
A Trigger Date A5	ddmmyyy-hhmmss	DateTime

Field Name	Units	Type
A Reset Date A5	ddmmyyy-hhmmss	DateTime
A Acknowledged By A5	N/A	Int
A Submitted 2OBD A5	N/A	Boolean
Alarm ID6	N/A	Int
A Type A6	N/A	Int
A Trigger A6	N/A	Int
A Trigger ID A6	N/A	Int
A Trigger Date A6	ddmmyyy-hhmmss	DateTime
A Reset Date A6	ddmmyyy-hhmmss	DateTime
A Acknowledged By A6	N/A	Int
A Submitted 2OBD A6	N/A	Boolean
Rec Has Errors?	N/A	Boolean
Error Description(s)	N/A	Char

Note: The size of the fuel-log file is restricted to 10KB, so, if the information to be transmitted from the on-board system to the back-office system is larger than 10KB, several fuel-log files will be created.

APPENDIX D: VEHICLE DATABUS MESSAGES POSTED BY THE DEPLOYED SENSORS

STSWRF SAE J1939 Communications Specifications

Source Addresses

Tractor T2TCU

The J1939-81 NAME information that the Tractor T2TCU will use during address claim at power up is as follows:

Parameter	Value
Arbitrary Address Capable Field	1
Industry Group Field	0
Vehicle System Instance Field	0
Vehicle System Field	0
Reserved Field	0
Function Field	139
Function Instance Field	0
ECU Instance Field	0
Manufacturer Code Field	187
Identity Field	unit's serial number modulo 2,097,152 (=2^{21})

The T2TCU will initially attempt to claim a Source Address in the following order:

1. 180 through 247, i.e., first 180, or if not available 181, or if not available 182, etc. through 247.
2. If these addresses are not available, then 128, or if not available 129, etc. through 179.

Telematics Device

J1939-81 NAME information that the telematics device will use during address claim at power up is as follows:

NAME Field	Value	Notes
Arbitrary Address Capable	1	the mDash will need to negotiate for its source address, from a list of preferred source addresses
Industry Group	0	On-Highway Equipment
Vehicle System Instance	0	First instance
Vehicle System	0	Non-specific system
Reserved	0	
Function	130	On-board data logger
Function Instance	0	First instance
ECU Instance	0	First Instance
Manufacturer Code	582	582 = Innovative Software Engineering
Identity Number	mDash Serial Number - last 5 digits.	

Heartbeat Message

In accordance with J1939/73, the telematics device will generate the DM1 message at a rate of 1 Hz. The absence of this message for several seconds will indicate to the T2TCU that the data bus is no longer active and message buffering will begin (as described in the following sections). During this transition state (in which the engine is turned off), it is expected that about 5 seconds of sensor messages, beginning when the ignition is turned off, will be lost before buffering is initiated.

GPS Time and Date
Once every minute, the tractor-side T2TCU will request the Time/Date message (PGN 65254) from the telematics device. The telematics device will generate this message from the UTC date/time data available from the GPS or the TBOS (without accounting for the negligible propagation time). Local minute and hour offset data (SPNs 1601, 1602) does not need to be populated in this message. The T2TCU and sensors will use this GPS date and time in conjunction with its internal clock to generate the time and date portion of the sensor message (seconds, minute, hour, and day).

Date and time will be passed from the obTD to the T2TCU using the SAE J1939 PGN 65254, Time/Date. This contains SPN 959 Seconds, SPN 960 Minutes, SPN 961 Hours, SPN 962 Day, SPN 963 Month, SPN 964 Year, SPN 1601 Local minute offset, and SPN 1602 Local hour offset.

Trailer Sensor Message Format

The PS (PDU Specific Field) to be used in the Proprietary B messages will be 0; thus, the PGN will be 65280.

In keeping with J1939 standard, any unpopulated data space in this (or any other) message will be filled with “all F’s,” i.e., 255 decimal for each unpopulated byte, except where another value is specified in the J1939 standard.

Field	Possible values
Compartment Number	general trailer information
	compartment 1, closest to cab
	compartment 2
	compartment 3
	compartment 4
	compartment 5
Switch type	hatch
	emergency valve
	primary/passenger-side loading valve
	secondary/driver-side loading valve
	trailer axle group weight
Status code	closed
	open
	failed sensor or sensor error
	not available or not applicable
Trailer Axle Group Weight	similar to SAE J1939 SPN 409
UTC Seconds	similar to SAE J1939 SPN 959
UTC Minutes	similar to SAE J1939 SPN 960
UTC Hours	similar to SAE J1939 SPN 961
UTC Day	similar to SAE J1939 SPN 962

Trailer Sensor Message Frequency
When the tractor databus is active and the tractor and trailer are connected, status messages for each sensor will be sent at 1-second intervals such that all messages (one for each hatch or valve relayed

through the tanker T2TCU) will be posted to the databus by the tractor-side T2TCU over a period of 1 second.

When the tractor databus is inactive but the tractor and tanker are connected, the tanker and T2TCU will be connected to the vehicle battery and remain powered on for a minimum of one hour (up to three hours) after the ignition (and therefore tractor databus) is turned off. During this time, the T2TCU will buffer only those messages which indicate a status change (and only Proprietary B tanker weight messages associated with a hatch/valve status change), up to 100 messages or all the status change messages generated during the 1-3-hour period in which the tanker sensors are powered (whichever is smaller). These buffered messages will be sent by the tractor T2TCU upon tractor databus startup.

When the tractor databus becomes active, the tractor T2TCU will post the buffered messages to the tractor databus at a rate of approximately 20 Hz until all buffered messages have been sent (up to 5 seconds). Buffered messages will be sent with the Proprietary B tanker weight messages preceding their corresponding Proprietary B hatch/valve status messages. Current, real-time data will not be posted to the tractor data bus until all buffered messages have been sent. This may result in a loss of up to 5 seconds of real-time data once the telematics device is ready to accept data (depending on the number of buffered messages).

When the tanker is disconnected from the tractor, it will not be possible to power the tanker sensors or to generate any sensor messages. Should the databus be active during this disconnected state, the absence of any tanker sensor messages will serve as an indication that the tanker is disconnected.

Weight Data

Axle Group Weight
Vehicle weight messages will conform to the J1939/71 standard for PGN 64874, Axle Group Weight. As such, the telematics device will need to request this information when needed, so that it will, at a minimum, have the current weight readings when the vehicle is stopped before the ignition is turned off (where fuel may be loaded or offloaded) and soon after the ignition is turned on, before the vehicle begins moving. Relevant excerpts from the standard follow.

Available Axle Group Weight

In applications with tractors and one or more drop-and-hook tankers, the tractor transmits this message immediately after NAME claim. A similar sequence may occur with the STSWRF system or the tractor may be aware of the tanker so soon after broadcasting the NAME claim, or even earlier, that it will only transmit PGN 64875, Available Axle Group Weights, once.

Individual SPNs within this PGN listed all have similar format to that for the first SPN, SPN 4059 Steer Axle Group Weight Available.

PT Tanker-Specific Details
The tanker used for the pilot test was expected to have five compartments, each with a hatch, emergency valve, and primary valve. Thus, the total number of unique tanker sensor messages (including the tanker weight message) was 16.

APPENDIX E: BOERS APPLICATION PROGRAMMING INTERFACE

boERS API

The boERS dll has two properties, one method, and one event as shown in the table below. The initialization property DriverReportFolder should be set when the class is loaded (alternatively, this property can be an argument of the boERS class). Every time fuel-log files are transmitted from the vehicles to the back office (BO), the TBOS software shall set the FuelLogName property with uploaded filename(s) to be processed, and invoke the ProcessFuelLog method (alternatively, the FuelLogName could be a parameter of the ProcessFuelLog method).

When the boERS has generated a Driver Report, the OnDriverReportReady event will be raised and the carrier ID, driver ID and the name of the Driver Report file will be passed to the TBOS. Alternatively, another approach where no events are raised could be deployed. In this case the Driver Report is simply saved in the Driver Report folder. The telematics provider can check this folder at regular intervals, “distribute” to the corresponding carrier, and delete the file from that folder.

Class Name: *boERSProcessor(,)*

boERS Parameters:	*FuelLogFileFolder*	Public	String	The folder where the BO system expects the boERS application to save the Driver Report files.
	DriverReportFolder	Public	String	The folder where the BO system expects the boERS application to save the Driver Report files.
Properties:	*FuelLogName*	Public	String	A vector with the name(s) of the uploaded Fuel Log file(s) that needs to be processed.
	CarrierID	Public	Integer	Carrier US DOT Number
	NormalEventProbabilityThreshold	Public	Double	Probability of occurrence of an event that is considered normal. Default probability threshold = 0.75; any event with a computed probability of occurrence > 75% will be labeled a Normal Event.
	LikelyEventProbabilityThreshold	Public	Double	Probability of occurrence of an event that is considered likely to occur. Default probability threshold = 0.50; any event with a computed probability of occurrence between 50% and 75% will be labeled a Likely Event.
Carrier Parameters	*RareEventProbabilityThreshold*	Public	Double	Probability of occurrence of an event that is considered rare. Default probability threshold = 0.25; any event with a computed probability of occurrence between 25% and 50% will be labeled a Rare Event.
	UnlikelylEventProbabilityThreshold	Public	Double	Probability of occurrence of an event that is considered unlikely to occur. Default probability threshold = 0.05; any event with a computed probability of occurrence between 5% and 25% will be labeled an Unlikely Event. Any event with a computed probability of occurrence < 5% will be labeled a Very Unlikely Event. **Note:** The following conditions should be true for these parameters to be accepted:

			NormalEventProbabilityThreshold > LikelyEventProbabilityThreshold; LikelyEventProbabilityThreshold > RareEventProbabilityThreshold; RareEventProbabilityThreshold > UnlikelylEventProbabilityThreshold; UnlikelylEventProbabilityThreshold >0. If not, then the default values will be assigned.
Methods:	*ProcessFuelLogs(OrganizationKey)*	Public	Method invoked to process the list of fuel log files submitted through the *FuelLogName* property. Has as parameter the OrganizationKey, an integer.
	AddProbabilityOfOccurrenceParameters	Public	Method invoked to process override the default values of the thresholds of the probability of occurrence of events. Must set Carrier Parameters properties.
Events:	*OnDriverReportReady*		Passes the Carrier ID, Driver ID, and the name of the Driver Report file

Accessing TBOS Databases

Besides the fuel-log file, the boERS software needs the information (stored in TBOS databases) to determine:

1. Whether or not locations included in the event log file are in the Authorized Location Database (ALD);
2. The statistical parameters corresponding to probability distributions of valve and hatch dwell times, as well as valve opening sequences for the driver and vehicle indicated in the event log file. The probability distribution parameters include (all are for this carrier):
    a. This driver and this vehicle;
    b. This driver and all vehicles driven by this driver;
    c. All drivers that have driven this vehicle;
    d. All drivers and all vehicles;

The TBOS will implement a 'create, read, update and delete' procedure to allow the boERS component to use the four basic functions of persistent storage: create, read, update and delete information contained in the *Statistical Parameters* database (create, read, and update functions) and the *Authorized Fuel Load and Drop Spatial Locations* database (read function).

boERS Generated and Induced Reports

The boERS will generate one report: the Driver Report. This report will contain the driver loading and unloading activities, safety and other alerts, and any fuel event that is labeled "out of the ordinary." The report will also contain location information identifying places where fuel has been loaded/offloaded and places that are not already classified as permissible loading and unloading points. The report will also flag cases in which a Diversion Number is needed but has as yet not been provided. This Driver Report will be made available to the carrier through the carrier interface, and if there is missing information, the Carrier interface will attempt to collect it and update the Driver Report Database and/or Authorized Fuel

Load and Drop Spatial Location Database. Once the Driver Report has been revised, a subset of it will be saved in the FDAS database for uploading to the FDAS server at pre-specified intervals (once a week).

Note: The only database that the boERS software will update is the Statistical Parameters database with the information contained in the event logs (i.e., only one record of the Statistical Parameters database will be updated per fuel-log file; i.e., the one corresponding to the driver and vehicle identified in that fuel-log file).

Driver Report

The Driver Report will contain the following information:

Report Name:
Starts with "DR", then Log in Date and Time, Carrier ID (US DOT Number), Driver ID, Tractor ID, Trailer ID, Log out Date and Time

For each fuel-flowing event, valve openings without fuel-flowing event, hatch open event, and alerts:

Start Date, Start Time, Elapsed Time, Latitude, Longitude, State, Event Type, Type of Fuel, Fuel Volume (TD), Fuel Volume (ERS), BOL (for up to three BOLs), Diversion Number, Likelihood of Occurrence, Event Flag, Alarm Type, Alarm Trigger, Reset Time, and other flags as shown in Table 29.

Format:

The driver report will be a comma separated values file with the following fields and data types:

Table 29. Driver Report Fields

Field Name	Units	Type
Login Date and Time	ddmmyyy-hhmmss	DateTime
Organization ID	N/A	Char
Carrier ID (US DOT Number)	N/A	Int
Driver ID	N/A	Char
Tractor ID	N/A	Char
Trailer ID	N/A	Char
Log out Date and Time	ddmmyyy-hhmmss	DateTime
Event Type	N/A	Int
Event Short Description	N/A	Char
Event Long Description	N/A	Char
Compartment ID	N/A	Int
Order Number	N/A	Char
First BOL	N/A	Char
Second BOL	N/A	Char
Third BOL	N/A	Char
Destination State	N/A	Char
Event Start Date and Time	ddmmyyy-hhmmss	DateTime
Event End Date and Time	ddmmyyy-hhmmss	DateTime

Field Name	Units	Type
Type of Fuel BOL1	N/A	Char
Fuel Volume (TD) BOL1	gal	Single
Fuel Volume (ERS) BOL1 Note: depending on the availability of not of the trailer databus while loading or offloading fuel, this field may not be present	gal	Single
Type of Fuel BOL2	N/A	Char
Fuel Volume (TD) BOL2	gal	Single
Fuel Volume (ERS) BOL2 Note: depending on the availability of not of the trailer databus while loading or offloading fuel, this field may not be present	gal	Single
Type of Fuel BOL3	N/A	Char
Fuel Volume (TD) BOL3	gal	Single
Fuel Volume (ERS) BOL3 Note: depending on the availability of not of the trailer databus while loading or offloading fuel, this field may not be present	gal	Single
Steer Axle Delta Weight	lb	Long
Drive Axle Delta Weight	lb	Long
Trailer Axle Delta Weight	lb	Long
Fuel-flowing Elapsed Time	sec	Int
Event Latitude	deg	Int
Event Longitude	deg	Int
Event GPS Status	N/A	Int
Event Start Odometer	miles	Single
Event State	N/A	Int
Diversion Number	N/A	Char
Diversion State	N/A	Int
Valve Actuation Elapsed Time	sec	Single
Valve Actuation Sequence	N/A	Char
Likelihood of Occurrence (Dwell Time)	N/A	Single
Likelihood of Occurrence (Valve Operation Sequence)	N/A	Single
Flagged Record Based On Likelihood Of Occurrence	N/A	Boolean
Probability of Occurrence of Event	N/A	Single
Statistical Test Condition	N/A	Int
Number of Alarms at This Location	N/A	Int
Alarm Type	N/A	Char
Alarm Trigger	N/A	Int
Reset Date and Time	ddmmyyy-hhmmss	DateTime
Alarm Acknowledged by	N/A	Int
Location in Database	N/A	Boolean
Location Key	N/A	Long
Authorized Location	N/A	Boolean
Show on Location Report	N/A	Boolean
Diversion Number Missing	N/A	Boolean
BOL Number Mismatch	N/A	Boolean

Field Name	Units	Type
Amount of Fuel Mismatch	N/A	Boolean
Type of Fuel Mismatch	N/A	Boolean
FDAS Record	N/A	Boolean

Note 1: If the field "Event Location in Database" is False, then the TBOS should present the location(s) to the carrier to clarify whether this is an authorized location. The information should then be updated in the Driver Report database -if it is necessary to do so (note: this database is maintained by the TBOS). The same procedures should be applied if the Diversion Number is missing.

Note 2: If there is more than one alarm/alert associated with a fuel distribution event, then there will be repeated records with different information in the alarm fields. To avoid uploading the same record many times to the FDAS server, a flag will be included (i.e., the FDAS Record field; if False, then this record should not be uploaded to the FDAS server).

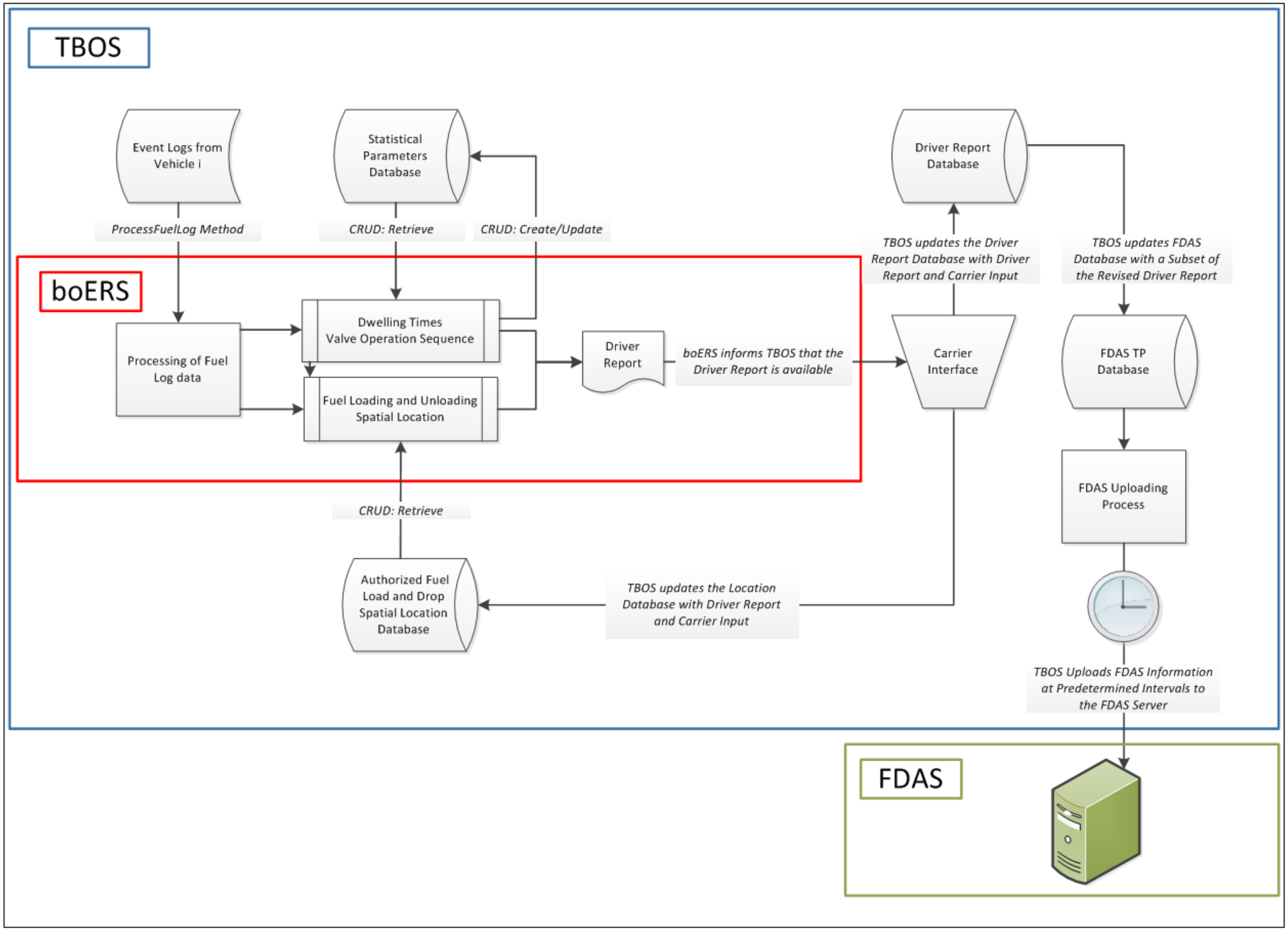


Figure 74. boERS Components and Interactions with the TBOS and FDAS.

File Name:
The name of the file will be composed by concatenating a report type identifier (DR in this case), the Login Date and Time, Carrier ID, and Driver ID: DR_ddmmyyy-hhmmss_12345678_driverID.csv.

Note:

- Some of the above information could be labeled N/A.
- The "Likelihood of Occurrence" field (for dwell times and valve sequence) will display the highest probability of occurrence of this event (compared to this driver and vehicle and other drivers and vehicle combinations within the company). The "Event Flag" field will rate the event as normal (greater than 75% probability of occurrence), likely (between 50% and 75%), rare (25% to 50%), unlikely (5% to 25%), very unlikely (less than 5% probability of occurrence). The rating will be based on the "Likelihood of Occurrence" information and the lower and upper boundaries of the ranges could be specified by the carrier (if this is the case, then a file with these ranges should be made available to the boERS by the TBOS). The flag will also contain a qualifier to describe the event which likelihood is being evaluated (i.e., dwell time or valve sequence; note: the latter may be irrelevant).
- Hatch issues will be captured by the Alarm Type and Alarm Trigger fields.

FDAS Report:
The FDSA report will be basically the same as the driver report, but with fewer fields. It will be extracted by the TBOS from the Driver Report Database and if necessary saved in a FDAS database (at the discretion of the telematics provider) before uploading the information to the FDAS server.

FDAS Fields:
The FDAS records will contain the fields shown in Table 30. Prior to being uploaded to the FDAS server, the FDAS records will be stored in a comma separated values file with the data types shown in the table (note: the units are shown for clarification purposes and do not need to be included in the csv file; a header with the names of the fields should be included in the csv file).

Table 30. FDAS Report Fields

Field Name	Units	Type
Carrier ID (US DOT Number)	N/A	Int
Carrier Name		Char
Tractor ID	N/A	Char
Trailer ID	N/A	Char
Event Type	N/A	Int
First BOL	N/A	Char
Second BOL	N/A	Char
Third BOL	N/A	Char
Destination State	N/A	Char
Event Start Date and Time	ddmmyyy-hhmmss	DateTime
Type of Fuel BOL1	N/A	Char
Fuel Volume (TD) BOL1	gal	Single
Type of Fuel BOL2	N/A	Char
Fuel Volume (TD) BOL2	gal	Single
Type of Fuel BOL3	N/A	Char

Field Name	Units	Type
Fuel Volume (TD) BOL3	gal	Single
Event Latitude	deg	Int
Event Longitude	deg	Int
Event GPS Status	N/A	Int
Event Start Odometer	miles	Single
Event State	N/A	Int
Diversion Number	N/A	Char
Diversion State	N/A	Int
Diversion Number Missing	N/A	Boolean
BOL Number Mismatch	N/A	Boolean
Amount of Fuel Mismatch	N/A	Boolean
Type of Fuel Mismatch	N/A	Boolean

File Name:
The name of the file will be composed by concatenating a report type identifier (FR in this case), the Date when the file is created, and the Carrier ID: FR_ddmmyyy _12345678.csv.

Uploading to the FDAS:
The FDAS reports will be combined into a single csv file that will be uploaded weekly through an FTP server (specific information for the FTP server TBD).

Statistical Parameters
Table 30 shows all the statistical parameters that will be maintained in a BO database within the TBOS.

Table 31. Probability Distribution Parameters

Org ID	Driver ID	Trailer ID	Com-part-ment ID	npl[1]	mpl[2]	sdpl[3]	npo[1]	mpo[2]	sdpo[3]	nsl[4]	ms[5]	sds[6]	nso[4]	ms[5]	sds[6]
O_o	D_d	T_t	1	n_{plodt1}	m_{pldt1}	sod_{plodt1}	n_{poodt1}	m_{poodt1}	sod_{poodt1}	n_{slodt1}	m_{slodt1}	sod_{slodt1}	n_{soodt1}	m_{soodt1}	sod_{soodt1}
O_o	D_d	T_t	2	n_{plodt2}	m_{pldt2}	sod_{plodt2}	n_{poodt2}	m_{poodt2}	sod_{poodt2}	n_{slodt2}	m_{slodt2}	sod_{slodt2}	n_{soodt2}	m_{soodt2}	sod_{soodt2}
O_o	D_d	T_t	3	n_{plodt3}	m_{pldt3}	sod_{plodt3}	n_{poodt3}	m_{poodt3}	sod_{poodt3}	n_{slodt3}	m_{slodt3}	sod_{slodt3}	n_{soodt3}	m_{soodt3}	sod_{soodt3}
O_o	D_d	T_t	4	n_{plodt4}	m_{pldt4}	sod_{plodt4}	n_{poodt4}	m_{poodt4}	sod_{poodt4}	n_{slodt4}	m_{slodt4}	sod_{slodt4}	n_{soodt4}	m_{soodt4}	sod_{soodt4}
O_o	D_d	T_t	5	n_{plodt5}	m_{pldt5}	sod_{plodt5}	n_{poodt5}	m_{poodt5}	sod_{poodt5}	n_{slodt5}	m_{slodt5}	sod_{slodt5}	n_{soodt5}	m_{soodt5}	sod_{soodt5}
O_o	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
O_o	D_d	T_u	i	n_{plodui}	m_{pldui}	sod_{plodui}	n_{poodui}	m_{poodui}	sod_{poodui}	n_{slodui}	m_{slodui}	sod_{slodui}	n_{soodui}	m_{soodui}	sod_{soodui}
O_o	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
O_o	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
O_o	D_f	T_w	i	n_{plofwi}	m_{plfwi}	sof_{plofwi}	n_{poofwi}	m_{poofwi}	sof_{poofwi}	n_{slofwi}	m_{slofwi}	sof_{slofwi}	n_{soofwi}	m_{soofwi}	sof_{soofwi}
O_o	…	…	…	…	…	…	…	…	…	…	…	…			

[1] Number of observations of fuel-flowing for the primary valve of compartment C_c [Integer] – Both loading (l) and offloading (o) events
[2] Mean of the distribution of fuel-flowing time for the primary valve of compartment C_c [Double] – Both loading (l) and offloading (o) events
[3] Standard Deviation of the distribution of fuel-flowing time for the primary valve of compartment C_c [Double] – Both loading (l) and offloading (o) events

[4] Number of observations of fuel-flowing for the secondary valve of compartment C_c [Integer] – Both loading (l) and offloading (o) events
[5] Mean of the distribution of fuel-flowing time for the secondary valve of compartment C_c [Double] – Both loading (l) and offloading (o) events
[6] Standard Deviation of the distribution of fuel-flowing time for the secondary valve of compartment C_c [Double] – Both loading (l) and offloading (o) events

Table 32. Probability Distribution Parameters (Cont.)

Org ID	Driver ID	Trailer ID	Com-part-ment ID	npe[7]	ppe[8]	nse[9]	pse[10]	npoc[11]	ppoc[12]	nsoc[13]	psoc[14]	neoc[15]	peoc[16]	nh[17]	mh[18]	sdh[19]	nae[20]	pne[21]
O_o	D_d	T_t	1	n_{peodt1}	p_{peodt1}	n_{seodt1}	p_{seodt1}	n_{poodt1}	p_{poodt1}	n_{soodt1}	p_{soodt1}	n_{eoodt1}	p_{eoodt1}	n_{hodt1}	m_{hodt1}	sd_{hodt1}	n_{aeodt1}	p_{neodt1}
O_o	D_d	T_t	2	n_{peodt2}	p_{peodt2}	n_{seodt2}	p_{seodt2}	n_{poodt2}	p_{poodt2}	n_{soodt2}	p_{soodt2}	n_{eoodt2}	p_{eoodt2}	n_{hodt2}	m_{hodt2}	sd_{hodt2}	n_{aeodt2}	p_{neodt2}
O_o	D_d	T_t	3	n_{peodt3}	p_{peodt3}	n_{seodt3}	p_{seodt3}	n_{poodt3}	p_{poodt3}	n_{soodt3}	p_{soodt3}	n_{eoodt3}	p_{eoodt3}	n_{hodt3}	m_{hodt3}	sd_{hodt3}	n_{aeodt3}	p_{neodt3}
O_o	D_d	T_t	4	n_{peodt4}	p_{peodt4}	n_{seodt4}	p_{seodt4}	n_{poodt4}	p_{poodt4}	n_{soodt4}	p_{soodt4}	n_{eoodt4}	p_{eoodt4}	n_{hodt4}	m_{hodt4}	sd_{hodt4}	n_{aeodt4}	p_{neodt4}
O_o	D_d	T_t	5	n_{peodt5}	p_{peodt5}	n_{seodt5}	p_{seodt5}	n_{poodt5}	p_{poodt5}	n_{soodt5}	p_{soodt5}	n_{eoodt5}	p_{eoodt5}	n_{hodt5}	m_{hodt5}	sd_{hodt5}	n_{aeodt5}	p_{neodt5}
O_o	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
O_o	D_d	T_u	i	n_{peodui}	p_{peodui}	n_{seodui}	p_{seodui}	n_{poodui}	p_{poodui}	n_{soodui}	p_{soodui}	n_{eoodui}	p_{eoodui}	n_{hodui}	m_{hodui}	sd_{hodui}	n_{aeodui}	p_{neodui}
O_o	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
O_o	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
O_o	D_f	T_w	i	n_{peofwi}	p_{peofwi}	n_{seofwi}	p_{seofwi}	n_{poofwi}	p_{poofwi}	n_{soofwi}	p_{soofwi}	n_{eoofwi}	p_{eoofwi}	n_{hofwi}	m_{hofwi}	sd_{hofwi}	n_{aeofwi}	p_{neofwi}
O_o	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…

THE FOLLOWING ARE ONLY FOR OFFLOADING. IN A LOADING EVENT THERE WILL ALWAYS BE GAS IN THE PIPE BETWEEN EMERGENCY AND PRIMARY VALVES

[7] Number of observations for the primary valve and the emergency valve of compartment C_c working together OPENING [Integer]

[8] Probability that the primary valve of compartment C_c opens after the emergency valve [Double] (= Probability of Normal Operations of the valves)

[7] Number of observations for the primary valve and the emergency valve of compartment C_c working together CLOSING ***NOT SHOWN IN TABLE ABOVE*** [Integer]

[8] Probability that the primary valve of compartment C_c Closes before the emergency valve CLOSING ***NOT SHOWN IN TABLE ABOVE*** [Double] (= Probability of Normal Operations of the valves)

THE FOLLOWING ARE ONLY FOR OFFLOADING. IN A LOADING EVENT THERE WILL ALWAYS BE FUEL IN THE PIPE BETWEEN EMERGENCY AND PRIMARY VALVES

[9] Number of observations for the secondary valve and the emergency valve of compartment C_c working together OPENING [Integer]

[10] Probability that the secondary valve of compartment C_c opens after the emergency valve [Double] (= Probability of Normal Operations of the valves)

[9] Number of observations for the secondary valve and the emergency valve of compartment C_c working together CLOSING ***NOT SHOWN IN TABLE ABOVE*** [Integer]

[10] Probability that the secondary valve of compartment C_c Closes before the emergency valve CLOSING ***NOT SHOWN IN TABLE ABOVE*** [Double] (= Probability of Normal Operations of the valves)

[11] Number of observations for the primary valve of compartment C_c opening and closing without the emergency valve being opened [Integer]

[12] Probability that the primary valve of compartment C_c opens and closed without the emergency valve being opened [Double]

[13] Number of observations for the secondary valve of compartment C_c opening and closing without the emergency valve being opened [Integer]

[14] Probability that the secondary valve of compartment C_c opens and closed without the emergency valve being opened [Double]

[15] Number of observations for the emergency valve of compartment C_c opening and closing without the primary or secondary valve being opened [Integer]

[16] Probability that the emergency valve of compartment C_c opens and closed without the primary or secondary valve being opened [Double]

[17] Number of observations when compartment C_c hatch is open [Integer]

[18] Mean of the distribution of time that compartment C_c hatch is open [Double]

[19] Standard Deviation of the distribution of time that compartment C_c hatch is open [Double]

[20] Number of observations of all events registered by this driver [Integer]

[21] Probability that of observing normal events for this driver [Double]

LOCATION DATABASE

The location database will consist of records that describe the different locations at which a driver is authorized to load and offload fuel. The table below shows the fields that describe these authorized locations (Note: more fields could be added if necessary).

Table 33. Authorized Load/Drop Location Fields

Field Name	Units	Type
Location ID		Int
Location Name		Char
Location City		Char
Location State		Char
Location Type (i.e., Load/Offload/Load-Offload)		Char
Location Latency (i.e., Permanent/Temporary)		Char
Location Latitude	deg	Char
Location Longitude	deg	Char
Location Last Used	ddmmyyy-hhmmss	DateTime

INFORMATION FROM FUEL LOGS

The boERS will receive a list of locations (each location is defined by their latitude Lat_i and longitude $Long_i$) and will determine whether fuel was loaded or offloaded at these locations. It will then proceed to determine if these were authorized locations or not for such activities. To do so, it will request the TBOS to provide information (i.e., latitude and longitude) residing in the ALD. A direct comparison of the spatial information collected on-board against the data residing in the ALD will not yield any usable results since it is very unlikely that the latitude/longitude collected by the vehicle's GPS device will match exactly that of the ALD. Therefore, rather than using two points for the comparisons (one from the GPS and one from the ALD), the methodology will compute the distance between these two points, and if that distance is less than a predefined threshold (e.g., 100 ft) it will be considered a match.

The ALD may be a large database, especially for companies that haul fuel in many states. To simplify the search, the following procedure will be used. From the list of all locations that the vehicle has visited, the minimum and maximum values for the latitude and longitude dimensions will be found. The minLat, MaxLat, minLong, and MaxLong will define a "box,"i.e., NW[10] corner defined by (MaxLat, minLong) and SE corner defined by (minLat, MaxLong), that contains all the locations visited by the vehicle. This information (i.e., the NW and SE corners of this box plus a small increase in size) will be the search criteria passed to the TBOS to query the ALD (CRUD: Retrieve). The information returned will be a list of locations contained in the ALD that are within this NW-SE defined "box." The distances between these points and those obtained from the on-board information will be compared to determine whether or not the latter corresponds to authorized fuel load/drop locations. This information will be added to the Driver Report.

FUEL-LOG FILE MANAGEMENT AT THE BACK OFFICE

The telematics device system is designed in such a way that it cannot determine when an end-of-shift occurs for a given driver; however, it registers driver logout and driver login events. Because of this indetermination regarding the end-of-shift, the obERS, through the obTD, will submit a fuel-log file for driver *d* every time this driver logs out of the device.

[10] We assume northern hemisphere west of Greenwich.

When the boERS is notified that fuel-log files (one or more based on file-size constraints) are available for driver *d*, the software will read the time stamp of the driver login (DLIT) and driver logout (DLOT) events. Those parameters will used to update a database of information (fuel-log files database, or FLFdb) about driver *d* and his/her unprocessed fuel-log files. That is, the system will keep the earliest DLIT ($DLIT_0$) and latest DLOT ($DLOT_n$) for this driver and analyze the following conditions:

1. If $DLOT_n$ - $DLIT_0$ >=14 hours, then all of the pending fuel-log files for driver *d* will be processed and a fuel report for this driver will be generated. The FLFdb will be updated and references to this driver eliminated.
2. If $DLOT_n$ - $DLIT_0$ <14 hours then the FLFdb records for this driver will be updated by adding the name of the fuel-log files that were received and by setting $DLOT_n$ as the latest driver logout time stamp.
3. In either case, and also at pre-determined times (i.e., once every hour), the boERS will go through the FLFdb and determine for each driver *j* in the database if Time(Now) - $DLIT_0$(j) >=14.5 hours.
    a. If this condition is true, then the fuel-log files for driver *j* will be processed and a driver report generated. The FLFdb will be updated and references to this driver eliminated.
    b. If this condition is false, nothing will be done for driver *j* until a new fuel-log file for this driver is received or another FLFdb processing event happens (e.g., one hour later).

APPENDIX F: TELEMATICS CARRIER INTERFACE SCREENS

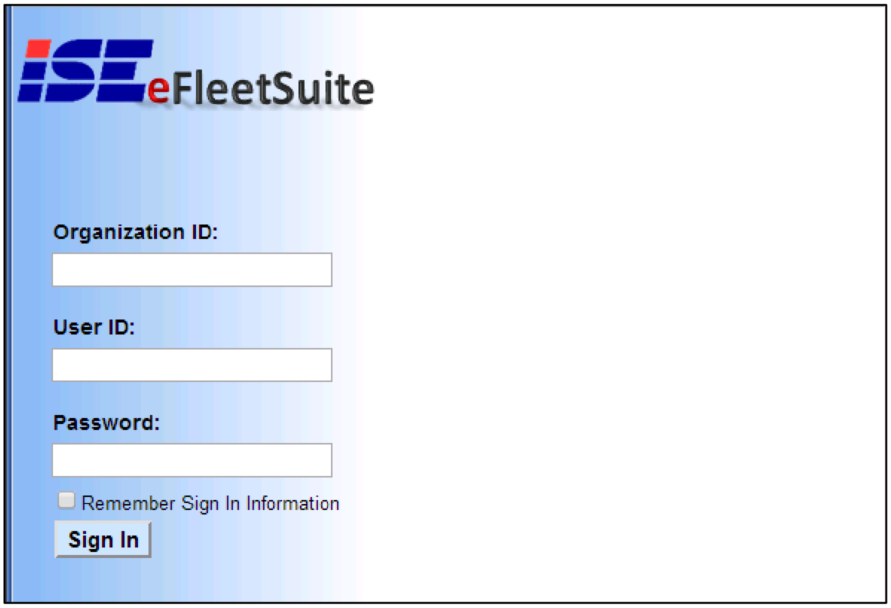


Figure 75. Carrier interface website logon.

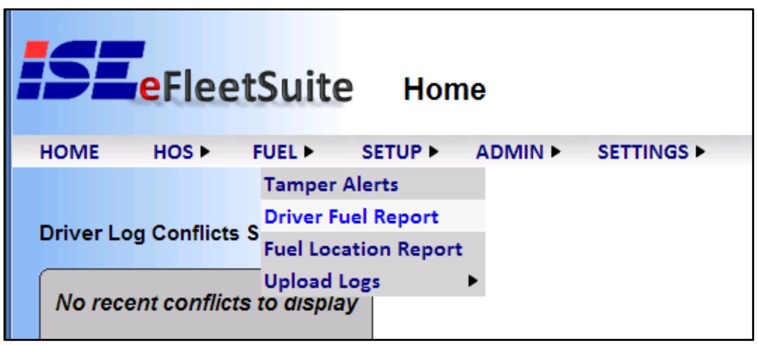


Figure 76. The telematics company's commercial carrier interface was modified to add a new fuel tracking feature for this project.

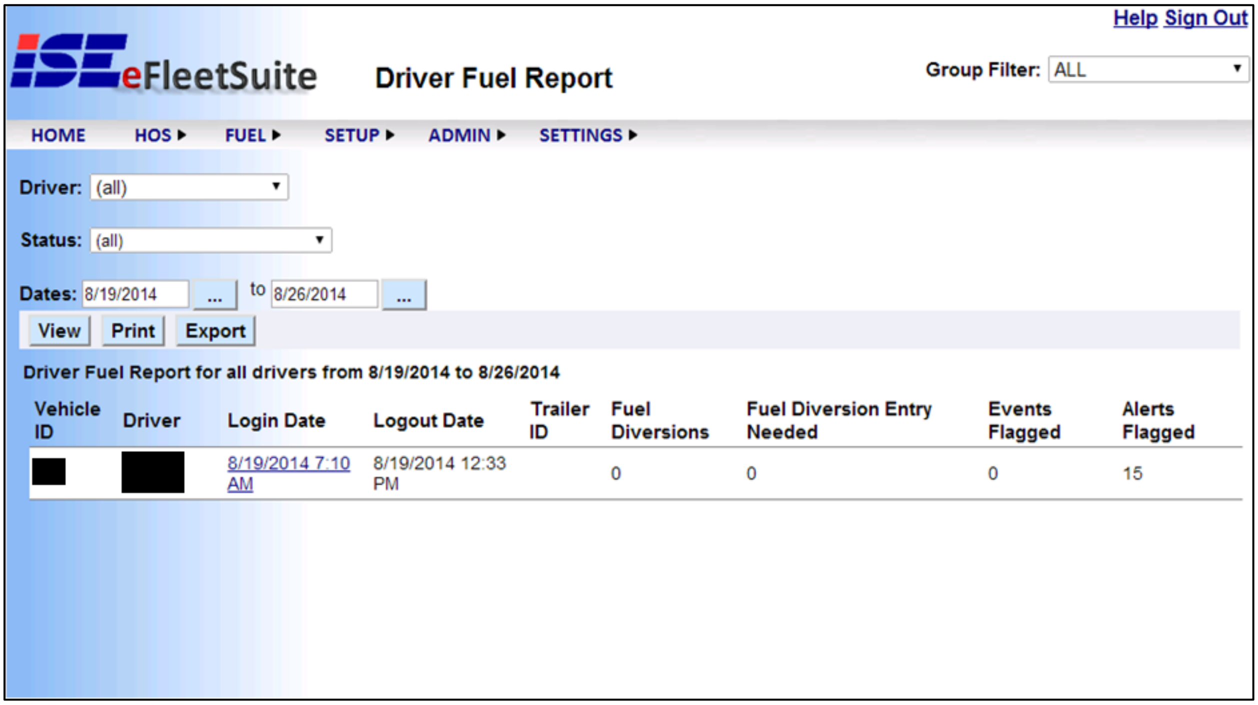


Figure 77. The Driver Fuel Report lists summary information for one driver shift.

If the link for a shift is clicked on, the system will provide details for that shift.

Figure 78. Driver fuel report detail.

For each event, the eFleetSuite interface lists the timestamp, type of event (loading, offloading, alert, other, etc.) GPS location, BOL information such as BOL #, destination state, fuel amount and quantity, and compartment number.

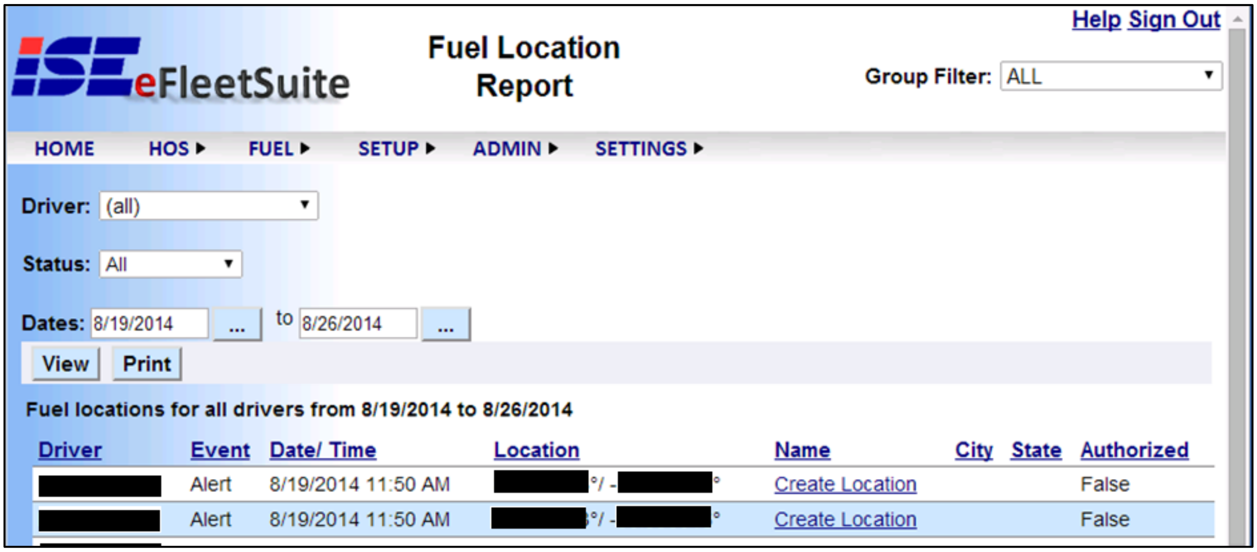


Figure 79. The Fuel Location Report shows events that happen at unknown locations.

The user can click on a row to add that to the known locations database, where it can be authorized for loading, offloading, and/or hatch opening.

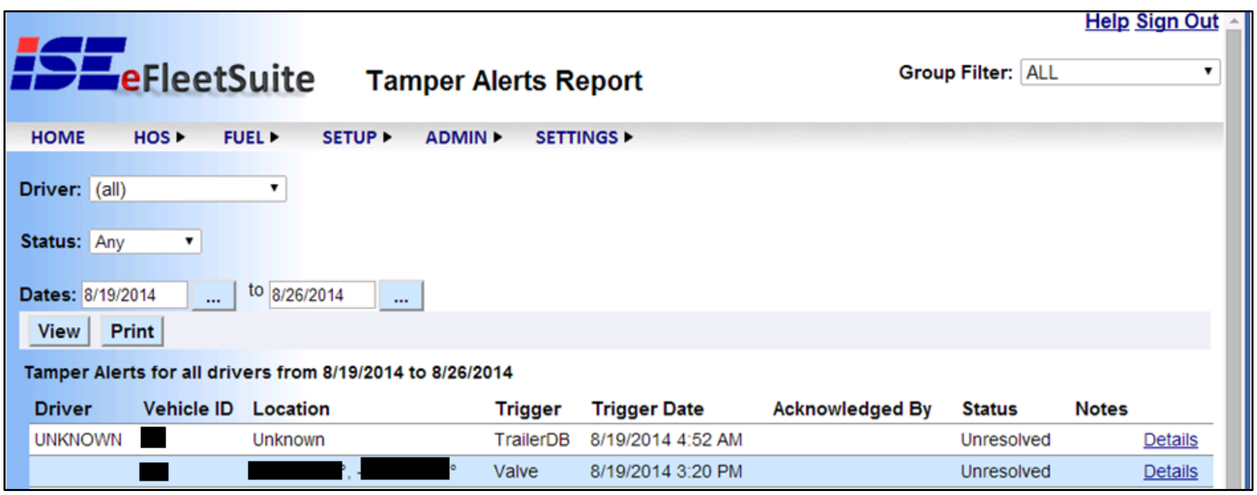


Figure 80. The tamper alerts report shows information related to a sensor or cable disconnected.

APPENDIX G: DRIVER REPORT

	Login Date [1]	Organization Key [2]	USDOT Number [3]	Driver ID [4]	Tractor ID [5]	Trailer ID [6]	Logout Date [7]	Event Type [8]	Event Short Description [9]
[1]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	0	Unlikely event (ff time).
[2]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	0	Very unlikely event (ff time).
[3]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	0	Rare event (va w/ff).
[4]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	0	Rare event (ff time).
[5]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	0	Rare event (va w/ff).
[6]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	1	Rare event (ff time).
[7]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	1	Unlikely event (ff time).
[8]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	1	Rare event (va w/ff).
[9]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	1	Rare event (ff time).
[10]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	1	Rare event (ff time).
[11]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	0	Unlikely event (ff time).
[12]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	0	Very unlikely event (ff time).
[13]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	0	Rare event (va w/ff).
[14]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	0	Rare event (ff time).
[15]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	0	Rare event (ff time).
[16]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	1	Rare event (ff time).
[17]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	1	Rare event (ff time).
[18]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	1	Rare event (va w/ff).
[19]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	1	Very unlikely event (va w/ff).
[20]	23012015-123526	1234	271629	D84	1067	A	24012015-003026	1	Rare event (ff time).

0: Loading
1: Offloading

	Event Long Description [10]	Comp. ID [11]	Order Number [12]	BOL1 [13]	BOL2 [14]	BOL3 [15]	Destination State [16]	Event Start Date [17]	Event End Date [18]
[1]	Unlikely event; (fuel-flowing elapsed time). Loc in DB.	1		337402			33	23012015-154131	23012015-155300
[2]	Very unlikely event; possible suspicious act (fuel-flowing elapsed time). Loc in DB.	4		337402			33	23012015-154152	23012015-154903
[3]	Rare event; (valve actuation w/fuel-flowing). Loc in DB.	3		337402			33	23012015-154203	23012015-154936
[4]	Rare event; (fuel-flowing elapsed time). Loc in DB.	2		337402			33	23012015-154915	23012015-155328
[5]	Rare event; (valve actuation w/fuel-flowing). Loc in DB.	5		337402			33	23012015-154941	23012015-160039
[6]	Rare event; (fuel-flowing elapsed time). Loc in DB.	1		337402			33	23012015-173855	23012015-174614
[7]	Unlikely event; (fuel-flowing elapsed time). Loc in DB.	2		337402			33	23012015-174619	23012015-175117
[8]	Rare event; (valve actuation w/fuel-flowing). Loc in DB.	3		337402			33	23012015-175121	23012015-175440
[9]	Rare event; (fuel-flowing elapsed time). Loc in DB.	4		337402			33	23012015-175445	23012015-175845
[10]	Rare event; (fuel-flowing elapsed time). Loc in DB.	5		337402			33	23012015-175849	23012015-180637
[11]	Unlikely event; (fuel-flowing elapsed time). Loc in DB.	1		337427			42	23012015-200908	23012015-202048
[12]	Very unlikely event; possible suspicious act (fuel-flowing elapsed time). Loc in DB.	4		337427			42	23012015-200917	23012015-201609
[13]	Rare event; (valve actuation w/fuel-flowing). Loc in DB.	3		337427			42	23012015-200927	23012015-201558
[14]	Rare event; (fuel-flowing elapsed time). Loc in DB.	5		337427			42	23012015-201606	23012015-202315
[15]	Rare event; (fuel-flowing elapsed time). Loc in DB.	2		337427			42	23012015-201625	23012015-202052
[16]	Rare event; (fuel-flowing elapsed time). Loc in DB.	1		337427			42	23012015-231515	23012015-232241
[17]	Rare event; (fuel-flowing elapsed time). Loc in DB.	2		337427			42	23012015-232245	23012015-232620
[18]	Rare event; (valve actuation w/fuel-flowing). Loc in DB.	3		337427			42	23012015-232830	23012015-233220
[19]	Very unlikely event; possible suspicious act (valve actuation w/fuel-flowing). Loc in DB.	4		337427			42	23012015-233224	23012015-234022
[20]	Rare event; (fuel-flowing elapsed time). Loc in DB.	5		337427			42	23012015-234027	23012015-234817

33: North Carolina
42: Tennessee

	Type of Fuel BOL1 [19]	Fuel Volume TD BOL1 [20]	Fuel Volume ERS BOL1 [21]	Type of Fuel BOL2 [22]	Fuel Volume TD BOL2 [23]	Fuel Volume ERS BOL2 [24]	Type of Fuel BOL3 [25]	Fuel Volume TD BOL3 [26]	Fuel Volume ERS BOL3 [27]
[1]	11	2,800	0	-1	0	0	-1	0	0
[2]	11	1,051	0	-1	0	0	-1	0	0
[3]	12	1,000	0	-1	0	0	-1	0	0
[4]	11	1,250	0	-1	0	0	-1	0	0
[5]	11	2,502	0	-1	0	0	-1	0	0
[6]	11	2,800	0	-1	0	0	-1	0	0
[7]	11	1,250	0	-1	0	0	-1	0	0
[8]	12	1,000	0	-1	0	0	-1	0	0
[9]	11	1,051	0	-1	0	0	-1	0	0
[10]	11	2,502	0	-1	0	0	-1	0	0
[11]	11	2,800	0	-1	0	0	-1	0	0
[12]	11	1,050	0	-1	0	0	-1	0	0
[13]	12	1,000	0	-1	0	0	-1	0	0
[14]	11	2,500	0	-1	0	0	-1	0	0
[15]	11	1,251	0	-1	0	0	-1	0	0
[16]	11	2,800	0	-1	0	0	-1	0	0
[17]	11	1,251	0	-1	0	0	-1	0	0
[18]	12	1,000	0	-1	0	0	-1	0	0
[19]	11	1,050	0	-1	0	0	-1	0	0
[20]	11	2,500	0	-1	0	0	-1	0	0

11: Regular-Ethanol
12: Premium-Ethanol

	Steer Axle Delta Weight [28]	Drive Axle Delta Weight [29]	Trailer Axle Delta Weight [30]	Fuel-flowing Elapsed Time [31]	Event Start Latitude [32]	Event Start Longitude [33]	Event Start GPS Status [34]	Event Start Odometer [35]	Event State [36]
[1]	0	0	7,792	689	34.924554	-81.866974	0	458,568.1	40
[2]	0	0	3,212	431	34.924554	-81.866974	0	458,568.1	40
[3]	0	0	3,392	453	34.924554	-81.866974	0	458,568.1	40
[4]	0	0	5,444	253	34.924554	-81.866974	0	458,568.1	40
[5]	0	0	8,500	658	34.924554	-81.866974	0	458,568.1	40
[6]	5,217	11,979	-15,196	439	35.545450	-82.667235	0	458,643.7	33
[7]	-154	-2,320	-15,140	298	35.545476	-82.667225	0	458,643.7	33
[8]	-80	-1,216	-15,078	199	35.545439	-82.667254	0	458,643.7	33
[9]	-70	-1,078	-15,040	240	35.545446	-82.667248	0	458,643.7	33
[10]	-80	-1,198	-15,222	468	35.545373	-82.667159	0	458,643.7	33
[11]	0	0	9,726	700	34.924582	-81.866950	0	458,718.7	40
[12]	0	0	3,202	412	34.924582	-81.866950	0	458,718.7	40
[13]	0	0	3,230	391	34.924582	-81.866950	0	458,718.7	40
[14]	0	0	8,692	429	34.924582	-81.866950	0	458,718.7	40
[15]	0	0	6,666	267	34.924582	-81.866950	0	458,718.7	40
[16]	5,135	10,735	-15,186	446	36.331634	-82.267509	0	458,858.3	42
[17]	-132	-2,024	-15,368	215	36.331635	-82.267513	0	458,858.3	42
[18]	-82	-1,244	-15,332	230	36.331634	-82.267515	0	458,858.3	42
[19]	-76	-1,142	-15,294	478	36.331622	-82.267497	0	458,858.3	42
[20]	-62	-956	-15,222	470	36.331602	-82.267518	0	458,858.3	42

0: Valid Reading

33: North Carolina
40: South Carolina
42: Tennessee

	Diversion Number [37]	Diversion State [38]	Valve Actuation Elapsed Time [39]	Valve Actuation Sequence [40]	Likelihood of Occurrence - Dwell Time [41]	Likelihood of Occurrence - Valve Operation Sequence [42]	Flagged Record Based on Likelihood of Occurrence [43]	Probability of Occurrence [44]	Statistical Test Condition [45]
[1]		-1	689	EPPE	0.0487	0.8602	1	0.0487	3
[2]		-1	431	EPPE	0.0000	0.8736	1	0.0000	3
[3]		-1	453	EPPE	0.3332	0.8636	0	0.3332	3
[4]		-1	253	EPPE	0.0380	0.9070	1	0.0380	3
[5]		-1	658	EPPE	0.3517	0.7500	0	0.3517	1
[6]		-1	439	EPPE	0.0487	0.8602	1	0.0487	3
[7]		-1	298	EPPE	0.0380	0.9070	1	0.0380	3
[8]		-1	199	EPPE	0.3332	0.8636	0	0.3332	3
[9]		-1	240	EPPE	0.0000	0.8736	1	0.0000	3
[10]		-1	468	EPPE	0.3517	0.7500	0	0.3517	1
[11]		-1	700	EPPE	0.0487	0.8602	1	0.0487	3
[12]		-1	412	EPPE	0.0000	0.8736	1	0.0000	3
[13]		-1	391	EPPE	0.3332	0.8636	0	0.3332	3
[14]		-1	429	EPPE	0.3517	0.7500	0	0.3517	1
[15]		-1	267	EPPE	0.0380	0.9070	1	0.0380	3
[16]		-1	446	EPPE	0.0487	0.8602	1	0.0487	3
[17]		-1	215	EPPE	0.0380	0.9070	1	0.0380	3
[18]		-1	230	EPPE	0.3332	0.8636	0	0.3332	3
[19]		-1	478	EPPE	0.0000	0.8736	1	0.0000	3
[20]		-1	470	EPPE	0.3517	0.7500	0	0.3517	1
		-1: N/A					0: False 1: True		1: This Driver and Vehicle vs. This Driver and This Veh. 3: This Driver and Vehicle vs. All Drivers and This Veh.

	Number of Alarms at This Location [46]	Alarm Type [47]	Alarm Trigger [48]	Alarm Reset Date [49]	Alarm Acknowledged by [50]	Location in Database [51]	Location Key [52]	Authorized Location [53]	Show on Location Report [54]
[1]	0	-1	-1	01011970-000000	-1	1	86	1	0
[2]	0	-1	-1	01011970-000000	-1	1	86	1	0
[3]	0	-1	-1	01011970-000000	-1	1	86	1	0
[4]	0	-1	-1	01011970-000000	-1	1	86	1	0
[5]	0	-1	-1	01011970-000000	-1	1	86	1	0
[6]	0	-1	-1	01011970-000000	-1	1	94	1	0
[7]	0	-1	-1	01011970-000000	-1	1	94	1	0
[8]	0	-1	-1	01011970-000000	-1	1	94	1	0
[9]	0	-1	-1	01011970-000000	-1	1	94	1	0
[10]	0	-1	-1	01011970-000000	-1	1	94	1	0
[11]	0	-1	-1	01011970-000000	-1	1	86	1	0
[12]	0	-1	-1	01011970-000000	-1	1	86	1	0
[13]	0	-1	-1	01011970-000000	-1	1	86	1	0
[14]	0	-1	-1	01011970-000000	-1	1	86	1	0
[15]	0	-1	-1	01011970-000000	-1	1	86	1	0
[16]	0	-1	-1	01011970-000000	-1	1	124	1	0
[17]	0	-1	-1	01011970-000000	-1	1	124	1	0
[18]	0	-1	-1	01011970-000000	-1	1	124	1	0
[19]	0	-1	-1	01011970-000000	-1	1	124	1	0
[20]	0	-1	-1	01011970-000000	-1	1	124	1	0
		-1: N/A	-1: N/A		-1: N/A	0: False 1: True		0: False 1: True	0: False 1: True

	Diversion Number Missing [55}	BOL Number Mismatch [56]	Amount of Fuel Mismatch [57]	Type of Fuel Mismatch [58}	FDAS Record [59]
[1]	0	0	0	0	1
[2]	0	0	0	0	1
[3]	0	0	0	0	1
[4]	0	0	0	0	1
[5]	0	0	0	0	1
[6]	0	0	0	0	1
[7]	0	0	0	0	1
[8]	0	0	0	0	1
[9]	0	0	0	0	1
[10]	0	0	0	0	1
[11]	0	0	0	0	1
[12]	0	0	0	0	1
[13]	0	0	0	0	1
[14]	0	0	0	0	1
[15]	0	0	0	0	1
[16]	0	0	0	0	1
[17]	0	0	0	0	1
[18]	0	0	0	0	1
[19]	0	0	0	0	1
[20]	0	0	0	0	1
	0: False 1: True	0: False 1: True	0: False 1: True	0: False 1: True	0: False 1: True

APPENDIX H: FDAS REPORT

	USDOT Number [1]	Carrier Name [2]	Tractor ID [3]	Trailer ID [4]	Event Type [5]	BOL1 [6]	BOL2 [7]	BOL3 [8]	Destination State [9]
[1]	271629	ORNLQA	1067	A	0	337402			33
[2]	271629	ORNLQA	1067	A	0	337402			33
[3]	271629	ORNLQA	1067	A	0	337402			33
[4]	271629	ORNLQA	1067	A	0	337402			33
[5]	271629	ORNLQA	1067	A	0	337402			33
[6]	271629	ORNLQA	1067	A	1	337402			33
[7]	271629	ORNLQA	1067	A	1	337402			33
[8]	271629	ORNLQA	1067	A	1	337402			33
[9]	271629	ORNLQA	1067	A	1	337402			33
[10]	271629	ORNLQA	1067	A	1	337402			33
[11]	271629	ORNLQA	1067	A	0	337427			42
[12]	271629	ORNLQA	1067	A	0	337427			42
[13]	271629	ORNLQA	1067	A	0	337427			42
[14]	271629	ORNLQA	1067	A	0	337427			42
[15]	271629	ORNLQA	1067	A	0	337427			42
[16]	271629	ORNLQA	1067	A	1	337427			42
[17]	271629	ORNLQA	1067	A	1	337427			42
[18]	271629	ORNLQA	1067	A	1	337427			42
[19]	271629	ORNLQA	1067	A	1	337427			42
[20]	271629	ORNLQA	1067	A	1	337427			42
					0: Loading 1: Offloading				33: North Carolina 42: Tennessee

	Event Start Date [10]	Type of Fuel BOL1 [11]	Fuel Volume TD BOL1 [12]	Type of Fuel BOL2 [13]	Fuel Volume TD BOL2 [14]	Type of Fuel BOL3 [15]	Fuel Volume TD BOL3 [16]	Event Start Latitude [17]	Event Start Longitude [18]
[1]	23012015-154131	11	2,800	-1	0	-1	0	34.924554	-81.866974
[2]	23012015-154152	11	1,051	-1	0	-1	0	34.924554	-81.866974
[3]	23012015-154203	12	1,000	-1	0	-1	0	34.924554	-81.866974
[4]	23012015-154915	11	1,250	-1	0	-1	0	34.924554	-81.866974
[5]	23012015-154941	11	2,502	-1	0	-1	0	34.924554	-81.866974
[6]	23012015-173855	11	2,800	-1	0	-1	0	35.545450	-82.667235
[7]	23012015-174619	11	1,250	-1	0	-1	0	35.545476	-82.667225
[8]	23012015-175121	12	1,000	-1	0	-1	0	35.545439	-82.667254
[9]	23012015-175445	11	1,051	-1	0	-1	0	35.545446	-82.667248
[10]	23012015-175849	11	2,502	-1	0	-1	0	35.545373	-82.667159
[11]	23012015-200908	11	2,800	-1	0	-1	0	34.924582	-81.866950
[12]	23012015-200917	11	1,050	-1	0	-1	0	34.924582	-81.866950
[13]	23012015-200927	12	1,000	-1	0	-1	0	34.924582	-81.866950
[14]	23012015-201606	11	2,500	-1	0	-1	0	34.924582	-81.866950
[15]	23012015-201625	11	1,251	-1	0	-1	0	34.924582	-81.866950
[16]	23012015-231515	11	2,800	-1	0	-1	0	36.331634	-82.267509
[17]	23012015-232245	11	1,251	-1	0	-1	0	36.331635	-82.267513
[18]	23012015-232830	12	1,000	-1	0	-1	0	36.331634	-82.267515
[19]	23012015-233224	11	1,050	-1	0	-1	0	36.331622	-82.267497
[20]	23012015-234027	11	2,500	-1	0	-1	0	36.331602	-82.267518

11: Regular-Ethanol -1: N/A -1: N/A

12: Premium-Ethanol

	Event Start GPS Status [19]	Event Start Odometer [20]	Event State [21]	Diversion Number [22]	Diversion State [23]	Diversion Number Missing [24]	BOL Number Mismatch [25]	Amount of Fuel Mismatch [26]	Type of Fuel Mismatch [27]
[1]	0	458,568.1	40		-1	FALSE	FALSE	FALSE	FALSE
[2]	0	458,568.1	40		-1	FALSE	FALSE	FALSE	FALSE
[3]	0	458,568.1	40		-1	FALSE	FALSE	FALSE	FALSE
[4]	0	458,568.1	40		-1	FALSE	FALSE	FALSE	FALSE
[5]	0	458,568.1	40		-1	FALSE	FALSE	FALSE	FALSE
[6]	0	458,643.7	33		-1	FALSE	FALSE	FALSE	FALSE
[7]	0	458,643.7	33		-1	FALSE	FALSE	FALSE	FALSE
[8]	0	458,643.7	33		-1	FALSE	FALSE	FALSE	FALSE
[9]	0	458,643.7	33		-1	FALSE	FALSE	FALSE	FALSE
[10]	0	458,643.7	33		-1	FALSE	FALSE	FALSE	FALSE
[11]	0	458,718.7	40		-1	FALSE	FALSE	FALSE	FALSE
[12]	0	458,718.7	40		-1	FALSE	FALSE	FALSE	FALSE
[13]	0	458,718.7	40		-1	FALSE	FALSE	FALSE	FALSE
[14]	0	458,718.7	40		-1	FALSE	FALSE	FALSE	FALSE
[15]	0	458,718.7	40		-1	FALSE	FALSE	FALSE	FALSE
[16]	0	458,858.3	42		-1	FALSE	FALSE	FALSE	FALSE
[17]	0	458,858.3	42		-1	FALSE	FALSE	FALSE	FALSE
[18]	0	458,858.3	42		-1	FALSE	FALSE	FALSE	FALSE
[19]	0	458,858.3	42		-1	FALSE	FALSE	FALSE	FALSE
[20]	0	458,858.3	42		-1	FALSE	FALSE	FALSE	FALSE

0: Valid

33: North Carolina
40: South Carolina
42: Tennessee

-1: N/A

APPENDIX I: COLLECTED FUELLOG FILES

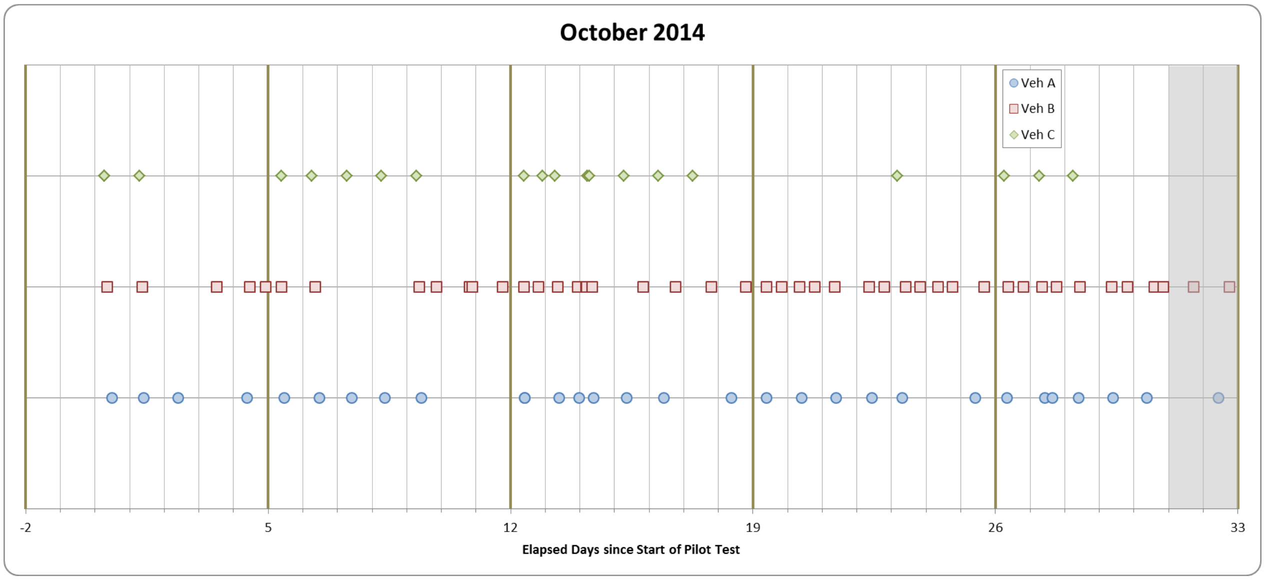


Figure 81. Pilot Test Fuel-Log Files by Vehicle and Day (October 2014)

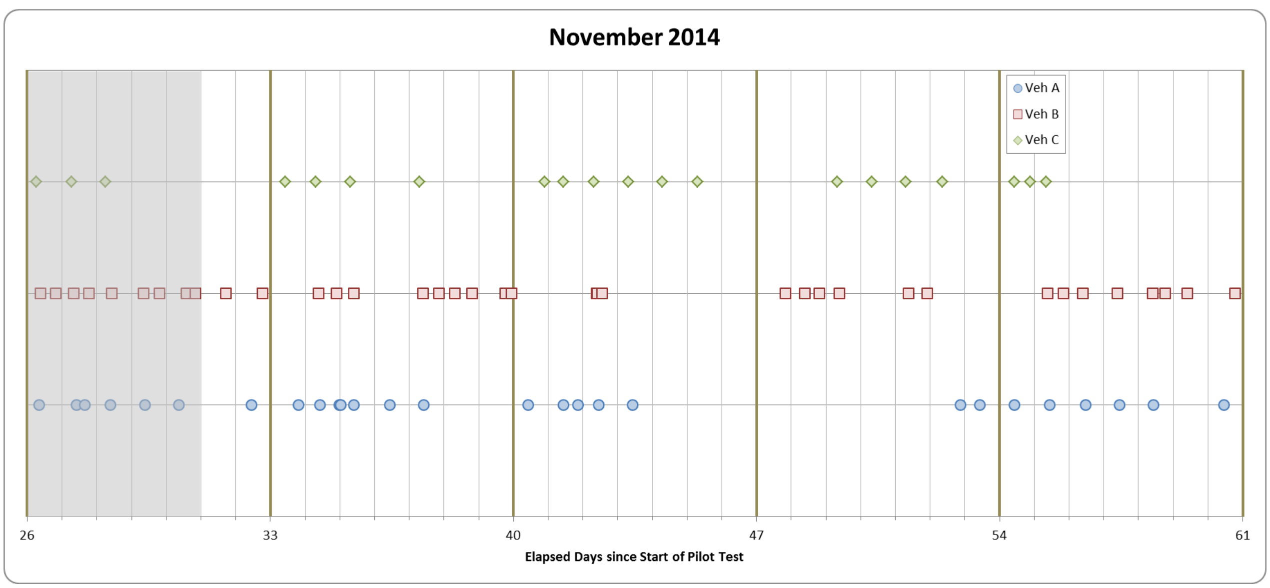


Figure 82. Pilot Test Fuel-Log Files by Vehicle and Day (November 2014)

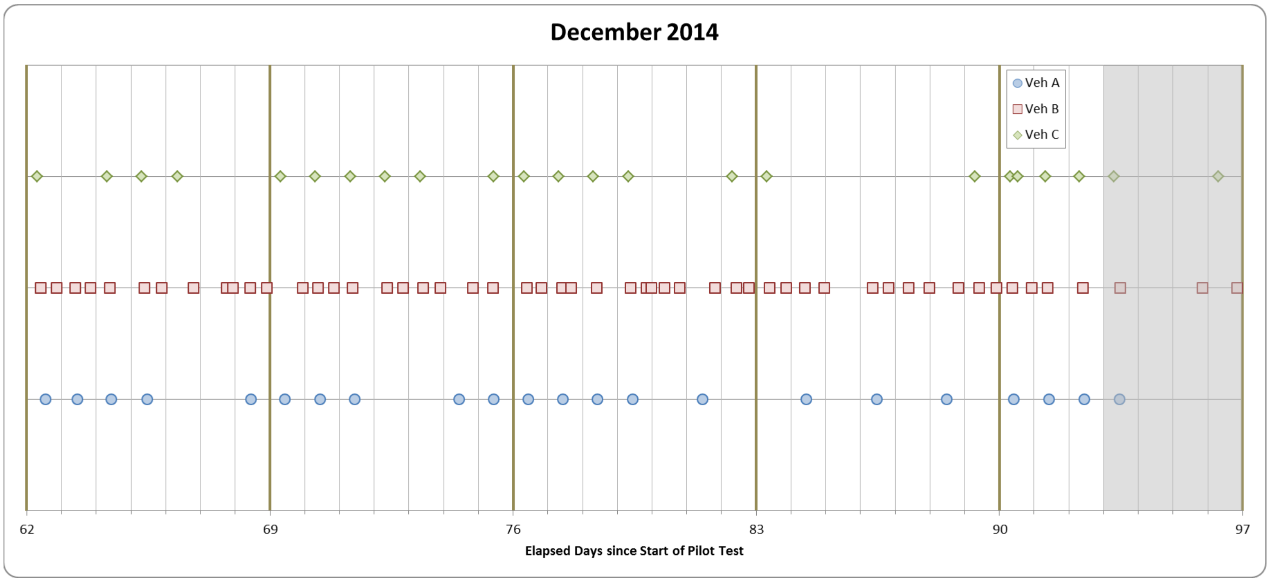


Figure 83. Pilot Test Fuel-Log Files by Vehicle and Day (December 2014)

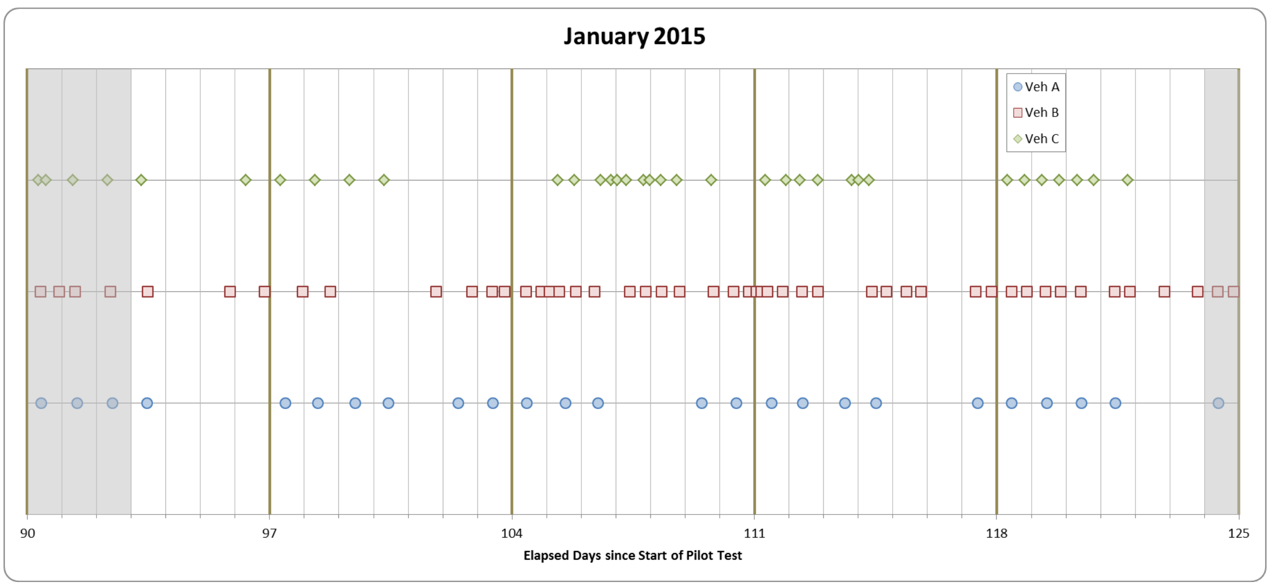


Figure 84. Pilot Test Fuel-Log Files by Vehicle and Day (January 2015)

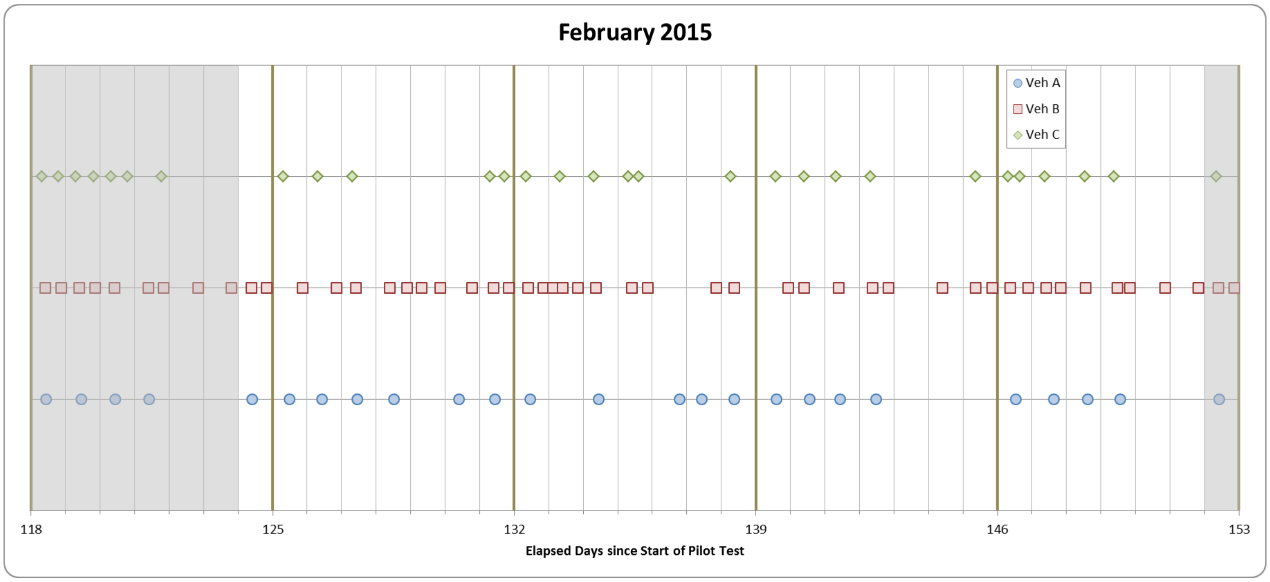


Figure 85. Pilot Test Fuel-Log Files by Vehicle and Day (February 2015)

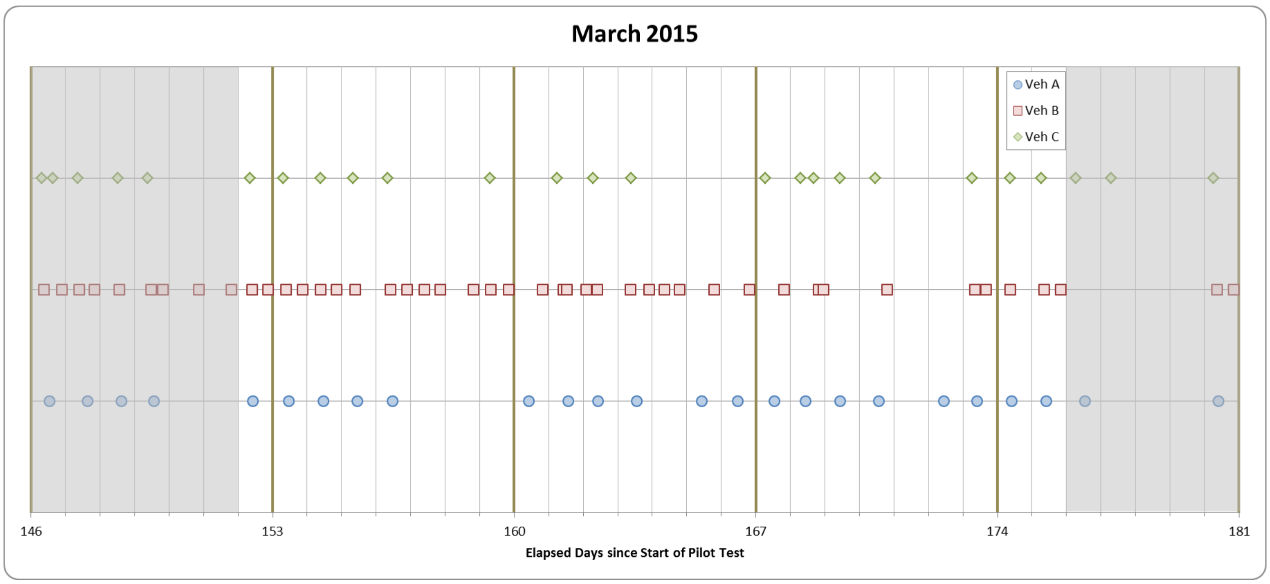


Figure 86. Pilot Test Fuel-Log Files by Vehicle and Day (March 2015)

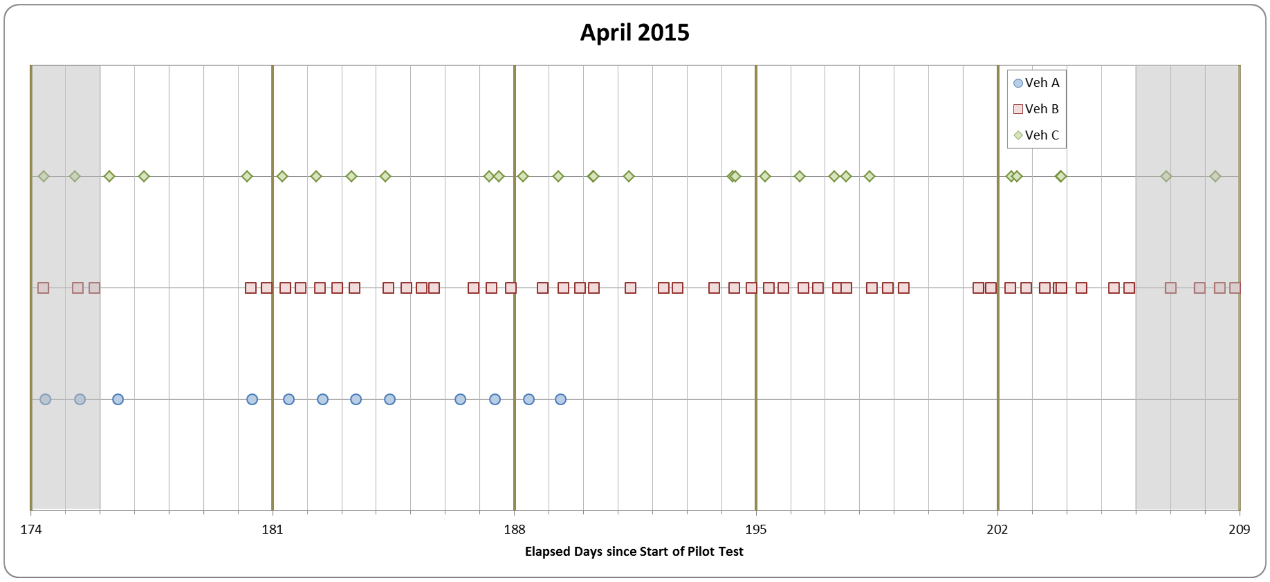


Figure 87. Pilot Test Fuel-Log Files by Vehicle and Day (April 2015)

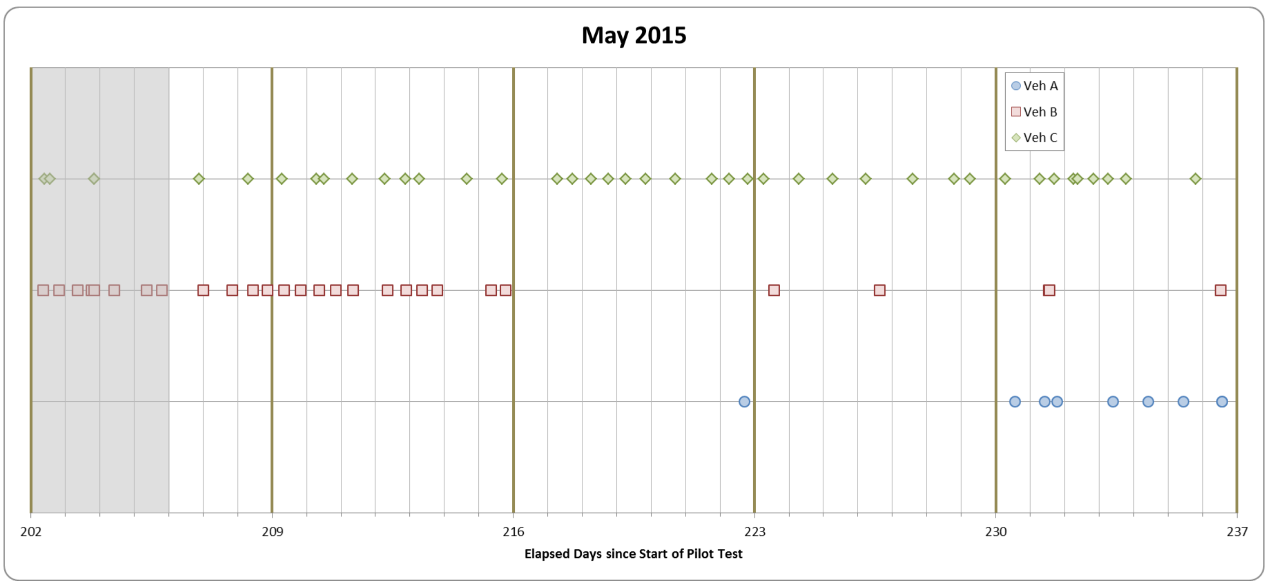


Figure 88. Pilot Test Fuel-Log Files by Vehicle and Day (May 2015)

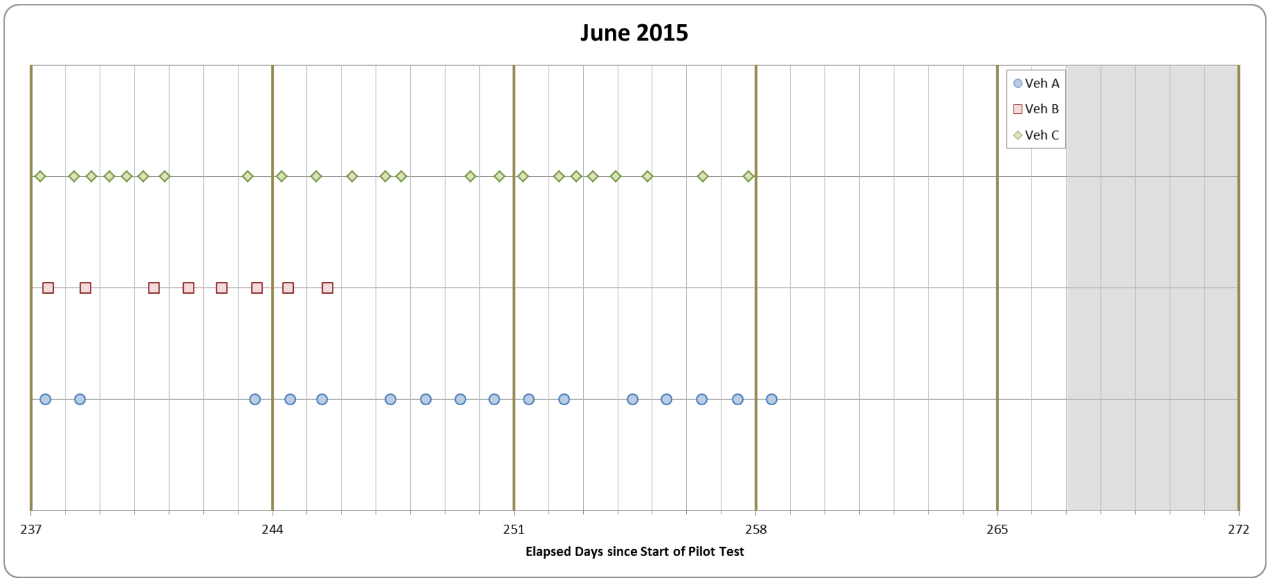
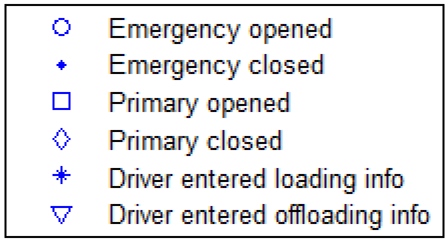


Figure 89. Pilot Test Fuel-Log Files by Vehicle and Day (June 2015)

APPENDIX J: REPRESENTATIVE VALVE SEQUENCE GRAPHS

For this section, the following legend is applicable. A description of each figure is given in the caption.



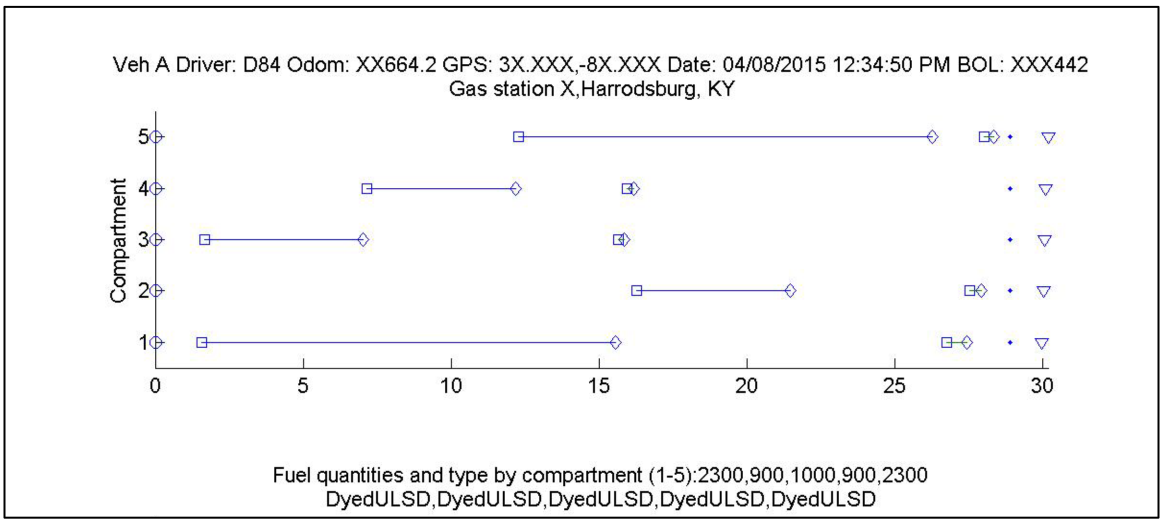


Figure 90. Example of "getting the last drips" out at an offloading location.

For example, for compartment 3 at 16 minutes, the driver opened the primary valve again for several seconds and then closed it. In this example, that technique was executed for each compartment. This would be an EoPoPcPoPcEc valve sequence instead of the more common EoPoPcEc.

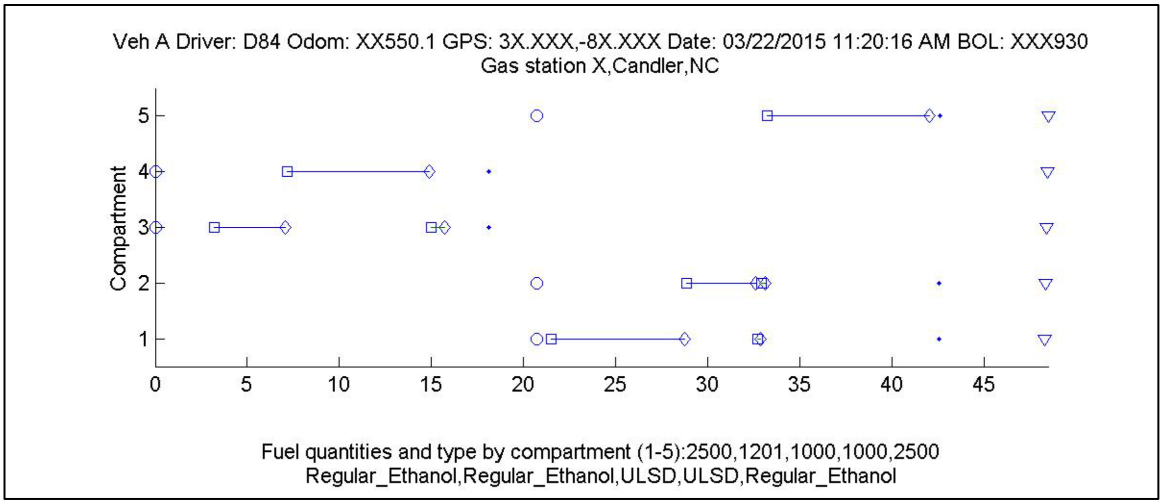


Figure 91. Example of a driver who opens all 5 emergency valve compartments at the same time.

This is convenient to do because they are all air-actuated switches that can all be easily switched at once. This plot shows an example in which the driver first completely finishes with compartments 3 and 4, and then proceeds to open the emergency valves for compartments 1, 2 and 5.

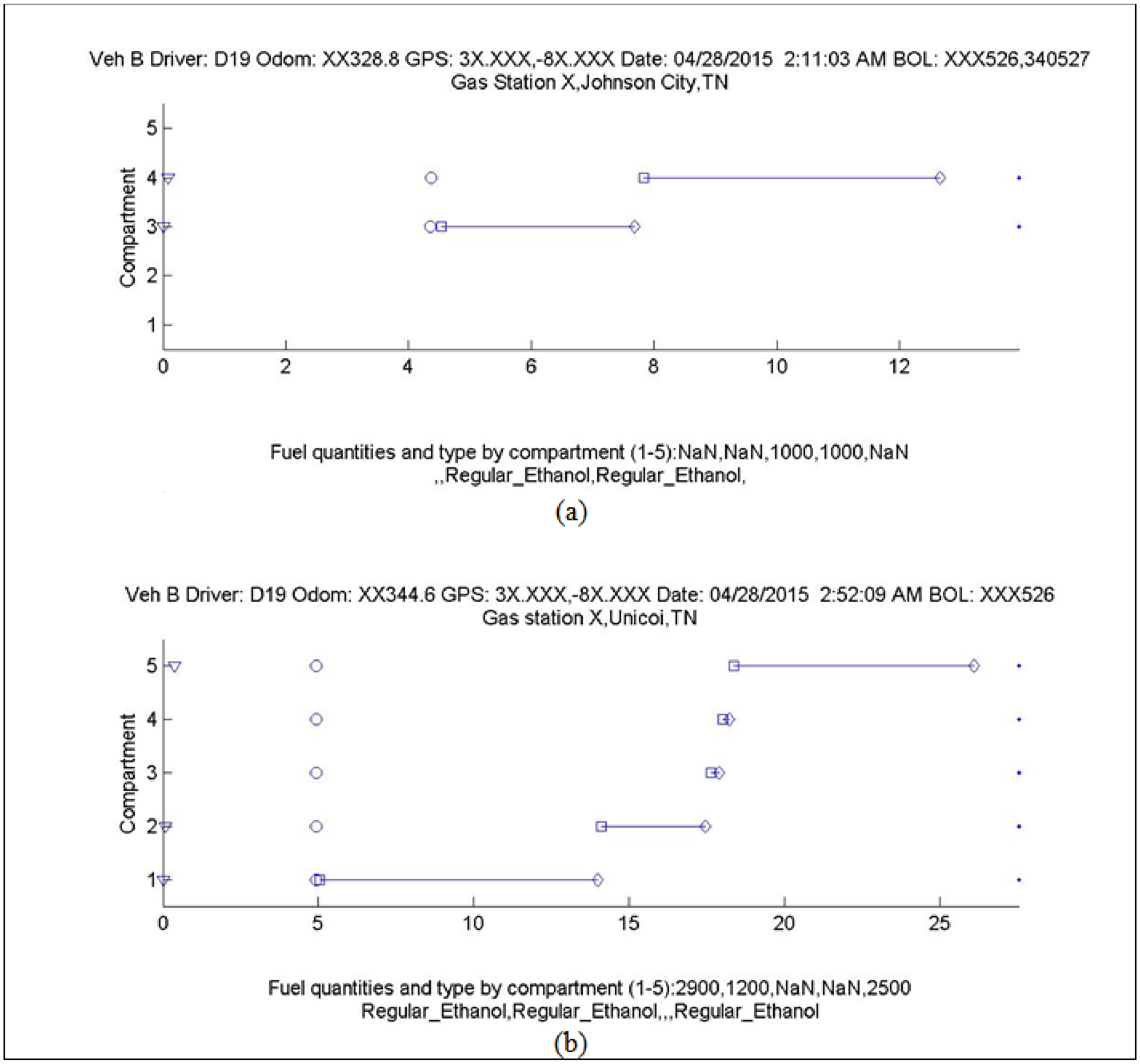


Figure 92. These charts show an offload at two locations - first location (a) and second location (b).

It is a little unusual for the valves of compartments 3 and 4 to have been operated at the second stop, since they were already offloaded at the first stop.

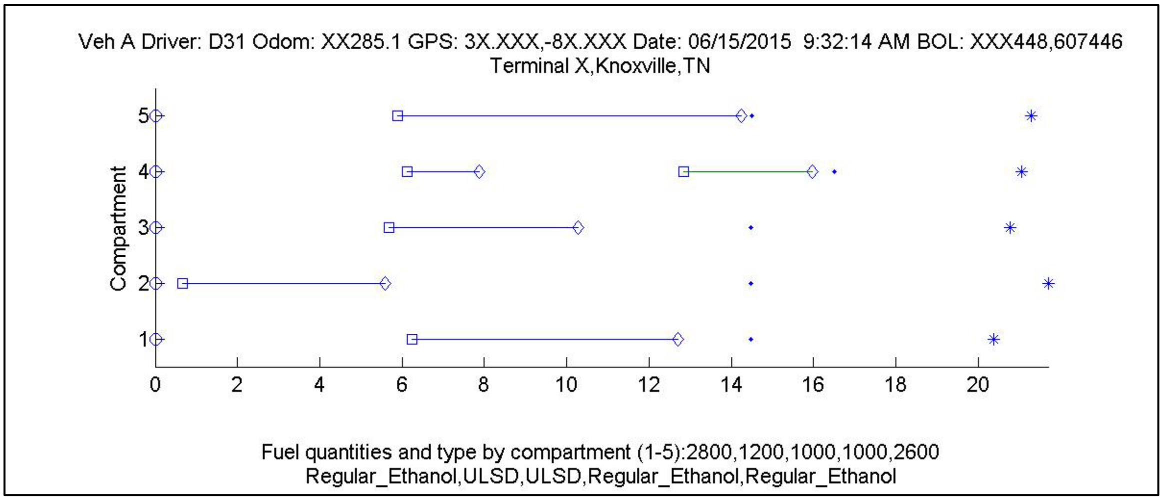


Figure 93. This chart shows an example of a "gap" in the loading valve sequence for compartment 4.

An example that could cause this is a “splash mix” in which regular fuel is loaded from one riser at the terminal, and Ethanol is loaded from a separate riser at the terminal.

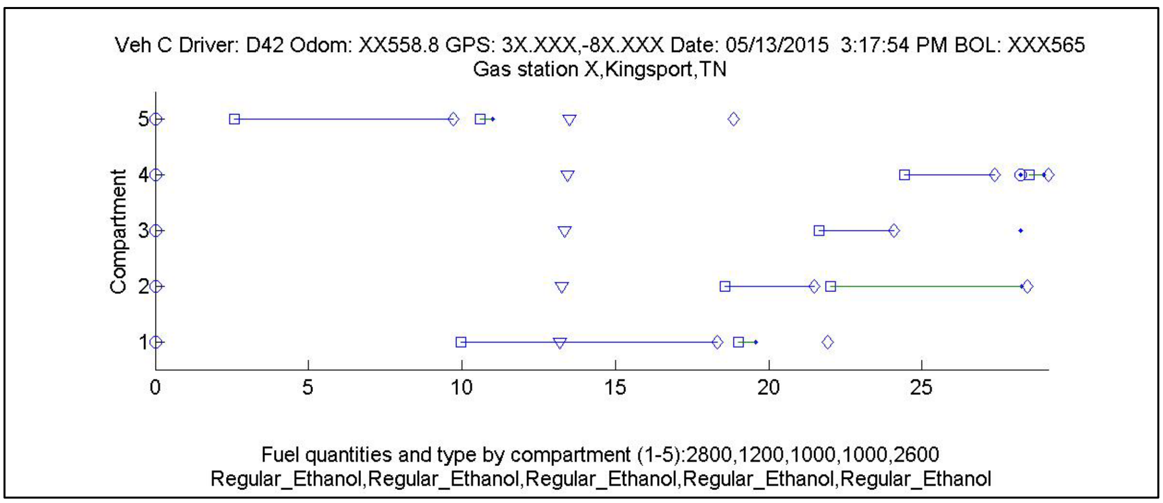


Figure 94. This chart shows an example of a “gap” in the offloading valve sequence for compartments 2 and 4.

An example that could cause this is when one Regular Ethanol tank in the ground has become full, and the driver switches the hose to a different tank to drain the remainder of the fuel in that compartment.

The following 4 plots show unusual valve actual sequences. It is not clear what caused these.

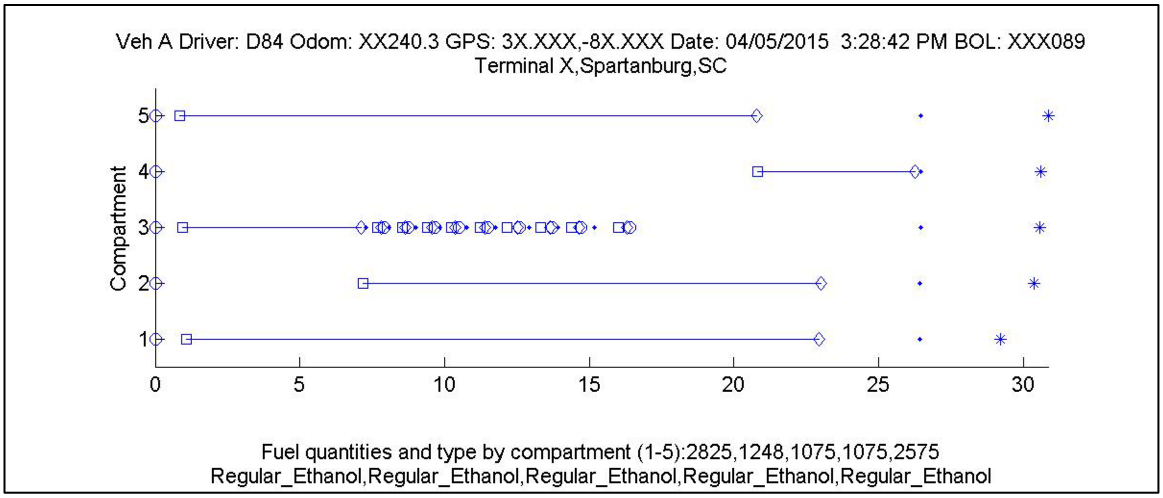


Figure 95. This chart shows an unusual frequent opening and closing of the primary valve for compartment 3 between 6 and 16 minutes.

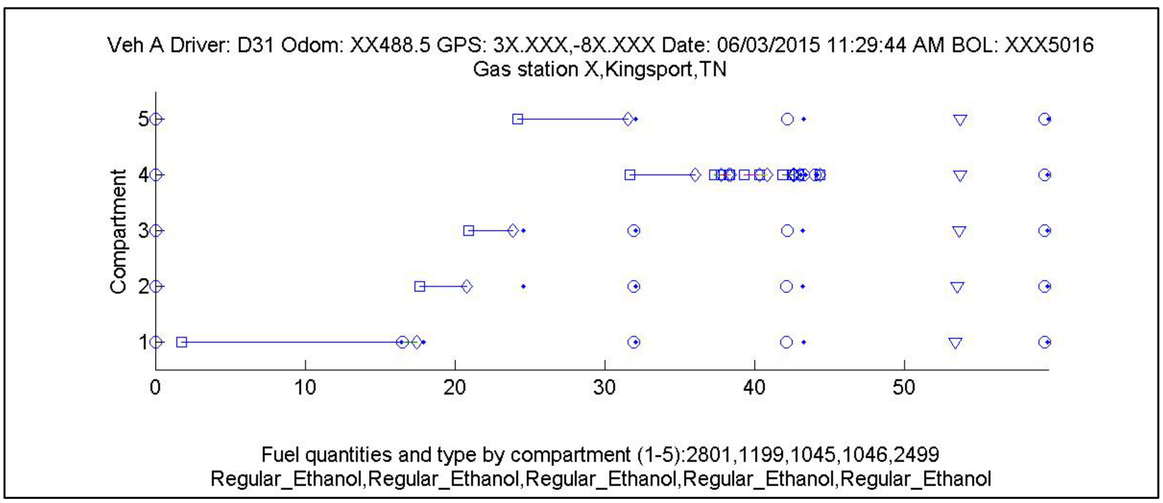


Figure 96. This chart shows an unusual frequent opening and closing of the primary valve for compartment 4 between 37 and 44 minutes.

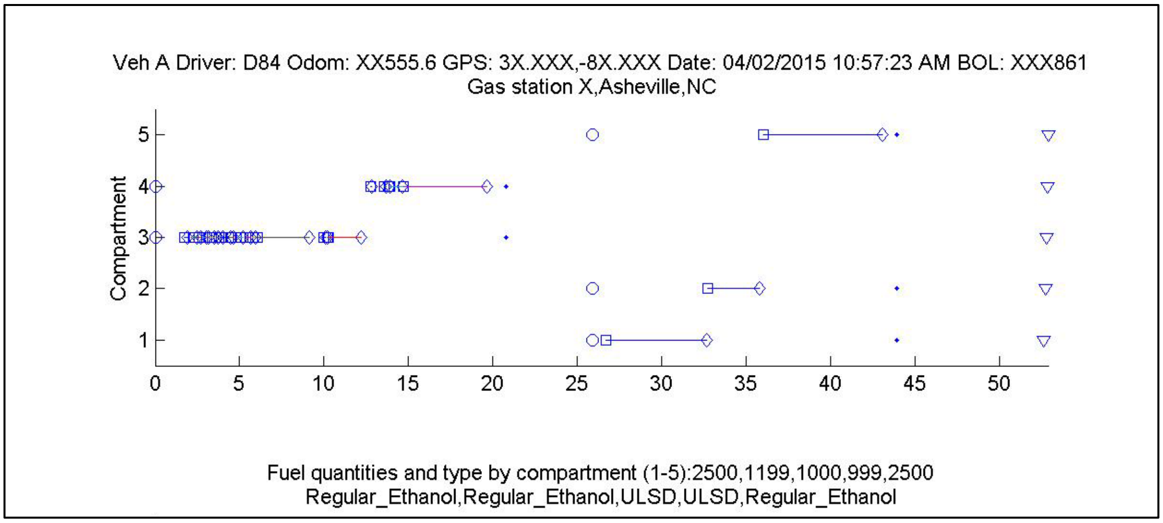


Figure 97. This chart shows an unusual frequent opening and closing of the primary valve for compartment 3 between 2 and 13 minutes, and for the compartment 4 primary loading valve between 13 and 15 minutes.

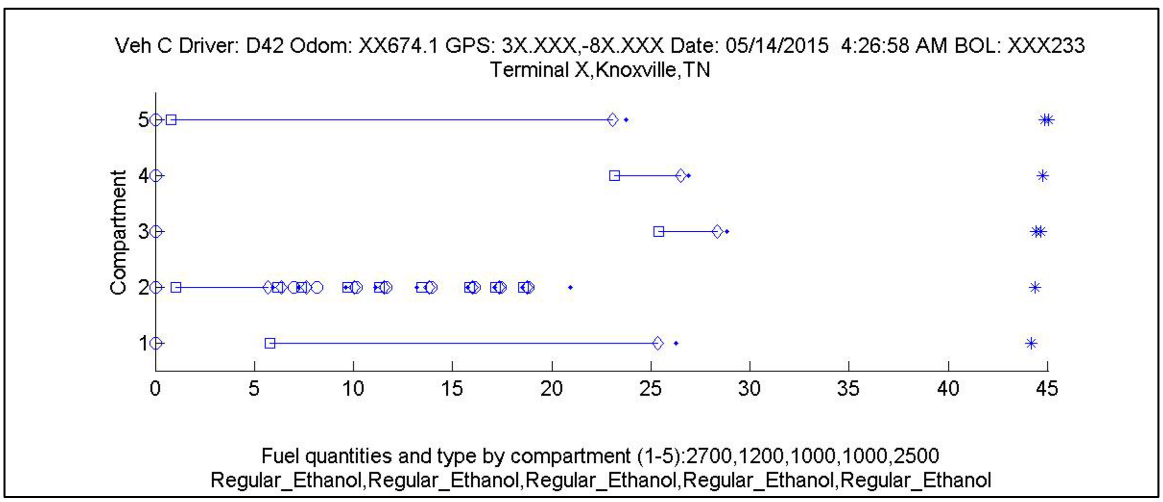


Figure 98. This chart shows an unusual frequent opening and closing of primary valve for compartment 2 between 6 and 18 minutes.

APPENDIX K: NOVEMBER 5, 2015 TECHNICAL WORKING GROUP MEETING

ORNL hosted the FHWA, FMCSA, and FTE technical work group at the NTRC building in Knoxville, Tennessee on November 5, 2015, for the FTE project closeout meeting. The agenda for this meeting was as follows:

Event contact	Gary Capps, 865-946-1285 (office); 865-603-4363 (mobile); cappsgj@ornl.gov	
Thursday, November 5, 2015 NTRC, Multipurpose Conference Room (2nd Floor)		
Time	**Event**	**Lead**
8:30am – 8:45am	Welcome and Introductions with Video *(Coffee and bagels will be available)*	Gary Capps
8:45am – 9:00 am	FHWA Office of Highway Policy Information	Michael Dougherty
9:00am – 9:15am	FHWA Exploratory Advanced Research Program	David Kuehn
9:15am – 10:00am	STSWRF Analysis Presentation and FDAS Review	Oscar Franzese and Adam Siekmann
10:00 – 10:15am	Break	
10:15am – 10:45am	Army Logistics Innovation Agency's Safeguarding Fuel Distribution	Grady Embrey (via teleconference)
10:45am – 11:00am	LBT, Inc. Overview (15 min)	Tom Anderson (LBT)
11:00am – 12:00pm	Working Lunch • Air-Weigh Proposed System Improvements (30 min) • ISE Proposed System Improvements (30 min)	Andrew Meier (Air-Weigh) Joe Barry (ISE)
12:00pm – 12:45pm	Lessons Learned	ORNL Team
12:45pm – 1:45pm	• Demonstration of Revised FDAS • Discussion of overall system requirements and improvement with Technical Working Group	Adam Siekmann All
1:45pm –2:00	Break	All
2:00pm – 2:45pm	Group discussion of overall system requirements and improvement with Industry Partners and Next Generation Carrier Interface Group	All

Event contact	Gary Capps, 865-946-1285 (office); 865-603-4363 (mobile); cappsgj@ornl.gov	
Thursday, November 5, 2015 **NTRC, Multipurpose Conference Room (2nd Floor)**		
Time	**Event**	**Lead**
2:45pm – 3:15pm	Technical Summarization	All
3:15pm – 4:00pm	Fuels, Engines and Emissions Research Lab Tour	Brian West
4:00pm – 4:45pm	Power Electronics and Electric Motors Research Lab Tour	Burak Ozpineci
4:45pm – 5:00pm	Adjourn	All

The following individuals were in attendance for the project closeout meeting:

Federal Highway Administration
- Michael Dougherty
- David Kuehn

Volpe, National Transportation Systems Center
- Jeffrey Bellone

Federal Motor Carrier Safety Administration (FMCSA)
- Chris Flanigan
- Luke Loy

FTE Technical Working Group Members
- Al Howard, Retired IRS Consultant
- Dawn Lietz, Nevada Department of Motor Vehicles
- Rodney Pendley, Tennessee Department of Revenue
- Wayne Rhoads, Alabama Department of Transportation Bureau of Finance and Audit
- Chuck Ulm, Maryland Comptroller Field Enforcement Division

Industry Partners
- Andrew Meier, Air-Weigh
- Joe Barry, Innovative Software Engineering (ISE)
- Tom Anderson, LBT, Inc.

Army Logistics Innovation Agency
- Mr. Grady Embrey (was not able to fully participate)

Authenix, Inc.
- Kathy Payn

Oak Ridge National Laboratory
- Gary Capps
- Oscar Franzese
- Adam Siekmann
- Mary Beth Lascurain
- Alan Barker
- Sheila Moore

David Smith
Diane Davidson
Kim Askey

Tennessee Highway Patrol

Tpr. James Fillers
Tpr. Paul Penley
Tpr. Ray Stubblefield

Figure 99 shows a photo taken at the November 5, 2015 close out meeting.

Figure 99. Technical working group in session.

Salient information coming from this meeting has been folded into Chapters 3, 4, and 5 of this report.

APPENDIX L: ALTERNATIVE VEHICLE WEIGHT ASSESSMENT

In October 2015 ORNL conducted a short test to determine, as a first approximation, the feasibility of certain signals present in the vehicle databus to assess its weight. One Pilot Flying J fuel tanker vehicle was instrumented with a mini data logger which captured the databus signals shown in Table 34. The 18-mile trip started at a Knoxville, Tennessee area fuel terminal. The fuel cargo was delivered to a Pilot gas station in the vicinity of the McGhee-Tyson Airport (southwest of Knoxville), and ended in the same area where it started (see Figure 100 and Figure 101).

Table 34. Vehicle Databus Signals Queried

Signal #	Signal Queried	Signal Read?
1	Engine Torque Limit Request - Minimum Continuous (%)	No
2	Seat Belt Switch (bit)	No
3	Accelerator Pedal Position 1 (%)	Yes
4	Engine Percent Load At Current Speed (%)	Yes
5	Engine Torque Mode (bit)	Yes
6	Driver's Demand Engine - Percent Torque (%)	Yes
7	Engine Speed (rpm)	Yes
8	Engine Demand - Percent Torque (%)	Yes
9	Transmission Torque Converter Ratio (Ratio)	No
10	After Treatment Diesel Oxidation Catalyst Intake Temperature (C)	Yes
11	After Treatment Diesel Particulate Filter Lamp Status (bit)	Yes
12	After Treatment Diesel Particulate Filter Regeneration Inhibit Lamp Status (bit)	Yes
13	After Treatment Diesel Particulate Filter Regeneration Start Switch Status (bit)	Yes
14	After Treatment Diesel Particulate Filter Outlet Pressure (kPa)	Yes
15	After Treatment 1 Total Fuel Used (liters)	No
16	Particulate Trap Differential Pressure (kPa)	Yes
17	Particulate Trap Outlet Gas Temperature (C)	Yes
18	Particulate Trap Intake Gas Temperature (C)	Yes
19	Wheel Based Speed (m/s)	No
20	Transmission Torque Limit (Nm)	No
21	Engine Total Average Fuel Rate (l/h)	No
22	Engine Total Average Fuel Economy (km/L)	No
23	High Limit Threshold for Minimum Continuous Torque from Retarder (%)	No
24	Engine Maximum Continuous Torque (%)	No
25	Engine Minimum Continuous Torque (%)	No
26	Engine Power (kW)	No
27	Engine Peak Torque 1 (Nm)	No
28	Engine Peak Torque 2 (Nm)	No
29	Engine Torque Limit Feature (bit)	No
30	Torque Limiting Feature Status (bit)	No
31	Engine Torque Limit 1 Transmission (Nm)	No
32	Engine Torque Limit 2 Transmission (Nm)	No

Signal #	Signal Queried	Signal Read?
33	Engine Torque Limit 3 Transmission (Nm)	No
34	Engine Torque Limit 4 Transmission (Nm)	No
35	Engine Torque Limit 5 Switch (Nm)	No
36	Engine Torque Limit 6 Axle Input (Nm)	No
37	Trip Fuel (Gaseous) (kg)	No
38	Trip PTO Time (Seconds)	No
39	Trip Average Fuel Rate (Gaseous) (kg/h)	No
40	Trip Average Fuel Rate (l/h)	Yes
41	Trip Average Engine Speed (rpm)	No
42	Trip Drive Fuel Used (Gaseous) (kg)	No
43	Trip PTO Moving Fuel Used (Gaseous) (kg)	No
44	Trip PTO Non-moving Fuel Used (Gaseous) (kg)	No
45	Trip Vehicle Idle Fuel Used (Gaseous) (kg)	No
46	Trip Drive Fuel Economy (Gaseous) (km/kg)	No
47	Trip Drive Fuel Used (l)	No
48	Trip PTO Moving Fuel Used (l)	No
49	Trip PTO Non-moving Fuel Used (l)	No
50	Trip Vehicle Idle Fuel Used (l)	No
51	Trip Drive Fuel Economy (km/L)	No
52	High Resolution Total Vehicle Distance (m)	Yes
53	High Resolution Trip Distance (m)	Yes
54	Engine Total Idle Fuel Used (l)	Yes
55	Nominal Friction - Percent Torque (%)	Yes
56	Estimated Engine Parasitic Losses - Percent Torque (%)	Yes
57	Total Vehicle Distance (km)	Yes
58	Engine Percent Torque At Idle Point 1 (Engine Configuration) (%)	No
59	Engine Percent Torque At Point 2 (Engine Configuration) (%)	No
60	Engine Percent Torque At Point 3 (Engine Configuration) (%)	No
61	Engine Percent Torque At Point 4 (Engine Configuration) (%)	No
62	Engine Percent Torque At Point 5 (Engine Configuration) (%)	No
63	Engine Reference Torque (Engine Configuration) (Nm)	No
64	Engine Requested Torque Control Range Lower Limit (Engine Configuration) (%)	No
65	Engine Requested Torque Control Range Upper Limit (Engine Configuration) (%)	No
66	Engine Moment of Inertia (kg/m)	No
67	Engine Default Torque Limit (Nm)	No
68	Engine Total Hours of Operation (Hours)	Yes
69	Seconds (Seconds)	Yes
70	Minutes (Mins)	Yes
71	Hours (Hours)	Yes
72	Month (Months)	Yes
73	Day (Days)	Yes
74	Engine Trip Fuel (l)	Yes

Signal #	Signal Queried	Signal Read?
75	Engine Coolant Temperature (C)	Yes
76	Engine Oil Pressure (kPa)	Yes
77	Wheel-Based Vehicle Speed (kph)	Yes
78	Engine Fuel Rate (l/h)	Yes
79	Barometric Pressure (kPa)	Yes
80	Latitude	Yes
81	Longitude	Yes
82	Altitude	Yes
83	Velocity	Yes
84	Heading	Yes
85	Date	Yes
86	Time	Yes
87	FixType	Yes
88	NumSats	Yes

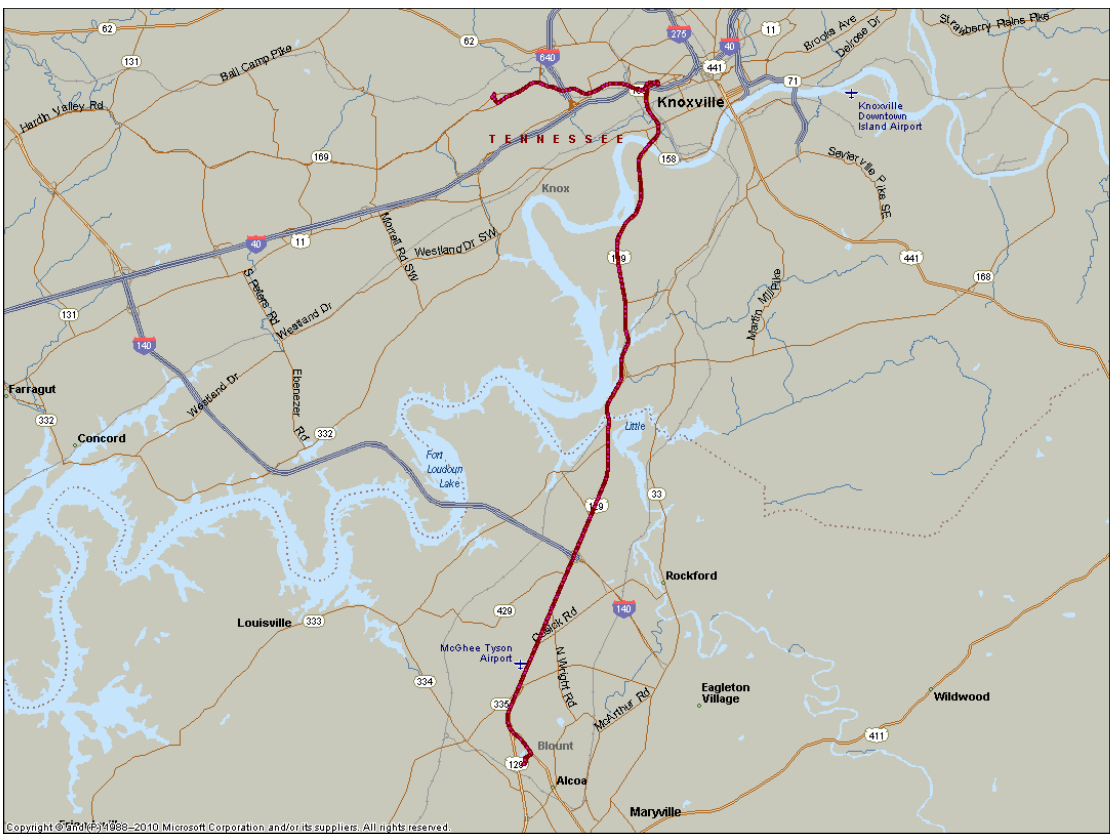


Figure 100. Trip from the fuel terminal to the Pilot gas station (17.6 m) with a loaded trailer.

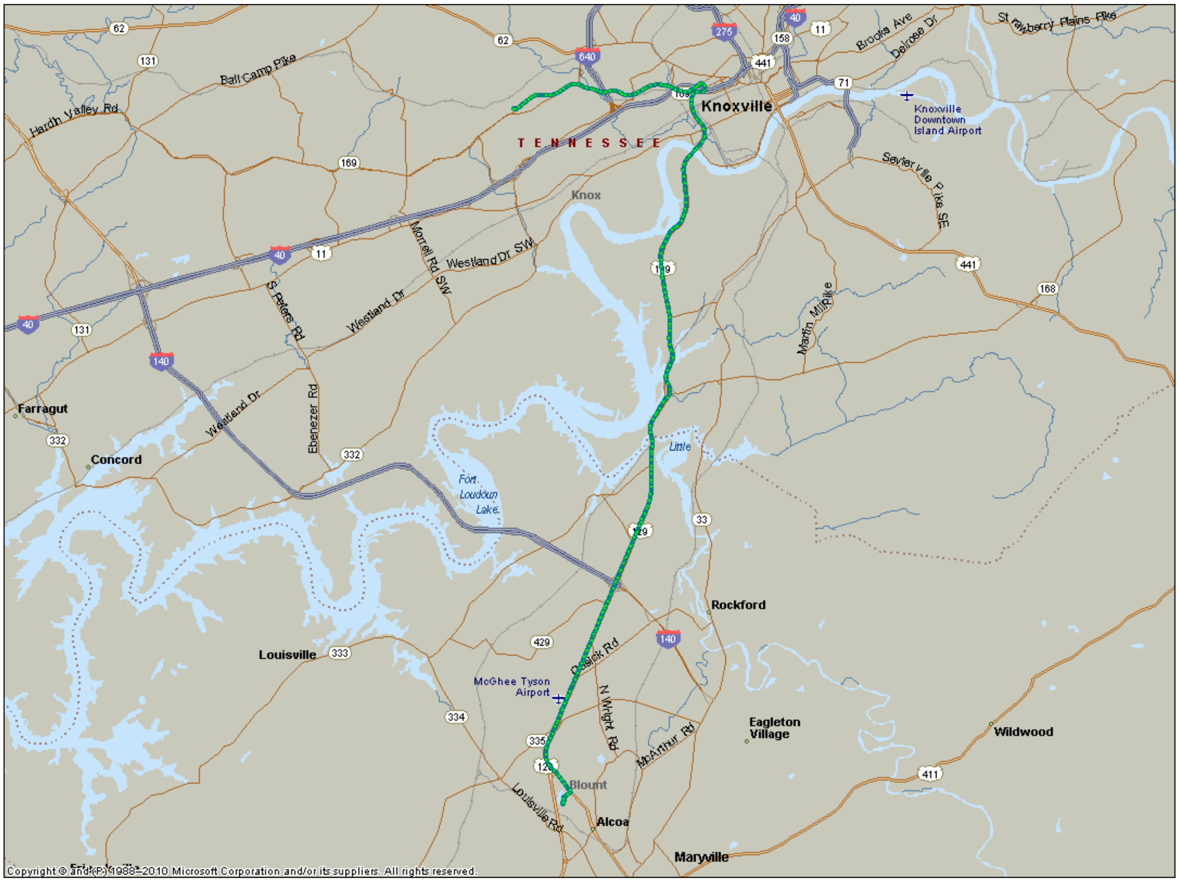


Figure 101. Trip from the Pilot gas station to the fuel terminal area (17.8 m) with an empty trailer.

As part of other projects sponsored by the U.S. Department of Energy (DOE), ORNL conducted research in which the effect of vehicle weight on fuel efficiency was extensively studied showing significant differences in fuel efficiencies between loaded and empty vehicles. In these DOE projects, class-8 commercial vehicles were instrumented with data acquisition systems that read signals from the vehicle's databus similar to those collected during this test.

The computation of the vehicle fuel efficiency (FE) can be performed, on an on-going basis, by integrating over time the Wheel-Based Vehicle Speed [km/h] and Engine Fuel Rate signals [l/h] (rows 77 and 78, respectively, in Table 34) and dividing the first one by the second.

Table 35 shows the results for the ending points of the two legs of the trip computed in this way for this particular vehicle. Although the computed fuel efficiencies show when the vehicle was loaded (low FE) and when it was empty (high FE), the two signals used in the computations had a significant proportion of readings that presented errors. Therefore these signals were unreliable and it was not possible to make any inferences about the vehicle's FE using this information.

Table 35. Fuel Efficiency for Loaded and Empty Trailer Computed Using Engine Fuel Rate [l/h] and Wheel-Based Vehicle Speed [km/h]

Vehicle Loading State	Total Fuel Consumed	Total Distance Traveled	Fuel Efficiency
Loaded	2.64 [l], 0.70 [gal]	0.75 [km], 0.47, [mi]	0.67 [mpg]
Empty	4.46 [l], 1.18 [gal]	9.27 [km], 5.76, [mi]	4.89 [mpg]

Table 36 shows the percentage of observations for the two variables under consideration that did not present errors and therefore could be used in the computations. Those percentages ranged from 18% for the Engine Fuel Rate signal (loaded vehicle trip) to 64% for the Wheel-Based Vehicle Speed signal (empty vehicle trip). With these low percentages of "good" readings the vehicle FE, computed with these signals, could not be used to determine vehicle loading state.

Table 36. Percentage of Total Observations without Errors - Engine Fuel Rate [l/h] and Wheel-Based Vehicle Speed [km/h]

Vehicle Loading State	Total Fuel Consumed	Total Distance Traveled
Loaded	18.21%	26.60%
Empty	59.36%	64.12%

However, other signals can be used to perform these computations, such as Engine Trip Fuel [l] and High Resolution Total Vehicle Distance [m] (rows 74 and 52, respectively, in Table 34). These signals do not allow for continuous calculation of the vehicle's FE, but they permit the computation of FE after the vehicle has traveled a certain distance (e.g., 5 miles).

Table 37 shows the computations of the vehicle's FE for each leg of the trip, which were defined as the distance traveled between engine off and engine on events. There is a clear difference in FE (low when the vehicle is loaded and high when it is empty), that can be used to infer the loading state of the vehicle and to determine without the use of weight sensors, whether the vehicle was loaded or offloaded.

Table 37. Fuel Efficiency for a Loaded and Empty Trailer Computed Using Engine Trip Fuel [l] and High Resolution Total Vehicle Distance [mi] for Each Leg of the Trip

Vehicle Loading State	Total Fuel Consumed	Total Distance Traveled	Fuel Efficiency
Loaded	12.00 [l], 3.17 [gal]	28.60 [km], 17.77 [mi]	5.61 [mpg]
Empty	8.00 [l], 2.11 [gal]	28.70 [km], 17.83 [mi]	8.44 [mpg]

These signals can be used to compute FE when a certain distance has been traveled after engine startup.

Table 38 shows the computations of FE every 5 miles (approximately) for each leg of the trip. The computations of FE are cumulative. That is, at 5 miles the computation of FE is performed considering the fuel consumed from mile 0 (last engine start event) to 5 miles; at 10 miles the computations use the fuel consumed from mile 0 to mile 10, and so on. The FE data that was computed in such a way is graphed and displayed in Figure 102. There seems to be a strong indication that this methodology can be used to differentiate the vehicle loading state, even after traveling only 5 miles. Fluctuations in FE measurements are due to topography and road traffic conditions.

Table 38. Fuel Efficiency for a Loaded and Empty Trailer Computed Using Engine Trip Fuel [l] and High Resolution Total Vehicle Distance [mi]

Distance Traveled [miles]	Fuel Efficiency [mpg] Loaded	Fuel Efficiency [mpg] Empty
5.03	3.81	7.62
10.07	4.76	9.53
15.10	5.20	9.53
17.77	5.61	
17.83		8.44

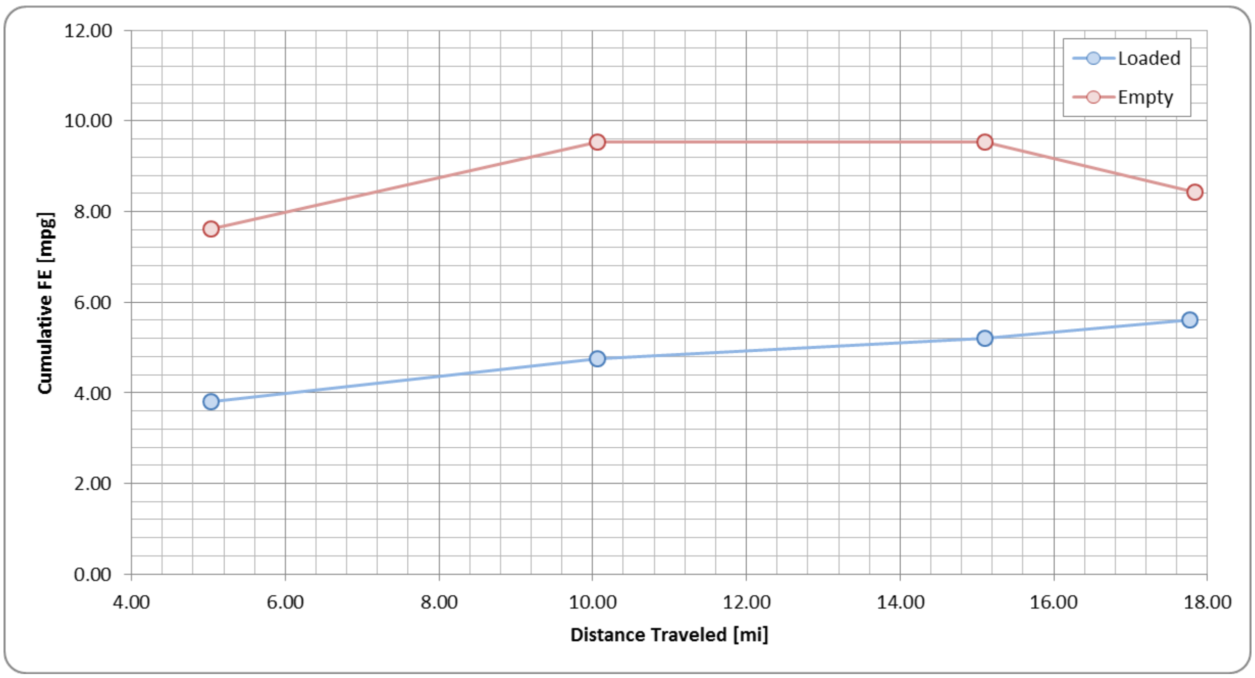


Figure 102. Fuel efficiency observations computed between engine-on and engine-off events.

For the case in which signals such as the Engine Trip Fuel [l] and High Resolution Total Vehicle Distance [m] are not available (and therefore FE cannot be computed as described above), it is possible to use other signals to make a determination of the vehicle loading state between engine on and off events. Figure 103 to Figure 105 show other signals for the same trip (torque-related signals). The first leg of the trip (loaded vehicle) goes from point 1 to point 1,966, and the second leg (vehicle empty) goes from point 1,967 to point 4,070 (the end of the graph). In these figures, the "loaded" and "empty" portions of the trip are separated by a vertical line (at point 1,966 on the horizontal axis). The horizontal lines in the graphs represent the average of the signal in each one of the two legs of the trip. Those average lines show that there are visibly higher torque signals with a full loaded vehicle compared to an empty trailer. If high accuracy in vehicle weight is not a critical factor, these differences can be used to infer (without weight sensors) when the vehicle is loaded and when it is empty.

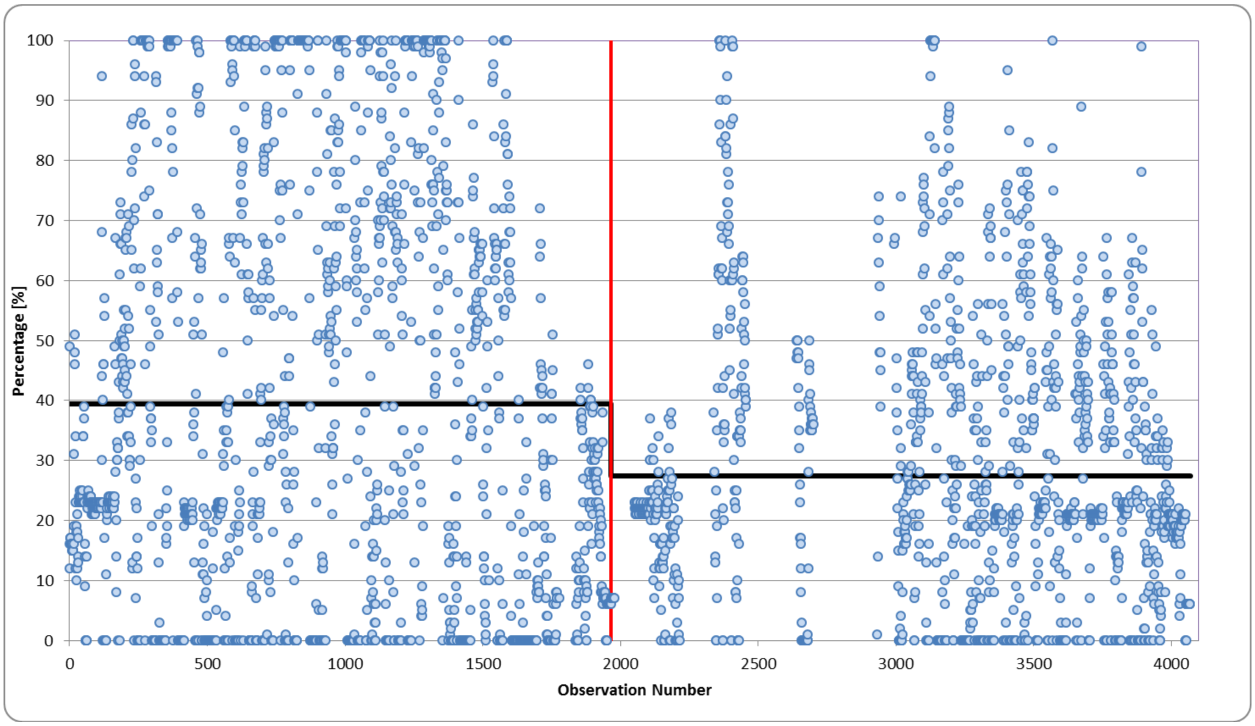


Figure 103. Engine percent load at current speed [%] loaded and empty trailer.

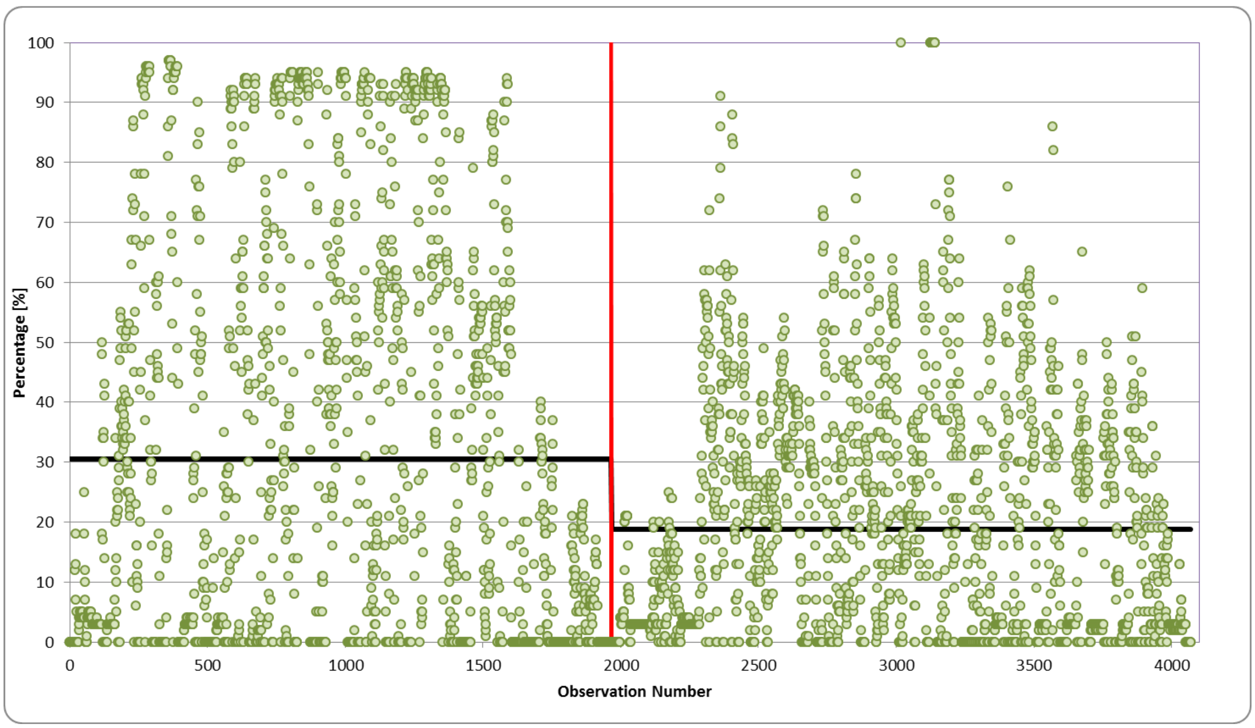


Figure 104. Engine percent load at current speed [%] loaded and empty trailer.

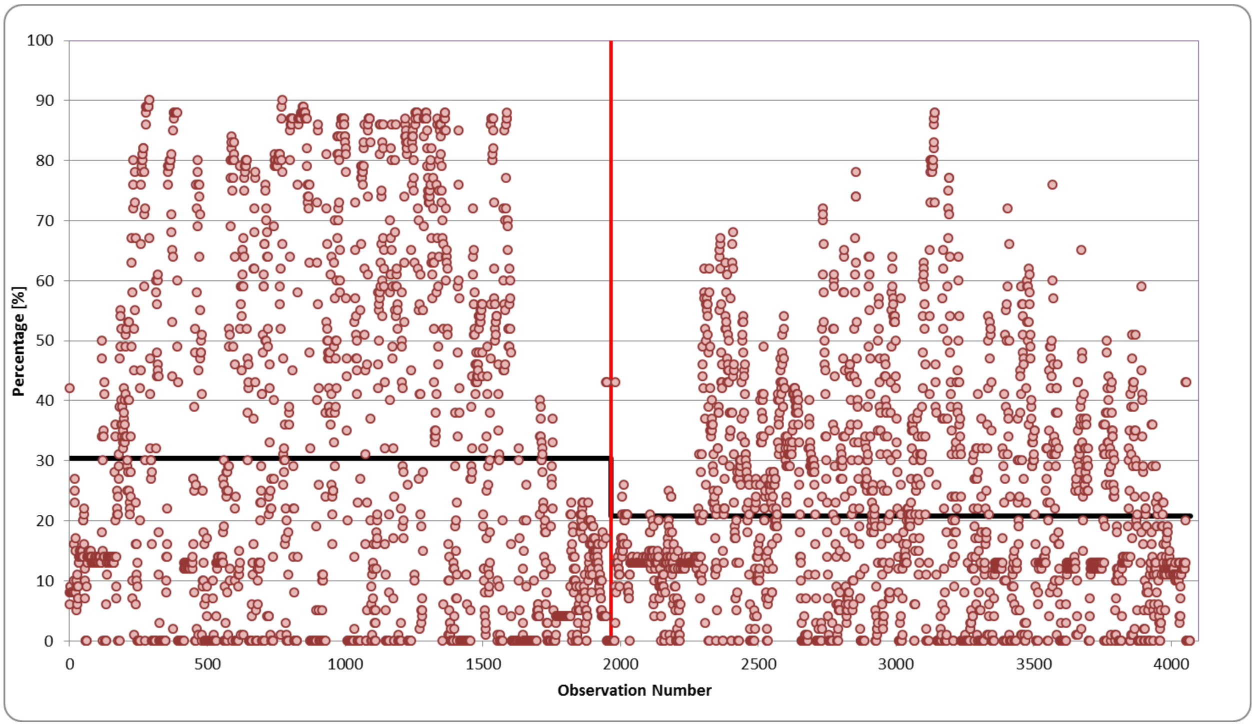


Figure 105. Engine demand - percent torque [%] loaded and empty trailer.

APPENDIX M: NATIONAL TANK TRUCK CARRIERS MEETING

Oscar Franzese and Gary Capps (ORNL) accompanied Michael Dougherty (FHWA, contracting officer's technical representative [COTR]) to the National Tank Truck Carriers 2015 Tank Truck Week exhibit and conference held November 12, 2015 in Houston, Texas (see Figure 106). The FTE video was presented along with slides that focused on the benefit of the FTE technology to the petroleum tanker industry. Face-to-face discussions about the technology were held with the following companies present at the conference:

Company	**Contact**	**Business**
AssetWORKS	Brandon Lakey	Oil-gas Software and Hardware
BASE	Al McNamara	Tanker Trailer Telematics and RFID Readers
CIVACON	Chris Gooding	Tanker Trailer Valve/Electronics Mfg
DIXON BAYCO	Daniel Burke	Tanker Trailer Valve/Electronics Mfg
Etnyre	Dean Fox	Tanker Trailer Mfg
Fort Vale	Jack Mueliner	Tanker Trailer Valve Mfg
MACLTT	Jim Maiorana	Tanker Trailer Mfg
NUVE	Mike Greig	Tanker Trailer Electronics Mfg (security)
PetroSync	Jo Ann Loftin	Crude Oil In-Cab Electronic Log
Polar	Coby McGuire	Tanker Trailer Mfg
Return Hauler	Peter Bennetto	Trailer Manufacturer
Scully	Christopher McGonagle	Overfill Protection Systems
Scully	Robert McGonagle	Overfill Protection Systems
Standfast	Ted O'Brien	Height Safety
TANKCON	Alain Chatillon	Tanker Trailer Mfg
Titan Logix Corp.	Brett Schmidt	Tanker Trailer Electronics Mfg
Tremcar	Andy Mulvey	Tanker Trailer Mfg
Ultraflo	Jeff Cross	Tanker Trailer Valve Mfg
USA Harness	Brett Miller	Cable and Harness Mfg
Westmor	Mike Hennen	Tanker Trailer Mfg and Full-line Petroleum Monitoring Systems

Figure 106. 2015 National Tank Truck Carriers meeting in Houston, Texas.

Noticeably absent from this industry meeting were petroleum hauling carriers who are the end-use market for the FTE technology. The absence of carriers prevented an assessment of their interest in the technology relative to fuel theft, tampering, and safety.

In attendance at the event were tanker manufacturers and tanker component manufacturers. Briefings were provided about the FTE work to six tanker-trailer manufacturers. Briefings were provided to thirteen manufacturers of tanker-trailer technology or telematics systems.