Supply Chain-based Solution to Prevent Fuel Tax Evasion

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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 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 oil products and the carriers’ customers. This paper presents a system developed by the Oak Ridge National Laboratory for the Federal Highway Administration which has the potential to reduce or eliminate many fuel-tax evasion schemes. The solution balances the needs of tax-auditors and those of the fuel-hauling companies and their customers. The technology was deployed and successfully tested during an eight-month period on a real-world fuel-hauling fleet. Day-to-day operations of the fleet were minimally affected by their interaction with this system. The results of that test are discussed in this paper.
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 has been assessed to be somewhere between $1 billion and $3 billion per year. Several countermeasures, including moving the point of taxation up in the supply chain (1988 for gasoline and 1994 for diesel) and adding red-dye markers to diesel fuel (1993) to be used for non-taxable purposes, resulted in significant increases in tax revenue collected and were attributed to a decrease in fuel-tax evasion. Nevertheless, there still exist fuel-tax avoidance schemes that cannot be easily addressed by a single countermeasure but with 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 oil products and their customers.

This paper presents a system developed by Oak Ridge National Laboratory (ORNL) for FHWA which has the potential to reduce or eliminate many fuel-tax evasion 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 (important for tax auditors) and detect potential illicit operations such as fuel theft (important for carriers and their customers, and may 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 instrumenting three vehicles and collecting real-world data during an eight-month period.

The focus of this paper is on the description of components of this system and the analysis of some of the extensive real-world information collected in this project. The paper also presents some general statistics, including distance traveled by carriers from terminals to the retail point-of-sale—which contradicts some common held belief that long fuel distribution trips could indicate suspicious activities—distributions of fuel-flowing times for loading and offloading activities which would permit identifying potential illicit activities at certain locations, and the distribution of the first two valve actuations elapsed times, which would identify potential fuel theft.

METHODOLOGY

Literature Review

A significant amount of research has been conducted determining the amount of fuel tax evasion (FTE) that the nation faces and in trying to control or minimize this problem. As early as 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 [1]. In the same report, the Government Accountability Office (GAO) identifies the most prevalent methodology to evade fuel taxes at that time a scheme named “daisy chaining.” This method involved a company
buying fuel tax free, selling that fuel to other companies in the organization implementing this
scheme, and finally selling the fuel to a retailer as tax-paid fuel but not submitting the tax
collected to the IRS. If the scheme was discovered the last company selling the fuel did not have
any assets or ceased operations making it impossible for the IRS to collect the taxes. 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.

In response to this, numerous other schemes of FTE started to appear, or became more
evident. A NCHRP Report 623 [2] describes in detail many of these schemes, including:
bootlegging across state lines (i.e., fuel is bought in state A which has a lower fuel tax than a
neighbor state B where it is sold without filing the proper “export” documentation; the
differential in fuel tax is the amount evaded); false claim 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 equipment is
malfunctioning, a tank trucker can purchase fuel as tax free–e.g., for construction or farming
equipment usage–but needs to add the dye directly to the tank for blending; not adding the dye to
the fuel, the tax evaded is the amount of tax 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 [3] presents a very comprehensive study
aimed at determining the FTE rates. Similar to the NCHRP Report [2], this study also includes a
description of the most prevalent schemes to avoid paying fuel taxes, but it also analyzes and
quantifies tax evasion in Montana. Using different techniques to estimate revenue losses, the
authors conclude that in 2004 diesel taxes errors, omissions and evasion (EOE) were about 16.3
percent of total tax liability (equivalent to 43.4 million gallons or $12.1 million). In contrast,
they found that EOE related to gasoline taxes were not as significant as those of diesel (about 2.1
percent of total tax liability; equivalent to $2.8 million or 10.3 million gallons 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 other
measures to curtail FTE.

Marion and Muehlegger [4] 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 perfect 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 TRB Special Report 285 [5] addresses the effect of
improving fuel efficiencies in fuel-tax collected, and forecasting 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 [6]). For
example, in 2003 New Jersey found that the annual cost of toll collection was about 92% of what
it costed the federal government to collect the fuel tax across the entire nation during that year (see the Capps et al. report [7]).

The Virginia’s Long-Range Multimodal Transportation Plan 2007-2035 [8] included the review of several other studies in which similar conclusions as those presented in the Oh and Sinha report [6] 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 auditing and only a few on the deployment of technology (e.g., red-dye applied to diesel). In the first phase of the study presented here, 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 a confirmation 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, no production of objectionable emissions or by-products, no visibility to the naked eye, chemical stability under thermal extremes over the period of months, and sufficient 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 trailer (switches, level sensor, marker sensor, weight), convey the sensor signals from the trailer to the tractor and send the data packets to a back office system (BOS) for processing. This study proved the technical feasibility of this FTE detection solution but it also demonstrated the need to substantially decrease the cost of chemical markers required to make the system economically viable.

System Architecture

The architecture of the system included discrete, trailer-borne valve and hatch sensors to monitor the activity of these elements. These sensors communicated with an on-board computer (a telematics provider device in this test) through the trailer-to-tractor communications unit (T2TCU) which was developed for the project. The T2TCU sent sensor-activity data to the tractor cab via a dedicated J1939 communication cable which allowed for real-time posting to the tractor’s J1939 data bus, and from there to the telematics device. The suite of instrumentation for the test vehicles also included a self-weighing system. Although such a system may be cost-prohibitive for a production system, its inclusion in the testing allowed the researchers to conduct a cursory analysis of the quality and utility that such a system provides regarding estimates of fuel loading and offloading.

Figure 1 shows a schematic diagram of the system architecture. On the top-left area, the diagram shows the on-board telematics device. This device, which could be replaced with a smartphone or a tablet, had a GPS (Global Positioning System) device to determine the spatial location of the vehicle; a wireless communication system that used a cellular network; and a connection and the capability to read information from the tractor data bus such as valve and hatch actuations, as well as trailer and tractor weight information (this data bus connection is not shown in the diagram).

A user interface was deployed on the device to allow the driver to enter fuel-related information consisting of fuel type, fuel quantity, destination of the load, diversion number (if the destination was changed after loading the tanker), bill-of-lading number, and other parameters. This interface was also used to convey any alerts to the driver. Also deployed on the on-board telematics device was an application named the on-board Evidentiary Reasoning
System, or obERS. This application merged all the information collected by the different sensors deployed (valve, hatch, weight, and spatial location sensors, as well as vehicle kinetic state) and driver input.

The central part of Figure 1 shows two other sub-components of the system which resided in the telematics provider back-office system (TBOS): (1) the back-office Evidentiary Reasoning System (boERS) and (2) the Carrier Interface (CI). Finally, the lower-right area of the diagram shows the Fuel Distribution and Auditing System (FDAS), the third main component of the FTE avoidance solution developed in this project. The FDAS runs on a separate server and consists of a centralized database and a tax-auditor user interface.

Concept of Operations

The trailer, equipped with hatch and valve monitoring switches, sent all opening and closing event data to the tractor cab via the T2TCU. The onboard telematics device, using the ORNL developed obERS merged the vehicle’s location and kinetic state with information sent by the on-board sensors and determined if any alerts were to be issued. Three types of alerts could be generated: (1) a safety alert (e.g., vehicle moving with an open valve) conveyed to the driver in real-time through the on-board telematics device; (2) a tampering alert (a hatch is open, a sensor is disconnected) sent real-time using the on-board communication systems to the carrier interface at the TBOS; and (3) a sensor malfunctioning alert (a faulty sensor) added to the on-board fuel logs and later added to the CI. All the alerts were also included into the fuel log file together with any action taken by the driver (only for safety alerts). Information from shipping documents entered by the driver through the on-board device interface was geo-coded and added to the fuel log file. Those log files were sent at given intervals to the TBOS and temporarily stored to be processed at a time when the boERS determined that the shift for that particular driver had ended and all the corresponding fuel logs had been received (see Figure 1).

The boERS application was “called” at periodic intervals by the operating system running on the TBOS. The application then processed all the fuel logs that were ready and generated, for each compartment and location, a determination of whether the tanker was being loaded or offloaded (by taking into consideration the information from the weight sensors), the valve operation sequence (each compartment has two valves, a so called “belly valve” or emergency valve, and the primary valve, which need to be open simultaneously for fuel to flow in either direction), and the elapsed time during which fuel was flowing. These valve sequences and fuel-flow elapsed times were used as input to a proprietary self-learning algorithm that determined the likelihood of the occurrence of FTE for these observed events for a driver compared with his/her past history, and compared against the rest of the drivers in the organization. If that likelihood was low (and “low” as well as other thresholds can be defined by the carrier), it was noted in the driver report which was the output of the boERS application.

The boERS self-learning algorithms also analyzed the elapsed times and sequencing of the first three valve actuations, since this could be an indication of fuel theft. For example, if the emergency valve is opened and then closed with the primary valve closed, fuel is loaded to the segment of pipe that runs between these two valves; by opening the primary valve a small amount of fuel could be removed. Again the likelihood of observing these events was computed and noted in the driver report.

The boERS also checked the locations at which fuel loading, fuel offloading and hatch opening happened against a database of authorized (by the carrier) locations for that activity. Any operation that occurred at an unauthorized location or at a location that was not in the
database of authorized locations was added to the driver report and noted in the CI for further processing (e.g., adding the location to the database of authorized locations for that particular activity, or further investigating the event). The CI also allowed the dispatcher or a manager to attach fuel-diversion numbers to any activity when required (the boERS determined which offloading operations needed a fuel diversion number by comparing the driver’s input destination when the fuel for that compartment was loaded to the actual location where the fuel was offloaded. If those locations disagreed and state borders were crossed, then the boERS noted this in the driver report).

The carrier had one week to revise the driver report and add any missing information (e.g., fuel diversion numbers) or make corrections to the driver reports. At the end of the seven-day period since first created, the driver report was processed to eliminate information not relevant to tax auditors (e.g., valve sequencing) and a fuel audit report file generated and transmitted to the FDAS (see Figure 1).

The FDAS archives the fuel logs received from the carrier as its main purpose to allow auditors to view the fuel logs containing the bill of lading information for each delivery, as well as linking the fuel data to a diversion number, if applicable. Auditors can also perform queries and conduct data analyses. For example, Figure 2 presents a screen capture of the FDAS interface showing all the fuel shipments for a selected period of time for a specific carrier (the USDOT number has been deleted from the screen capture). This query is made by using the filters shown on the left-side of the FDAS user interface. Once submitted, all of the bill of lading information for these shipments is presented in tabular form. In addition, these shipments can be shown in a graphical form on a map (see Figure 2 inset), allowing the tax auditors to have a quick view of the activities for this particular carrier.

**Data Collection and Management**

Three tanker trucks, from a fuel hauling company located in Virginia, participated in the pilot test. The three vehicles were similar (identical trailers and two tractors models), and were equipped with the same type of sensors. The trailers, 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 (trailer front to rear), respectively, were provided from new stock at no cost to the project by one of the participating industry partners. 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 on-board device and transmitted at regular intervals to the TBOS. There this “raw” information was processed by the boERS application generating the driver reports and, with the input from the carrier when needed, the FDAS reports.

The fuel logs, driver reports, and FDAS reports were uploaded daily to an ORNL ftp (file transfer protocol) server for archiving and analysis, as well as determining if any system was malfunctioning. This ftp server is not an integral part of the system tested, but rather it was deployed during the test as a research tool. The information was also stored on the TBOS databases (driver reports, FDAS reports, tampering and sensor malfunctioning alerts) and on the FDAS database (FDAS reports only).

**General Statistics**

During the pilot test, over 1,300 fuel logs were submitted from the three instrumented vehicles and processed by the boERS application. The data was collected during normal operations and
the twelve drivers that drove these vehicles during the pilot test were trained and were also supplied a “quick reference” guide on how to input the fuel data on the on-board device (the valve and hatch sensors did not alter the way these elements were operated so no training was needed). Part of the pilot test was conducted during the winter of 2015, and snow and road-deicing chemicals adversely affected the first generation of the wires and sensors connections deployed on the vehicles, mostly due a defective manufacturing process. Additionally, the T2TCU enclosures leaked causing corrosion on the circuit boards. These defects had to be corrected and the hardware hardened and replaced. As a consequence of this, there was a period of time in which some of the instrumented vehicles were not able to collect data. This problem was more acute for two of the three instrumented vehicles. These two vehicles collected about 30% each of the 1,300 fuel logs, with the third (less affected) vehicle collecting 40% of the data during the pilot test.

The area of operations covered mostly Virginia, Tennessee, and Kentucky, although fuel was delivered to other states as well. Figure 3 shows a distribution of distance traveled between the fuel terminal and the fuel-retail location for 390 randomly selected trips. The average distance was about 139 miles, with a standard deviation of 66 miles. A few trips involved very long distances (more than 400 miles) and slightly over 25% of the trips had a length of over 200 miles. This finding contradicts the perception (by some tax auditors) that long fuel-hauling trips may be rare and therefore, somehow suspicious. Final destination fuel price fluctuation and, in some cases, fuel availability at certain terminals during the pilot test dictated where the carrier bought the fuel for its customers (during the pilot test, there was no evidence of fuel “bootlegging”).

Table 1 shows the volume of fuel hauled during a randomly selected period of time 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 could be bought already blended (one bill of lading and one input from the driver) or separately (e.g., regular gasoline at one terminal and ethanol at another one with two different bills of lading in this case and two inputs from the driver). The remaining columns show the quantity of fuel in gallons that was transported by the driver shown in the header of the table, with the number in parenthesis indicating, in percentage, the difference between the total loaded fuel and the total unloaded fuel with respect to the number of gallons loaded. For example, during the selected period of time driver D19 loaded and offloaded 5,900 gallons of regular gasoline, and therefore the difference between the two operations was 0% [or (.0)] as indicated in the table. The same driver, however, offloaded more Regular-Ethanol fuel than what was loaded (2,000 gallons more). This driver also offloaded 2,000 gallons less of Premium-Ethanol than was loaded, for a net difference of 0 gallons between the total fuel loaded and the total fuel offloaded. Notice in the table, the four selected drivers as well as “All Drivers” have discrepancies in these two rows. The fuel-information user interface running on the on-board telematics device had a drop-down list of the different fuels (same list as shown in the first column of Table 1) and the driver had to select one of those when loading and offloading. Mistakes were made when selecting these types of blended fuels which resulted in some mislabeled fuel types. This error, however, can be easily found by using the FDAS interface.

The FTE prevention solution tested in this research had state-level tax auditors as its main focus. However, the technology will have to be adopted by the fuel carriers and therefore the solution has to address the needs of fuel-hauling companies and their customers. Carriers’ main concerns include misdelivery 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 to the customer), “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 does not address the cross-contamination issue, it is an essential first step in that direction. The other two issues, cocktailing and fuel theft, were taken into consideration when the architecture of the system was designed. Sensors in the hatchs allowed the obERS to recognize when one of those were opened (always a suspicious activity, unless it happens at locations where maintenance is performed on the tanker). In cases where a hatch was opened, a tampering alert was 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 was triggered, the carrier could then take the appropriate action. In a similar way, any sensor that became disconnected (including valve and hatch sensors, and tractor and trailer data bus connections) obERS generated a tampering alert conveyed in real-time to the carrier through the TBOS CI.

Addressing the fuel-theft issue was a more complicated problem since this activity can happen during normal operations (opening and closing of valves) and needed to be differentiated from legitimate actions by drivers and other operators. This was addressed by a proprietary self-learning algorithm deployed on the boERS that continuously processed 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 timestamped each valve actuation and added the corresponding weight-sensors reading (for trailer and tractor, when available). Those timestamps were later used by the boERS to determine the valve-actuation sequencing as well as the elapsed time when fuel was flowing (for fuel to flow out or into a compartment, both the emergency and actuation valves have to be opened). Each one of these measures became an observation for the probability distributions of those events (e.g., fuel flowing time \(fft\) for compartment \(c\), vehicle \(v\), driver \(d\)) and those probability distributions where constantly updated by the boERS application. The distributions were also combined (e.g., aggregated for all the drivers that have driven vehicle \(v\)) and used by the boERS algorithms to assess the likelihood of occurrence for the observed event \(fft\).

Probability thresholds, set up by the carrier, determined how to classify these observed events. Table 2 shows 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 2 was selected at random and was a sub-set of 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) 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. Each driver operates the valves in a different way, and that was also captured by the means and standard deviations of these distributions.

Each observation of a fuel flowing event was assessed by the obERS. Consider, for example, an observed fuel-flowing elapsed time \(fft = 241\) seconds for compartment 3. Assume also that the carrier has established the following probabilities thresholds: (1) normal event: probability of being observed \(\geq 60\%\); (2) unlikely event: probability of being observed between 40\% and 60\%; (3) rare event: probability of being observed < 40\%. Table 3 presents the likelihoods of observing a fuel-flowing elapsed time of 241 seconds (or less) by driver and tanker compartment. In this example, if the 241 seconds were observed for driver D42 for compartment 3, the event would be classified as normal (73.8\% > 60\%). The same observation
by driver D19 would be classified as rare (35.2% <40%). These likelihoods would be added to the driver report, but in the second case the event would be flagged so the carrier/dispatcher could investigate further.

Valve sequencing was also analyzed by the boERS. Although the entire valve-sequence for any valve actuation event at a given location was tracked, of particular interest are the first two-valve actuations. This particular sub-sequence could 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 were observed, the boERS would flag those in the driver report for further investigation by the carrier.

CONCLUSIONS

The research presented in this paper showed that the proposed supply-chain based solution to prevent FTE is technological feasible. The technology was deployed and tested on a real-world fuel-hauling fleet during day-to-day operations and minimally affected these operations. The harsh environment to which the hardware was subjected (ice, road snow removal chemical substances, etc.) had a negative effect on the first generation of wiring and connectors deployed. Those had to be hardened and were re-deployed during the pilot test with better results. Some adjustments had to be made to the software deployed, but in general the applications developed for the project worked as expected and were able to collect all the necessary information to conduct the tests.

Overall, 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 trailer. Fuel information (quantity, type, bill of lading 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 typed since the interface “remembered” what was entered at the rack). Some errors were made by 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 them in the driver reports so the carrier could correct the information before it was uploaded to the FDAS. But even in the case 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 odometer reading is one of the information elements submitted in the reports to this system.

The solution presented here balances the needs of tax-auditors and those of the fuel-hauling companies and their customers. For tax-auditors 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 “normal operation” for a given carrier. For example, in the discussion above we presented a carrier’s distribution of fuel-shipment distance traveled. 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) has to be borne by the carrier, so the technology has to provide incentives to the fuel hauling carriers to adopt it. Those incentives were one of the focuses in the development of the solution presented here. Two of the most relevant issues for a fuel transportation company were addressed: fuel theft and fuel cocktailing. In these cases the technology provides enough information to the carrier to help identify events that are likely indicators of illegal activities. The technology also offers a first step necessary towards the reduction or complete elimination of fuel misdelivery (or cross-contamination), a very costly problem for fuel hauling companies.

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 these fuel-hauling vehicles operate in one of two loading states: empty or fully loaded. The weight sensors, which are a very costly component of the system, could be replaced by other readily available on-board technology. ORNL has conducted other projects in which this technology has been used and it can provide information on the loading state of the tanker. Other components of the system such as the telematics devices are already on board most commercial motor vehicles (i.e., due to hours of service compliance requirements). Therefore, the system deployment cost could be reduced to just the valve and hatch sensors, with additional communications bandwidth, and additional monthly telematics service fee (about $300-$500 initial cost plus an additional $10/month per truck in 2015). Two other improvements to be researched further are the deployment of the technology using smart phones (which could further reduce deployment and operation costs) and the incorporation of electronic bills of lading (which could greatly simplify data entry).

Finally, although the pilot test helped to determine whether or not the technology was viable, it was a limited test with only one company and three vehicles. A larger field operation test, or the adoption of the technology by several companies together with data collection and analysis, would help assess the effectiveness of the system at detecting tax evasion.

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<td>2,800 (.0)</td>
</tr>
<tr>
<td>Regular</td>
<td>22,130 (.0)</td>
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<tr>
<td>Ethanol</td>
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<tr>
<td>Kerosene</td>
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<td>764,200 (.0)</td>
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TABLE 3 Probability of Observing a Fuel-Flowing Loading Event Lasting 241 Seconds by Selected Drivers and Tanker Compartment (Sub-sets of Pilot Test Trips)

<table>
<thead>
<tr>
<th>Comp ID</th>
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<td>43.4%</td>
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<td>58.1%</td>
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<td>5</td>
<td>4.1%</td>
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