Wireless Roadside Inspection Proof-of-Concept Test

U.S. Department of Transportation
Federal Motor Carrier Safety Administration

September 2009

FOREWORD

This study focuses on the ability of a Universal Wireless Inspection System to collect driver, vehicle, and carrier information; format a Safety Data Message Set from this information; and wirelessly transmit a Safety Data Message Set to a roadside receiver unit or mobile enforcement vehicle.

The work performed under the project included:

- Developing the Wireless Roadside Inspection Proof-of-Concept Fast Track Plan to conduct the Proof-of-Concept testing by using off-the-shelf technology to the fullest extent possible and by forming partnerships with the providers of such technology.
- Drafting the project Statement of Work.
- Drafting the Proof-of-Concept Test Plan.
- Developing technology to identify a vehicle and that vehicle's driver and carrier.
- Developing technology to give the status of a vehicle and that vehicle's driver and carrier.
- Developing technology to format a Safety Data Message Set from driver, vehicle, and carrier information.
- Developing technology to transfer the Safety Data Message Set to the roadside or Mobile Enforcement Vehicle.
- Conducting the Proof-of-Concept Test.
- Analyzing the data from the Proof-of-Concept Test.
- Drafting a Final Report.

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This program was administered through the Federal Motor Carrier Safety Administration (FMCSA). The FMCSA Program Manager is Jeff Loftus.

16. Abstract

This project was undertaken to determine the feasibility of gathering vehicle, driver, and carrier data to be used to format and wirelessly transmit from a commercial motor vehicle a Safety Data Message Set (SDMS). The Wireless Roadside Inspection (WRI) Program is defined in three phases:

- **Phase 1: Proof-of-Concept Test (POC)—Testing of commercial off-the-shelf technology to validate WRI concept.**
- **Phase 2: Pilot Test—Safety technology maturation and back-office system integration.**
- **Phase 3: Field Operational Test—Multi-vehicle testing over a multi-state region**

This report focuses on Phase 1 efforts. Technical efforts dealt with the ability of a wireless inspection system to collect driver, vehicle, and carrier information; format a SDMS from this information; and wirelessly transmit a SDMS to a roadside receiver unit or mobile enforcement vehicle. As a result of the WRI POC testing, it is concluded that WRI holds considerable promise in increasing highways safety by:

- **Improving the quality of the inspections performed.**
- **Allowing more inspections to be conducted**
- **Providing industry benefits for these technologies that encourage early adoption.**

Because of these positive results, it is recommended that Phase 2 (Pilot Testing) be engaged.

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SI* (MODERN METRIC) CONVERSION FACTORS

Table of APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft	square feet	0.093	square meters	m^2
yd	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi	square miles	2.59	square kilometers	km^2
		VOLUME	Note: Volumes greater than 1000 L shall be shown in m^3	
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE	Temperature is in exact degrees	
°F	Fahrenheit	5 × (F-32) ÷ 9 or (F-32) ÷ 1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
	FORCE	**and PRESSURE or**	**STRESS**	
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

Table of APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft
m^2	square meters	1.195	square yards	yd
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2000 lb)	T
		TEMPERATURE	Temperature is in exact degrees	
°C	Celsius	1.8C + 32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
	FORCE	**and PRESSURE or**	**STRESS**	
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003, Section 508-accessible version August 2009)

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LIST OF ACRONYMS

Acronym	**Definition**
ABS	antilock braking system
ASCII	American Standard Code for Information Interchange
BOA	back-office application
CAN	controller area network
CDL	commercial driver’s license
CMV	commercial motor vehicle
COTS	commercial off-the-shelf
CVO	commercial vehicle operations
DAS	data acquisition system
DDTS	day-to-day test schedule
DSRC	dedicated short-range communications
ECM	engine control module
EDT	Eastern Daylight Time
EOBR	electronic on-board recorder
FMCSA	Federal Motor Carrier Safety Administration
FOT	field operational test
FTP	file transfer protocol
GHz	gigahertz
GIS	geographic information system
GB	gigabyte
GUI	graphical user interface
GPS	global positioning system

Acronym	**Definition**
HOS	hours of service
Hz	Hertz
IEEE	Institute of Electrical and Electronics Engineers
IFTA	International Fuel Tax Agreement
KB	kilobyte
KUT	kernel under test
LCD	liquid crystal display
Mbps	millions of bits per second
MCNU	multi-band configurable networking unit
ME	mobile equipment
MEV	mobile enforcement vehicle
MHz	megahertz
mi/h	miles per hour
MOU	memorandum of understanding
NTRC	National Transportation Research Center
ORNL	Oak Ridge National Laboratory
OBC	on-board computer
Partners	industry suppliers of the UWIS in partnership with ORNL/FMCSA
PBBT	performance-based brake tester
PDA	personal digital assistant
POC	proof of concept
psi	pounds per square inch
QoS	quality of service

Acronym	**Definition**
RF	radio frequency
RTL	roadside testing laboratory
RSE	roadside equipment
RSU	roadside unit
RTC	Roadside Technology Corridor
Schrader	Schrader Trucking
SDMS	safety data message set
SDO	scheduled day off
SOW	statement of work
TELS	test event log sheet
TDOS	Tennessee Department of Safety
TDOT	Tennessee Department of Transportation
USB	Universal Serial Bus
USDOE	U.S. Department of Energy
USDOT	U.S. Department of Transportation
UTC	universal time coordinates
UWIS	universal wireless inspection system
VII	vehicle infrastructure integration
WRI	Wireless Roadside Inspection

EXECUTIVE SUMMARY

PURPOSE

The U.S. Department of Transportation (USDOT) Federal Motor Carrier Safety Administration (FMCSA) commissioned the Wireless Roadside Inspection (WRI) Program to validate technologies and methodologies that can improve safety through inspections using wireless technologies that convey real-time identification of commercial motor vehicles (CMVs), drivers, and carriers, as well as information about the condition of the vehicles and their drivers. It is hypothesized that these inspections will:

- Increase safety—Decrease the number of unsafe commercial vehicles on the road.
- Increase efficiency—Speed up the inspection process, enabling more inspections to occur, at least on a par with the number of weight inspections.
- Improve effectiveness—Reduce the probability of drivers bypassing CMV inspection stations and increase the likelihood that fleets will attempt to meet the safety regulations.
- Benefit industry—Reduce fleet costs, provide good return on investment, minimize wait times, and enable uniform roadside safety compliance checking of all motor carrier operations regardless of type and size of operations.

The WRI Program is defined in three phases, which are:

- **Phase 1:** Proof-of-Concept Test (POC)—Testing of commercial off-the-shelf (COTS) or near-COTS technology to validate the wireless inspection concept.
- **Phase 2:** Pilot Test—Safety technology maturation and back-office system integration.
- **Phase 3:** Field Operational Test (FOT)—Multi-vehicle testing over a multi-state instrumented corridor.

This report focuses on Phase 1 efforts that were initiated in March 2006. Technical efforts dealt with the ability of a universal wireless inspection system (UWIS) to collect driver, vehicle, and carrier information; format a safety data message set (SDMS) from this information; and wirelessly transmit a SDMS to a roadside receiver unit or mobile enforcement vehicle.

PROCESS

This POC Test involved the development and testing of a UWIS, the acquisition of lessons learned from the WRI POC testing, and the conduct of a public showcase of the tested technologies. Such testing and public demonstration would not have been possible without the efforts of a team of experts in the areas of vehicle enforcement, vehicle data generation, data collection, and data transmission. As a result, partnerships were formed between the Oak Ridge National Laboratory (ORNL), the Tennessee Department of Safety (TDOS), the Tennessee Department of Transportation (TDOT), and a number of private-industry participants, many of which participated in Phase 1 efforts without compensation. The purposes of the partnerships were to form teams that could:

- Develop the necessary capabilities for data collection, data buffering, and formatting of the SDMS.
- Secure the “best available” wireless technology and communications support.
- Define the required inputs for the UWIS based on COTS sensor and systems technology.
- Instrument a Class-8 tractor with the partner-developed and supplied kernels and transceivers.
- Cooperatively test each partner-kernel at the I-40/I-75 Inspection station in Knox County, TN, with the test vehicle in a static mode; traveling in the bypass lane; traveling at highway speed; and in close proximity to a patrol car at highway speed.

RESULTS

The POC testing was conducted via a WRI POC Test Plan that was developed by ORNL and followed during the associated efforts. The WRI POC effort involved a number of activities, including:

- Definition of a SDMS.
- Development of partner-based UWIS kernels.
- Testing of the UWIS on the FMCSA CMV Roadside Technology Corridor (RTC) to assess input to and output from the UWIS under varying conditions/situations.
- Conduct of a POC Data Analyses.
- Public Demonstration Testing on the CMV RTC on August 7, 2007.
- Production of a Final Report.

This report provides details of these efforts. Some of the major results from the WRI POC testing included the following:

- The POC testing demonstrated that it was possible for the kernel to gather information from different sources, including an electronic on-board recorder (EOBR) and a vehicle databus, assemble the required SDMS, and make it available for transmission to a roadside unit (RSU) or mobile enforcement vehicle (MEV).
- The transmission frequency at which these messages were generated was very high (i.e., an average of one SDMS every 10.2 seconds).
- The largest observed delay in generating a new SDMS was just over 5 minutes, which was considered acceptable.
- The accuracy of the information posted on the SDMS was measured within a certain tolerance that was arbitrarily set at three levels.
- Information related to the spatial position of the vehicle (obtained from global positioning system [GPS] readings) was 100 percent accurate when considering a tolerance of 1,000 ft.
- Vehicle speed (also determined via GPS readings) was provided at an accuracy level of more than 80 percent when considering a tolerance of 1 mile per hour (mi/h) or less, and close to 100 percent with a tolerance of 5 mi/h or less.
- Odometer information (read from the vehicle’s databus) was 79 percent accurate when considering a tolerance of 0.25 mi/h.

- Assessment of Hours of Service (HOS) information in the POC presented some problems. Inaccuracies, albeit minor, in the generation of a HOS diagram were experienced. More critical, however, was the delay in relaying of the messages, which ranged from 5 to 20 minutes.
- Antenna when tripod-mounted received the SDMS more reliably than when the antenna was mounted on the MEV.
- In the bypass-lane tests, the body of the truck itself and objects near the roadway limited the time during which transmission could occur; in addition, several pit-scale weight information signs were present along the right side of the bypass lane.
- Results of the dynamic orientation tests indicated that a central placement of the dome antenna on the MEV roof was preferable to other potential placements.
- Both the static and dynamic tests showed that there are unresolved issues regarding file transfers when the MEV is directly in front of the truck.
- Use of the stick antenna is very inefficient at 2.4 gigahertz (GHz).
- Use of the dome-type antenna at both 2.4 GHz and 5.9 GHz indicated much improved performance at 2.4 GHz.
- The POC test demonstrated that the wireless inspection system tested was sufficiently robust to function as designed in real-world driving environments.
- The reliability of file transfer varied with antenna type, placement, and frequency.
- The POC test demonstrated that it is possible to reliably transfer an SDMS at highway speeds.

CONCLUSION AND FUTURE DIRECTIONS

The primary conclusion of the WRI POC testing was that the information contained in the SDMS was sufficiently accurate and acceptable to engage in future related research. Suggested research topics, with the reasons for their inclusion, are as follows:

- Timeliness of the HOS information that is added to the SDMS: Most of the observed problems were attributed to communication and software issues; however, these problems are not insurmountable.
- Reduction of the delays inherent to the system due to back-office communication of the kernel.
- More extensive testing regarding ideal antenna parameters including type, height, position, and orientation: Antenna and communication requirements should be developed and refined to include required frequency (2.4 GHz vs. 5.9 GHz), antenna type, and optimal placement of the antenna on each instrumented vehicle.
- Testing a larger number of vehicles to verify system feasibility on a wider scale: Larger-scale testing should be designed to test performance when several instrumented vehicles pass an RSU all at the same time.
- Development of the ability to visually identify which truck (in a group) is providing the information viewed by enforcement personnel for each wireless inspection.

In future tests, several administrative issues also need to be emphasized. These are as follows:

- It is important that more detailed technical discussions be carried out between the tester and the developers of the system. Such communication would facilitate a better understanding of the idiosyncrasies of both the data acquisition system (DAS) and the kernel.
- Emphasis should also be placed on gratis partnerships to minimize cost and maximize industry buy-in.

As a result of the WRI POC testing, it is concluded that wireless roadside inspection holds considerable promise in increasing the safety of our highways by:

- Improving the quality of the inspections performed.
- Allowing more inspections to be conducted, due to the increased efficiency of the system.
- Assuring that a larger percentage of the trucks on our highways are inspected.
- Providing industry benefits for these technologies that encourage early adoption.

Because of these positive results, it is recommended that Phase 2 (Pilot Testing)—safety technology maturation and back-office system integration—be engaged. If these efforts are also successful, it is recommended that Pilot Testing be followed by Phase 3 (Field Operational Test)—multi-vehicle testing over a multi-state instrumented corridor.

1. PROJECT OVERVIEW

1.1 INTRODUCTION

The mission of the U.S. Department of Transportation (DOT) Federal Motor Carrier Safety Administration (FMCSA) is to reduce crashes, injuries, and fatalities involving large trucks and buses. Its goal by 2008 is to reduce commercial motor vehicle (CMV)-related fatalities to 1.65 fatalities per 100 million CMV-miles traveled.

There currently exists a safety inspection violation rate of 73 percent, or approximately 2.2 million annual inspections out of 3 million. This indicates that numerous CMVs are on the road with driver and/or vehicle infractions. Using wireless technology, FMCSA could potentially increase the number of inspections per year to approximately the number of weight inspections (82 million) and subsequently reduce the percentage of vehicles on the road with violations. It is expected that this will greatly reduce the violation rate by encouraging better vehicle maintenance and driver behavior.

The FMCSA has commissioned the Wireless Roadside Inspection (WRI) Program to validate technologies and methodologies that can improve safety through inspections using wireless technologies that convey real-time identification of commercial vehicles, drivers, and carriers, as well as information about the condition of the vehicles and their drivers. It is hypothesized that these inspections will:

- Increase safety—Decrease the number of unsafe commercial vehicles on the road
- Increase efficiency—Speed up the inspection process, enabling more inspections to occur, at least on a par with the number of weight inspections
- Improve effectiveness—Reduce the probability of drivers bypassing CMV inspection stations and increase the likelihood that fleets will attempt to meet the safety regulations
- Benefit industry—Reduce fleet costs, provide good return on investment, minimize wait times, and enable uniform roadside safety compliance checking of all motor carrier operations regardless of type and size of operations.

To this end, the WRI Program is defined in three parts:

- **Phase 1: Proof-of-Concept Test** (POC)—Testing of commercial off-the-shelf (COTS) or near-COTS technology to validate the wireless inspection concept.
- **Phase 2: Pilot Test**—Safety technology maturation and back-office system integration.
- **Phase 3: Field Operational Test**—Multi-vehicle testing over a multi-state instrumented corridor.

The Oak Ridge National Laboratory (ORNL) began discussions with FMCSA staff concerning the WRI Program in March 2006 and drafted a WRI discussion paper in May 2006. ORNL was asked to participate in an initial planning meeting for the WRI Program in June 2006. This meeting was held at FMCSA Headquarters in Washington, DC. From this meeting, ORNL was tasked to conduct the WRI POC testing within the CMV Roadside Testing Corridor (RTC) located in East Tennessee. ORNL drafted the WRI POC Fast Track Plan, which called for partnering with private industry to quickly develop and field test technology to accomplish the goals of the WRI POC. See Appendix A for a copy of the Fast Track Plan Discussion Paper.

ORNL was asked to lead the WRI POC and to conduct a Technology Showcase/Media Event on August 7, 2007, to showcase the WRI technology and other emerging and state-of-the-practice technologies being used at the Greene County, Tennessee CMV inspection station, located at mile marker 21 on southbound Interstate 81 (I-81). This inspection station is the northeast anchor point for the CMV RTC.

ORNL drafted the project Statement of Work (SOW) in the fall of 2006, drafted the Test Plan and formed partnerships in the spring of 2007, and conducted the POC and the Technology Showcase in the summer of 2007.

This final report addresses the Phase 1 POC that was conducted by ORNL to validate the technology needed to collect, assemble, and wirelessly transmit the vehicle, carrier, and driver safety data to fixed and mobile receivers. Phases 2 and 3 of the WRI Program were not conducted under this effort and will be addressed in this report only as efforts of these phases relate to the POC.

1.2 GOALS AND OBJECTIVES

1.2.1 Goals

The five goals of the Phase 1 WRI POC Program were to:

- Demonstrate the ability to gather appropriate vehicle, driver, and carrier data germane to the Phase 1 POC testing via a vehicle's data bus, Global Positioning System (GPS) receiver, the vehicle operator's input to the vehicle's Universal Wireless Inspection System (UWIS), and the carrier's input to the vehicle's UWIS.
- Demonstrate the industry partner-supplied kernel's ability to collect, store, and transfer vehicle, driver, and carrier information to the transceiver in the format specified for the Safety Data Message Set (SDMS) (see section 2.0 for description of kernel and transceiver).
- Demonstrate the transceiver's ability to wirelessly transmit data from the UWIS to a second unit (roadside and mobile) at Interstate speed.
- Obtain feedback from WRI stakeholders involved in the POC to verify the overall Concept of Operations and some of the high-level requirements.
- Obtain feedback from the test vehicle operators concerning UWIS.

1.2.2 Objectives

The objectives of the Phase 1 WRI POC Program were to:

- Formalize a partnership agreement with a kernel provider via a Memorandum of Understanding (MOU).
- Develop the WRI POC Test Plan.
- Conduct the WRI POC per the Test Plan.

- Analyze data from the WRI POC.
- Obtain stakeholder and operator feedback to the extent possible within the limited scope of the test.

1.3 PARTNERS

Through an MOU, ORNL partnered with PeopleNet, a mobile computing and communications provider, to provide the kernel for the UWIS, and with Air-Weigh, Inc. to provide the on-board vehicle weighing system to provide the tractor's real-time weight; these partnerships were gratis. ORNL also partnered with TechnoCom Corporation to provide the transceiver technology on a contractual basis.

1.3.1 PeopleNet

PeopleNet, based in Minneapolis, MN, is a provider of on-board computing and mobile communications solutions to the transportation industry, serving nearly 1,500 fleets across the for-hire and private fleet sectors. With more than 30 new product innovations delivered to the market in the last two years, PeopleNet's core platform enables rapid application delivery to the market. This core platform includes the patented over-the-air programming capability that allows for wireless software updating of mobile/on-board units. The platform is based on an "open" architecture that enables data exchange with multiple third-party systems, such as the WRI POC platform.

1.3.2 Air-Weigh, Inc.

Air-Weigh, Inc. is a supplier of on-board weighing technologies that provides reliable and accurate products. The company is based in Eugene, OR, and since its inception, has provided technological solutions to longstanding transportation industry problems.

Air-Weigh's vision is to help the transportation industry "load smart." The company's mission is to increase efficiency and reduce waste within the transportation industry by implementing on-board weighing. Through the use of on-board scales, Air Weigh, Inc. contends that companies can improve profits while reducing wasted fuel, overall emissions, and vehicle wear associated with over-weight miles. Air-Weigh scales have the potential to improve operations in the transportation industry and benefit the greater community through improved safety, reduction in road and bridge damage, improved fuel usage, and enhanced company efficiency.

1.3.3 TechnoCom Corporation

TechnoCom Corporation is a provider of solutions to enable wireless location networks and to ensure their ongoing performance. Based in Encino, CA, it offers location quality of service (QoS) test and measurement solutions to wireless operators and service providers, and provides Vehicle Infrastructure Integration (VII) solutions to the transportation and automotive industries, systems integrators, and Federal, state, and local government agencies.

1.4 PROJECT TEAM

The WRI POC project team consisted of the following entities, shown in Table 1.

Table 1. List of WRI POC Project Team Entities

FMCSA	Role:	WRI POC Sponsor
	Contact Name:	Jeff Loftus
	Title:	Transportation Specialist
	Phone Number:	202-385-2363
ORNL	Role:	WRI POC Technical Lead
	Contact Name:	Gary Capps
	Title:	Technical Director CMV RTC
	Phone Number:	865-946-1285
Tennessee Department of Safety (TDOS)	Role:	Provide Law Enforcement Support
Nashville	Contact Name:	Capt. Steve Binkley
	Title:	Test Coordinator
	Phone Number:	615-687-2317
Knoxville Inspection Station	Contact Name:	Capt. J. R. Bridgeman
	Title:	Officer in Charge
	Phone Number:	865-966-5071
Greene County Inspection Station	Contact Name:	Lt. James McKenzie
	Title:	Officer in Charge
	Phone Number:	423-235 4104
PeopleNet	Role:	Provide UWIS Kernel
	Contact Name:	Brian McLaughlin
	Title:	Director of Marketing
	Phone Number:	888-346-3486 ext. 211
Air-Weigh	Role:	Provide On-Board Weighing Capability
	Contact Name:	Jim Morton
	Title:	Product Management
	Phone Number:	704-876-1909
TechnoCom	Role:	Provide Transceiver Capability
	Contact Name:	Justin McNew
	Title:	Director, Mobility Solutions
	Phone Number:	818-501-1903
Commercial Carrier Consultants	Role:	Provide Test Tractor
	Contact Name:	Wilber Thomas
	Title:	Owner
	Phone Number:	719-545-7843
Greene Coach	Role:	Provide Motor Coach
	Contact Name:	Russell Ooten
	Title:	Owner
	Phone Number:	423-638-8271

1.5 APPROACH

As defined for this project, a proof of concept “is a short and/or incomplete realization (or synopsis) of a certain method or idea(s) to demonstrate its feasibility, or a demonstration in principle, whose purpose is to verify that some concept or theory is probably capable of exploitation in a useful manner. The proof of concept is usually considered a milestone on the way to a fully functioning prototype.”

To this end, the WRI POC tested the concept of inspecting a commercial vehicle wirelessly. This was accomplished by designing and specifying a UWIS. This “universal” system can be installed on any commercial vehicle in an aftermarket fashion, and it will gather and transmit data germane to motor vehicle enforcement.

ORNL gathered a team of experts in the areas of vehicle enforcement, vehicle data generation, data collection, and data transmission to participate in the WRI POC and to develop the UWIS. The WRI POC team was formed either by MOUs on a gratis basis (partnerships), or by contract.

The UWIS that was developed to inspect the test vehicles wirelessly during the WRI POC consisted of a user interface (for data input), a kernel (to collect and process the data), and a transceiver (to transfer the data wirelessly). The user interface allowed hand-entry of data by the vehicle operator (e.g., driver’s name) and by the carrier (e.g., carrier’s name, DOT number, vehicle license plate number, etc.). The kernel connected to the user interface, a GPS receiver, and the vehicle’s Controller Area Network (CAN) data bus to collect data relative to the driver, carrier, and vehicle. These data formed the SDMS (an American Standard Code for Information Interchange [ASCII] flat file).

ORNL conducted the POC using a commercial vehicle (Class-8 tractor) fitted with a UWIS which transferred the SDMS to the roadside and to a mobile enforcement vehicle (MEV). The POC was divided into two sets of testing: Phase 1A, UWIS kernel testing; and Phase 1B, transceiver testing (to include the Phase 1A UWIS kernel).

The WRI POC Test Plan was developed to guide the testing and data collection. The WRI POC Test Plan was submitted to FMCSA in its final form on December 4, 2007, as Rev 1.5.

1.5.1 Phase 1A

An MOU was put in place with PeopleNet, which supplied the UWIS kernel for testing. The MOU defined the roles of ORNL and PeopleNet for the POC, established the POC timeline, and acknowledged the gratis nature of the partnership.

Once the UWIS kernel was developed, PeopleNet hand-delivered its system to the National Transportation Research Center (NTRC), located in Knoxville, TN. It provided instructions to the ORNL staff regarding how to integrate its systems onto the test vehicle and how to operate the technology. A pre-POC shakedown was conducted to verify that the equipment was operational. After this preliminary equipment check, the POC testing was conducted as specified in the WRI POC Test Plan. The test vehicle was operated in various modes of driver status (e.g., on-duty, on-duty driving, off-duty) within a 100-air-mile radius of the NTRC. The POC testing for the partners' UWIS kernel was completed in approximately 10 hours. The technology of the partners remained on the test vehicle for Phase 1B testing.

1.5.2 Phase 1B

This phase involved the testing of the transceiver by transmitting the SDMS to the roadside CMV inspection station or MEV. The transceiver was tested at 5.9 GHz and 2.4 GHz in the following scenarios:

- Test Vehicle-to-Roadside (vehicle stopped at weigh station; "static test" for baseline).
- Test Vehicle-to-Roadside (low-speed bypass lane: 25 mi/h).
- Test Vehicle-to-Roadside (high-speed: 55 mi/h).
- Test Vehicle-to-MEV (neither vehicle moving for baseline).
- Test Vehicle-to-MEV (low-speed: 25 mi/h, both traveling in same direction).
- Test Vehicle-to-MEV (high-speed: 55 mi/h, both traveling in same direction).
- Test Vehicle-to-MEV (test vehicle stopped, enforcement vehicle moving).
- Test Vehicle-to-MEV (test vehicle moving, enforcement vehicle stopped).

The SDMS received at the roadside was checked against the output of the kernel. Results from this testing were reviewed throughout the testing process. Changes were made (as practical) to antenna placement, antenna cable length, antenna height, and frequency in an attempt to optimize the transmission in each scenario. All changes or adjustments during actual testing were done by ORNL personnel and recorded as to type, amount, and time of the change.

1.5.3 WRI POC Testing Platforms

Figure 1 shows the testing platforms involved in the WRI POC, their configuration, and the components involved. These platforms were present on the truck/motor coach (test vehicles), at the roadside (CMV inspection station), and the MEV. See section 2.0 for additional details.

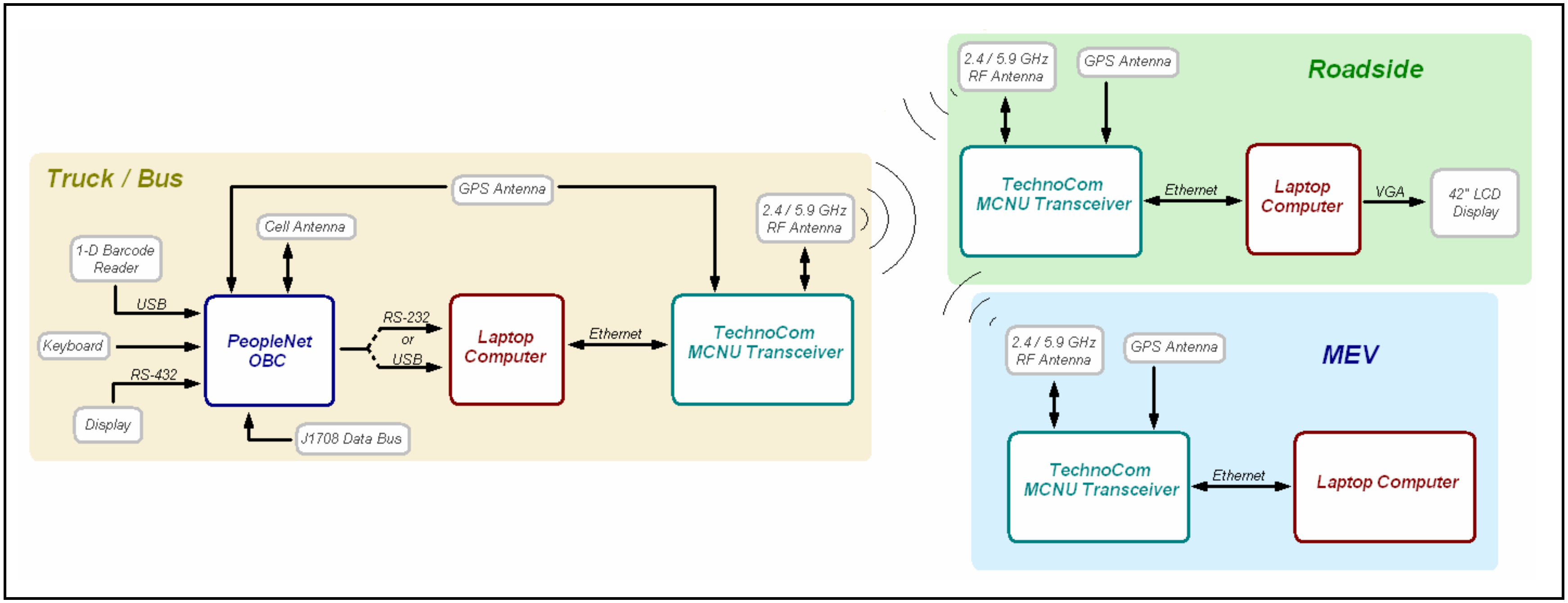

Figure 1. Diagram. The WRI POC Testing Platforms (configurations and components)

1.6 SCHEDULE

Figure 2 shows the schedule for the WRI POC and Technology Showcase.

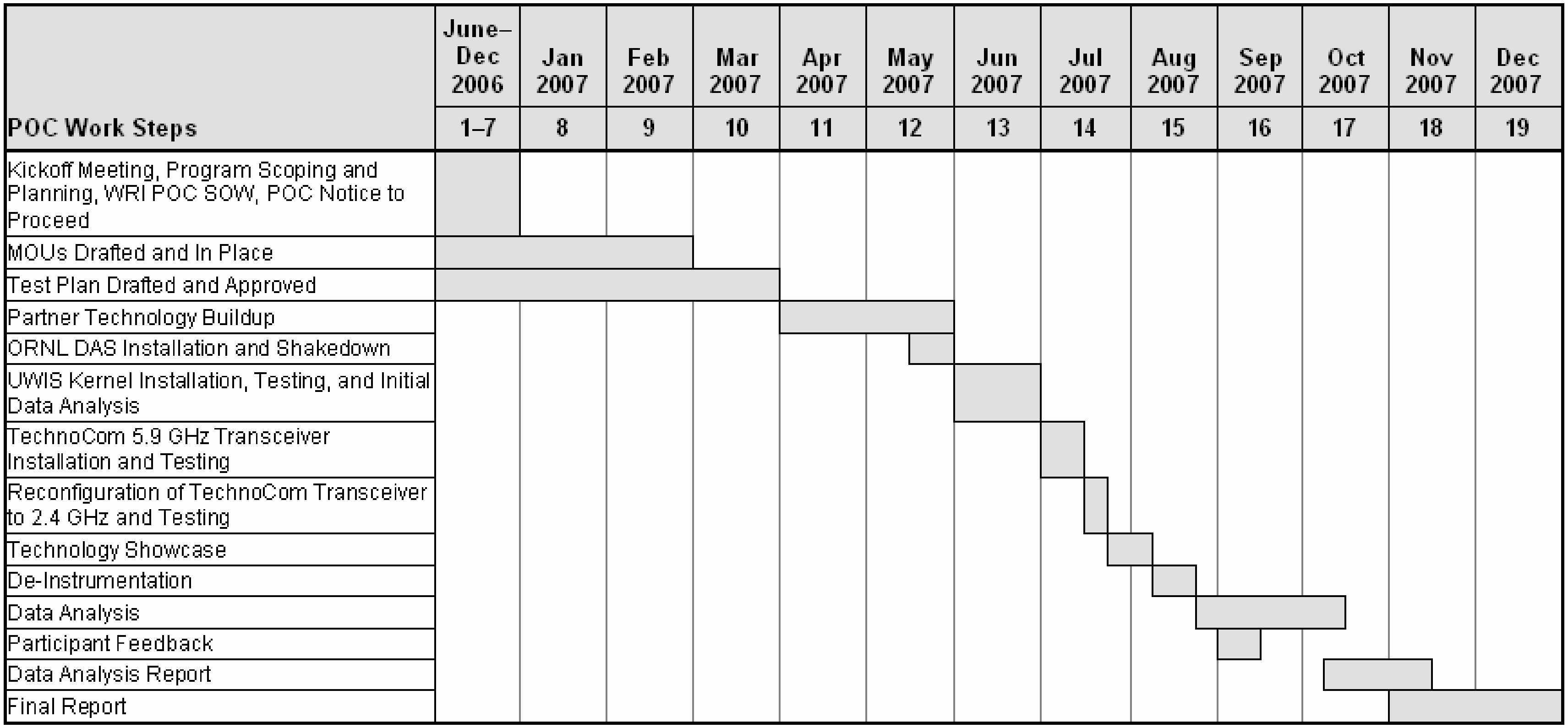

Figure 2. Gantt Chart. WRI POC Schedule

2. PROOF-OF-CONCEPT TEST DESCRIPTION

The POC was conducted beginning in late May 2007 and was completed just before the August 7, 2007 Technology Showcase.

2.1 WRI NETWORK AND UWIS OPERATION

The WRI application used a network configuration that consisted of the UWIS, Roadside Equipment (RSE) or Mobile Equipment (ME) and a back-office application (BOA) server (see Figure 3). The UWIS within the Commercial Motor Vehicle (CMV) consisted of three primary parts: the data collection kernel, a middle-ware computer, and the wireless transceiver. The kernel (provided by PeopleNet) interacted with the various data sources to collect and package information to form a single-line SDMS. PeopleNet also provided custom software to allow the transfer of these data from their on-board computer (OBC) to a middle-ware laptop where a single-line SDMS was generated every 10 seconds. These SDMSs were then collected on the middle-ware computer, further packaged and formatted by ORNL software, and sent to a wireless transceiver provided by TechnoCom. See Figure 4 for a block diagram of the UWIS and Figure 5 for an image of the UWIS as tested in the WRI POC. The transceiver on-board the CMV would immediately attempt to transfer these data to a transceiver at the roadside (or in a MEV).

The RSE subsequently transferred the data to a BOA server for processing and display on a second laptop running ORNL-developed software. In addition, the network supported querying the CMV by an MEV that contained the ME.

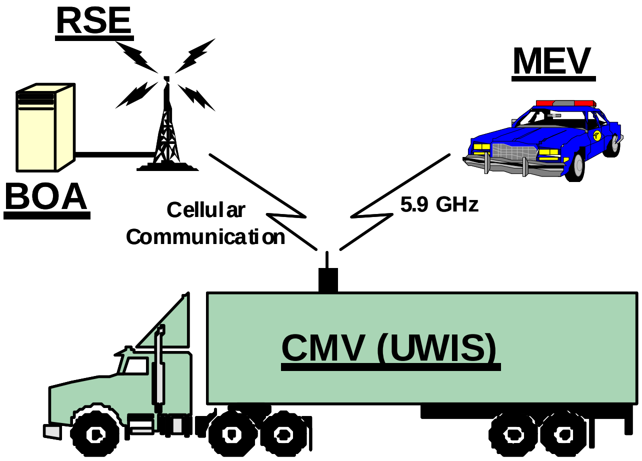

Figure 3. Drawing. WRI Network Configuration

For the POC, transfer of the SDMS was attempted as soon as the middle-ware computer provided new data to the transceiver (approximately every 10 seconds). However, the transceiver also had the ability to trigger data transfer by defining geo-zones* based on GPS. While this POC

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* Geo-zones are virtual boundaries established with a set GPS coordinates that can be placed around moving assets and user defined points of interest.

did not explore this feature of the transceiver technology, the transceiver suppliers indicated that the geo-zone information could be transmitted by the RSE to the UWIS to indicate where data upload should be triggered. Once an instrumented CMV entered the geo-zone associated with the RSE, it would transfer the data from the UWIS to the RSE and subsequently the BOA. The MEV could also be set up to query a CMV within a dynamic area centered around the MEV and based on current GPS locations.

The BOA consisted of a laptop running a second piece of ORNL software to display the information received from the roadside transceiver. This software was primarily a graphical user interface (GUI) which providing an intuitive, concise means to view the SDMS from the CMV. See section 5.0 of this report for further information and screenshots of the GUI.

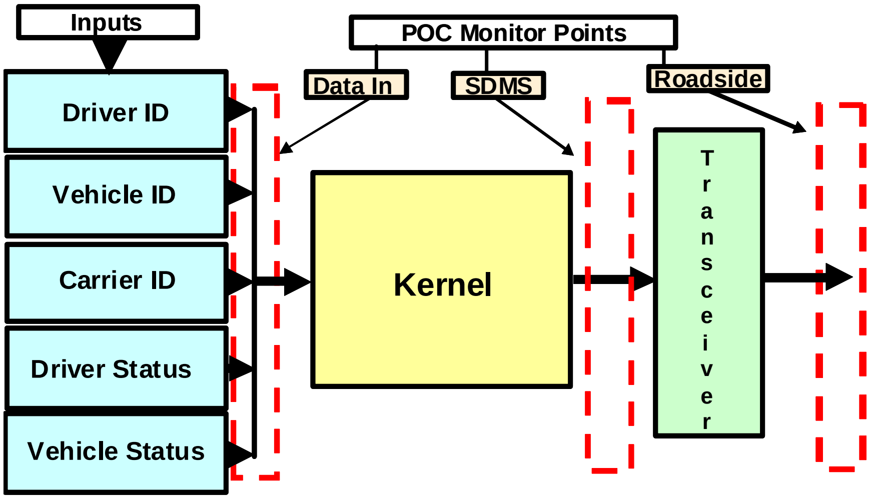

Figure 4. Block Diagram. WRI POC UWIS

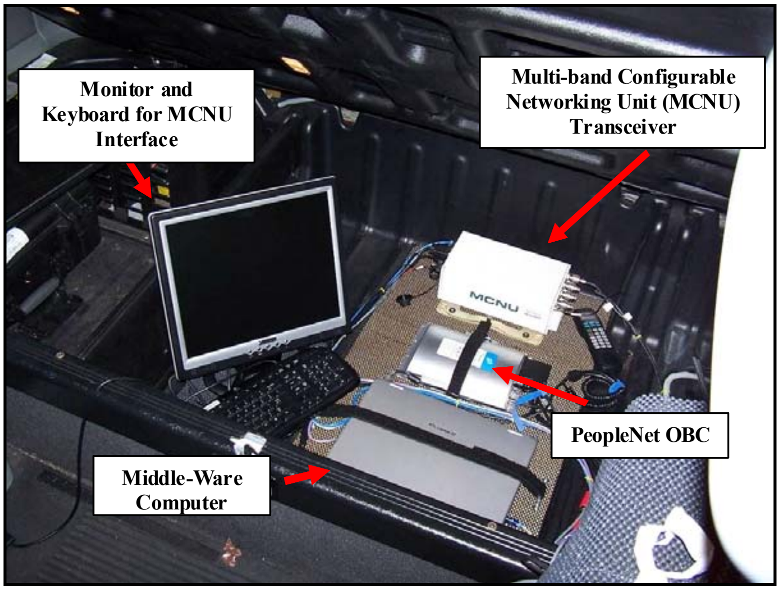

Figure 5. Photo. UWIS as Installed on the Test Tractor

2.2 EQUIPMENT AND TECHNOLOGY

2.2.1 PeopleNet System

PeopleNet provided a standard g3 model on-board computer, liquid crystal display (LCD), and keyboard for the WRI POC testing. The g3 provided wide-area communications and GPS positioning. This unit was connected to the vehicle's J1708 interface to collect critical engine and speed data. In addition, the g3 was connected by means of a serial cable to a laptop computer. By virtue of this interface, the laptop had direct access to the GPS and J1708 data, which were collected by the g3 and also had the ability to exchange data over the PeopleNet network. The g3 OBC and LCD are shown in Figure 6.

Figure 6. Photo. PeopleNet OBC and Display Used in the WRI POC

For the purposes of the WRI POC test, PeopleNet established a back-end data collection repository using the PeopleNet Link™. This repository extracted all available vehicle, messaging, and electronic driver log data from PeopleNet's network operations center and deposited those data in a local database.

PeopleNet also developed custom programming for the laptop to interface with the PeopleNet system and assemble the required SDMS. In order to produce a POC in a timely and inexpensive fashion, PeopleNet collected electronic driver log data from the g3 on-board computer to the local data base. PeopleNet also provided an electronic input form through which the driver could provide key personnel data, including medical certification information. The driver's Commercial Driver's License (CDL) number could be scanned directly for input using a tethered barcode reader. This format made all driver log and personnel information available in a local data base at any time. For the POC, PeopleNet caused an SDMS consisting of the driver log and personnel data to be communicated to the laptop every 5 minutes. The PeopleNet-interface software on the laptop received the SDMS and added to it pertinent GPS and J1708 data retrieved from the g3 on-board computer. The GPS and J1708 data in the SDMS were refreshed with newly collected information every 10 seconds.

Each time the SDMS was updated (every 10 seconds), a modified version (produced by ORNL-developed software) was transferred via File Transfer Protocol (FTP) to a TechnoCom device that ultimately passed the data set wirelessly to a receiver at the WRI POC test station.

2.2.2 Middle-Ware Computer

The computer chosen to interface between the PeopleNet OBC and the transceiver was a Lenovo 3000 N100 laptop Model 076807U. This computer contained both the PeopleNet-interface software mentioned above and software developed by ORNL to manipulate further the data provided by PeopleNet. ORNL's task was to generate an on-board history of SDMS messages as provided by PeopleNet and to send this history to the transceiver for subsequent transmission to an RSU or MEV. To this end, the software developed by ORNL first created a simple appended SDMS by appending the new SDMS line, provided by PeopleNet every 10 seconds, to a text file. This format was used in Phase 1A to provide a large number of SDMS messages for accuracy checking.

ORNL's software also provided the capability of generating a status-change SDMS, in which only messages from PeopleNet which differed in driver duty status from the previously stored line were appended to a text file. This resulted in a much shorter cumulative SDMS in which each line represented a different driver status. The software was also configured to retain a maximum of eight days' worth of such lines, deleting any entries that were more than eight days old each time a new line was added. This format closely approximates that which would be expected by FMCSA's Proposed Rule Making on Electronic On-Board Recorders (EOBRs) for commercial vehicles' eight-day history (395.16).

The third function of ORNL's software was to transfer data from the laptop to the transceiver, which then transmitted the data to the roadside or MEV. The software allows three options for which file to transfer:

- Only the single-line output from PeopleNet.
- The complete appended SDMS.
- The eight-day-history SDMS.

The selected option is sent to the transceiver every 10 seconds, when it is updated with the most recent PeopleNet information. The actual transfer was accomplished using the standard FTP. Because the laptop was running Windows XP and the transceiver ran on a Linux platform, this communication method provided a convenient method of transferring the data between the different operating systems.

2.2.3 TechnoCom Transceiver

The TechnoCom Multi-band Configurable Networking Unit (MCNU) served as the transceiver for the WRI POC and was tested at both 2.4 GHz and 5.9 GHz Dedicated Short-Range Communications (DSRC). The MCNU is a lightweight, weatherproof device used to build standards-compliant, high-speed, multi-band wireless communication networks. Optimized antennas for each frequency were supplied by TechnoCom and utilized by ORNL for the POC.

MCNU Specifications:

Wireless Interfaces

Two IEE 802.11a/b/g/j/p PHY-compliant interfaces

Each wireless interface

- Configurable locally or remotely
  - Institute of Electrical and Electronics Engineers (IEEE) 802.11a/b/g/j/p PHY
- Data rates
  - 1, 2, 5.5, 11 Mbps
  - 3, 4.5, 6, 9, 12,18, 24, 27 million bits per second (Mbps)
  - 6, 9, 12, 18, 24, 36, 48, 54 Mbps
- Frequency band
  - 2.400–2.484 GHz (ISM)
  - 4.940–4.990 GHz (PS)
  - 5.150–5.250 GHz (UNII)
  - 5.250–5.350 GHz (UNII)
  - 5.470–5.725 GHz (UNII)
  - 5.725–5.825 GHz (UNII)
  - 5.825–5.850 GHz (ISM)
  - 5.850–5.925 GHz (ITS-DSRC)
- Transmit power
  - 17–19 dBm maximum
- Enhanced MAC features
  - Security enhancements—IEEE 802.11.i
  - QoS enhancements—IEEE 802.11.e
- Antenna diversity: two antenna connections
  - N-Type RF Connectors
- Antennas
  - Antenna selection and purchasing guide included
- GPS
  - Ublox Antaris TIM-4H Super Sense Receiver
  - One external SMA antenna connector
- Processor
  - Via Eden CPU, 400 megahertz (MHz) or 733 MHz
- Memory
  - 256 MB SDRAM
- Storage
  - 2 gigabyte (GB) Compact Flash
- Standard Interfaces:
  - RS232 Serial (2)
  - 10/100 Mbps Ethernet (2)
  - Universal Serial Bus (USB) 2.0
  - SVGA port
- Operating System
  - Linux version 2.6.14.6
  - Based on Fedora Core Linux 4

Environmental

- Temperature
  - -35 to +55° C @733 MHz
  - -35 to +75° C @400 MHz

Physical

- Packaging
  - NEMA4X-compliant enclosure
- Size
  - 12" × 6" × 4.25" (33.3 cm × 16.7 cm × 10.8 cm)

Electrical

- Power requirement
  - 2A @ 12 VDC (24 watts)
  - 1240 VDC

The MCNU unit is shown in Figure 7 and Figure 8.

Figure 7. Photo. MCNU Interface Panel

Figure 8. Photo. MCNU RF Panel

2.2.4 Air-Weigh

The Air-Weigh on-board scale is an "on-the-ground axle weight scale." Axle weights can be determined in real time from the system installed on the vehicle.

Air-Weigh Air-Suspension Scales measure changes in air-suspension pressure to 1/27th of one pound per square inch (psi), or in increments of about 20–40 pounds of the vehicle's total on-the-ground weight. For the POC, the 5800 Series of truck scales were used on the tractor, interfaced to the vehicle's J1708 data bus. The 5800 Series on-board scale converts tractor load to weight by comparing empty and loaded axle group weights with empty and loaded suspension pressures.

The scale can be calibrated to display weights at any suspension load. The Air-Weigh display used in the WRI POC is shown in Figure 9.

Figure 9. Photo. Air-Weigh In-Cab Display

2.2.5 ORNL Comparison System

ORNL constructed a system similar to that provided by PeopleNet and TechnoCom to verify the contents of the test system's SDMS. This independent monitoring system was comprised of an eDAQ brand data acquisition system, VBOX III (a GPS-based system that provides data based on vehicle location such as speed, latitude, and longitude), Air-Weigh, and custom software to simulate the BOA. The ORNL DAS is shown in Figure 10 and Figure 11. The eDAQ data acquisition system received vehicle-related signals from the VBOX III and the vehicle's J1708 data bus. This information was received by the eDAQ via a CAN vehicle bus module, which interpreted the J1939 signals from the VBOX III. The eDAQ DAS received other vehicle information directly from the test vehicle's J1708 data bus through a J1708 vehicle bus module. This information included odometer readings, Antilock Braking System (ABS) status flags, and the vehicle axle weights (from the Air-Weigh system).

In addition to information obtained by the DAS, the ORNL comparison system included custom software run on a separate laptop computer to simulate a back-office system for driver records. Driver, carrier, and vehicle information such as medical certification, carrier DOT number, and license plate number were hand-entered at the beginning of testing to simulate information that would be available in company and state records. The program was run throughout the testing to maintain current eight-day HOS records for each driver. Driver status was recorded on this computer based on the scanned driver's license barcode and user-selected status. Post-processing of the data permitted the formatting of the data from the laptop and the DAS into an SDMS which could be compared to the SDMS of the WRI system.

Figure 10. Photo. ORNL Comparison System DAS

Figure 11. Photo. ORNL Comparison System Mounted in Test Vehicle

2.3 SDMS DATA CATEGORY AND SOURCE

The SDMS consists of information from the vehicle's data bus, inputs from the driver, and information calculated by the PeopleNet back-office system (e.g., HOS data). Table 2 lists the type of data in the SDMS and the source of the data (input method).

Table 2. SDMS Data and Input Method

SDMS Data	Input Method(s)
Driver ID	
Driver Name	Test Engineer/Driver
Driver License Number	Test Engineer/Driver
Driver State	Test Engineer/Driver
Vehicle ID	
Vehicle Identification Number	Test Engineer/Driver/J1708
Vehicle License Tag Number	Test Engineer/Driver
Carrier ID	
Carrier Name	Test Engineer/Driver
USDOT Number	Test Engineer/Driver
Driver Status	
Hours of Service Duty Status Change	Test Engineer/Driver
Medical Card Expire Date	Test Engineer/Driver
Medical Card Physician Name	Test Engineer/Driver
Medical Card Physician ID Number	Test Engineer/Driver
Medical Card State of Issue	Test Engineer/Driver
Vehicle Status	
IFTA (International Fuel Tax Agreement)Year	Test Engineer/Driver
IFTA State of Issue	Test Engineer/Driver
IFTA Number	Test Engineer/Driver
Annual Inspection Date	Test Engineer/Driver
Annual Inspection Performed By	Test Engineer/Driver
Annual Inspection Number	Test Engineer/Driver
ABS Warning Lamp Status	J1708
ABS Brake Control Status	J1708
ABS Retarder Control Status	J1708
ABS Off-Road Function Switch Status	J1708
Axle Weights	J1708

2.4 TEST VEHICLES

The test vehicles used in the WRI POC were secured by ORNL. The test tractor came from Salem Leasing (via a subcontractor). It was a 2005 Columbia Series Freightliner tractor with an Eaton 10-speed transmission and a J1708 data bus. The tractor is shown in Figure 12.

Figure 12. Photo. WRI POC Test Tractor

During most of the testing, a U.S. Department of Energy (DOE) fleet vehicle was used to simulate the MEV. For a limited part of the testing, an actual Tennessee Highway Patrol car was used. The van is shown in Figure 1 and an example of a patrol car is shown in Figure 14. Each vehicle was fitted with the TechnoCom MCNU transceiver, antenna, and laptop computer. The antenna used (either stick or dome style) depended on the frequency of test, either 2.4 GHz or 5.9 GHz.

Figure 13. Photo. DOE Van Used to Simulate a MEV

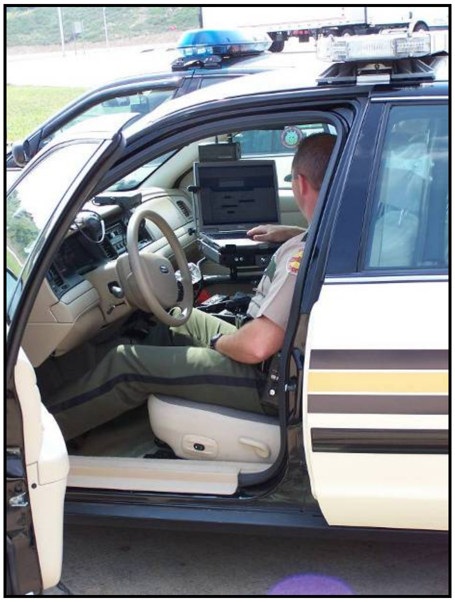

Figure 14. Photo. Tennessee Highway Patrol Car Similar to That Used as a MEV

2.5 ROADSIDE CONFIGURATIONS

RSE was set up temporarily at the Knox and Greene County CMV inspection stations. The RSE consisted of the transceiver, antenna, antenna tripod, and laptop computer. Again, the antenna used depended on the frequency of test (2.4 GHz or 5.9 GHz). Images of an antenna and the computer system can be seen in Figure 15 and Figure 16.

Figure 15. Photo. Roadside Unit at the Knox County Inspection Station

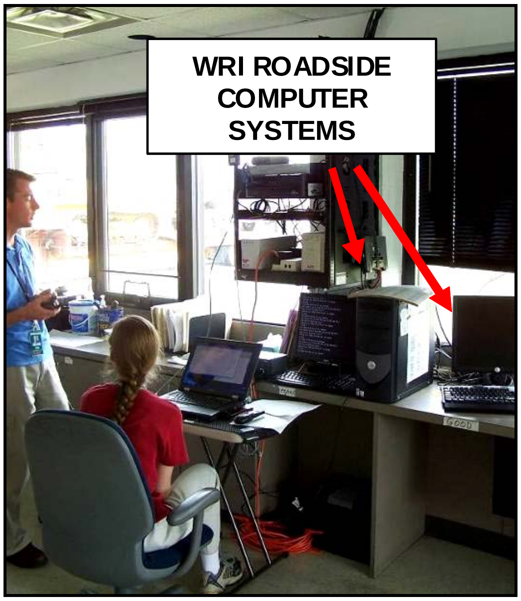

Figure 16. Photo. Roadside Unit at the Greene County Inspection Station

2.6 TESTING ELEMENTS

2.6.1 Tested Features

For the POC, the following features and capabilities were tested:

- The UWIS kernel's ability to capture and store the list of SDMS data called out in section 2.3 of this document.
- The UWIS kernel's ability to accurately process the required elements of the SDMS
- The UWIS kernel's ability to transfer the SDMS to the wireless transceiver using either an RS-232 or USB connection.
- The wireless transceiver's ability to receive the SDMS from the UWIS kernel.
- The wireless transceiver's ability to receive requests for the SDMS from the roadside under multiple conditions, as called out in the Test Plan, section 15.3.
- The wireless transceiver's ability to transmit the SDMS to the roadside under multiple conditions, as called out in the Test Plan, section 15.3.
- The wireless transceiver's ability to receive requests for the SDMS from the MEV under multiple conditions, as called out in the Test Plan, section 15.3.
- The wireless transceiver's ability to transmit the SDMS to an MEV under multiple conditions, as called out in The Test Plan, section 15.3.

2.6.2 Features Not Tested

For the POC, the following features were not tested:

- The UWIS kernel's ability to comply fully with FMCSA's Proposed Rule Making on EOBRs for CMVs (§395.16) (it is desirable that the kernel devices meet, or closely approximate, the requirements of §395.16. However, relative to the HOS for the POC, the testing was concerned only with finding status changes and total time in a status in order to construct the grid log).

- Vehicle status information beyond what is already present on the test tractor.
- Any features associated with the back-office analysis and storage systems (the BOAs were simulated for the WRI POC).
- The ability of the UWIS to transmit and receive the SDMS in various terrains, in varying levels of traffic congestion, and in the presence of electronic interference.
- Transmission of data above 55 mi/h (test vehicle or MEV speed).
- Definitive range limitations of the wireless transceivers.

2.6.3 Testing Entry and Exit Criteria

Entry conditions included the following:

- At least one UWIS kernel partner with operational equipment was desired; however, its absence would not have prevented Phase 1B testing of the transceiver using a simulated SDMS.
- A contract for 5.9 GHz and 2.4 GHz transceiver technology was desired; however, its absence would not have prevented the Phase 1A testing of the kernel.
- Availability of necessary test equipment.
- Access to an acceptable test vehicle.
- Finalized test plan and test procedures.
- Suitable, safe test location(s).

Exit conditions include the following:

- POC Phase 1A and 1B testing successfully completed.
- Expired POC test window (see section 1.6 for dates).

2.6.4 Technology Pass/Fail and Evaluation Criteria

In the event that the partner's kernel had failed properly to collect, structure, and output the SDMS information (e.g., no viable data output for monitoring, no SDMS, or SDMS with no data), a second testing opportunity would have taken place within seven calendar days. If the partner's technology had failed again to produce the SDMS, no further testing would have been conducted and ORNL would have deemed this partner unviable for the POC, per the MOU agreement.

Note: The test team had a high expectation of reliability (i.e., a match of input data to the SDMS of greater than 99.5 percent; see section 3.1.3 for the data analysis). However, if the partner was able to construct the SDMS with a lower level of reliability, it would not have been rejected from the POC or from future efforts.

3. PROOF-OF-CONCEPT TEST

3.1 PHASE 1A

3.1.1 Introduction

The objective of the Phase 1A test was to assess the UWIS kernel's ability to format the SDMS.

To accomplish this objective, ORNL configured a DAS to gather the comparison data ("ground–truth") using the system outlined in section 2.2.5. This comparison system consisted of a SoMat eDAQ DAS configured to collect data at 5 Hertz (Hz), and a laptop computer. ORNL had extensive experience with the DAS, which was used in other projects to collect more than 250 GB of spatial and databus information similar to the data needed for this project. The kernel and the DAS were integrated onto a 2005 Freightliner Class-8 truck with a box trailer.

The kernel included a system designed by mobile computing and communications provider PeopleNet. Because of time constraints, and in order to conserve funding, PeopleNet created a system to demonstrate the potential of WRI with the understanding that a different approach and additional design and coding would be required for its commercial release. The demonstration system took advantage of PeopleNet's existing eDriverLogs product, in which available HOS are tracked on the OBC and can be communicated periodically to a back-office system. The driver completed an electronic form on the OBC to provide key personal information such as name, medical exam doctor, medical exam date, and date of annual vehicle inspection among other information. In addition, a tethered barcode scanner allowed the barcode representing the CDL license number to be scanned in directly from the license itself. Once these data were entered and transmitted, the back-office system recorded them, and the driver did not have to use the form again unless updates were required.

In the truck itself, a laptop computer running software supplied by PeopleNet was connected via a serial port to the PeopleNet OBC. This software polled the OBC every 10 seconds (configurable interval) to obtain current GPS position and J1708 engine control module (ECM) data. Meanwhile, every 5 minutes (also configurable) the back-office system sent the most current driver identification data and HOS data on file to the laptop software via the OBC. When the OBC received these data from the back office, it simultaneously sent back the most recent driver HOS data, which was then communicated back to the laptop 5 minutes later. The software on the laptop provided a continuously updated SDMS file containing personal and HOS data that were 7–9 minutes old, as well as GPS and J1708 data that were approximately 10 seconds old. This file was sent to the transceiver via FTP as soon as it was updated every 10 seconds.

For this POC, PeopleNet combined several existing processes originally created for other reasons in order to form a demonstration of WRI. Because the HOS data are already tracked on the OBC and the driver personal data could be stored on the OBC as well, a commercially releasable system would extract all data from the OBC at a higher frequency (i.e., every few seconds) than the one used in the POC. This methodology would result in greater overall accuracy and reliability.

The test team consisted of a test driver and a ride-along engineer**.** The ride-along engineer was responsible for inputting the data reflecting the driver's duty-status changes into the kernel registering these changes, using the software deployed for the DAS's on-board laptop computer; handwritten notes were also taken as a backup. Other information, specifically databus-related information, was read directly by the kernel and the DAS. The test lasted approximately 10 hours, and consisted of a trip that visited three states. Departure was from Knoxville, TN; the first destination was London, KY, followed by Ringgold, GA, with the trip ending in Knoxville, TN. Figure 17 shows the route taken for this trip, as well as the CMV inspection stations along that route (marked with circles). Those inspection stations are located at Corbin, KY; Knox County, TN; and Ringgold, GA.

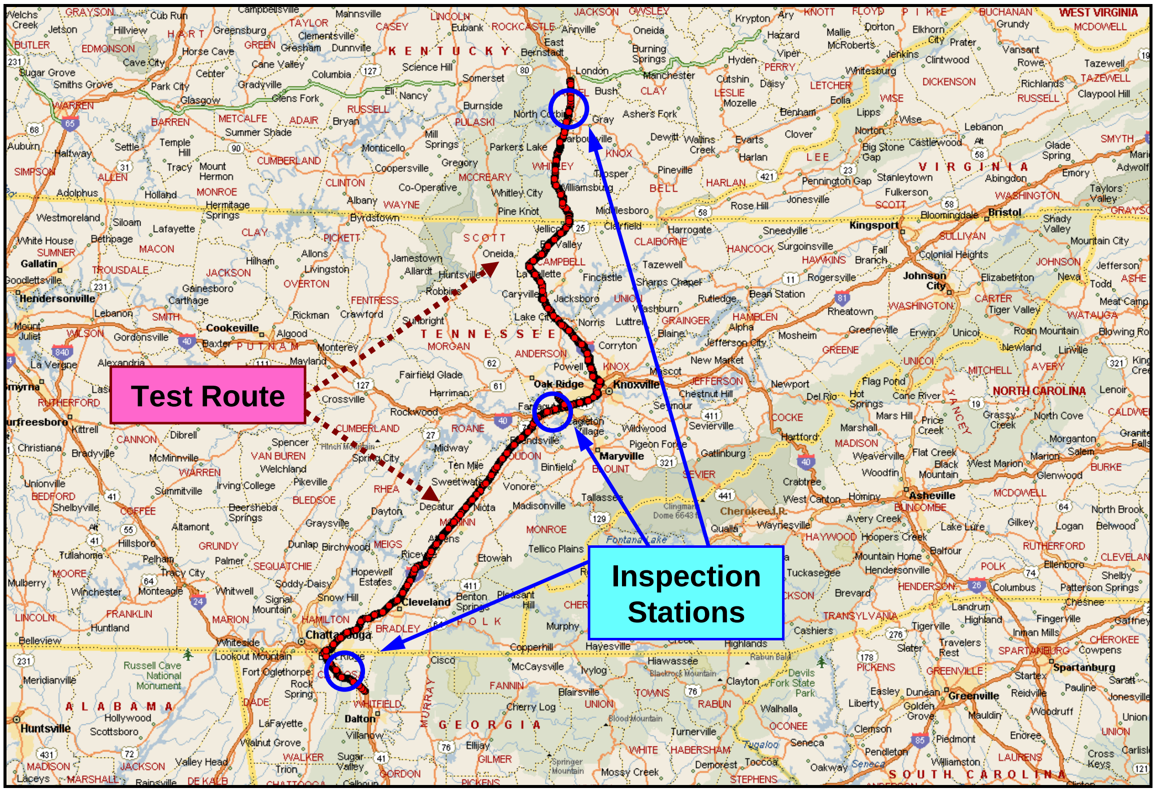

Figure 17. Map. Phase 1A Test Route and CMV Inspection Stations

3.1.2 Data Collected

The data fields collected during the test are presented in Table 3. The third column in that table shows an example of the contents of each field. Notice that although the DAS collected weight data, this information was not a requirement for the kernel and therefore an "NA" label is shown in column three for those weight-related fields. The DAS collected databus and vehicle location information (latitude, longitude, etc.) at 5 Hz (one reading every 0.2 seconds). An appended SDMS was generated throughout the duration of the Phase 1A test, which resulted in 3,597 lines of data, each containing the information listed in Table 3.

Table 3. Information Collected in Phase 1A Test

Field Name	Description	Contents (Example)
DRFIRSTNAME	Driver’s first name	John
DRLASTNAME	Driver’s last name	Doe
DRCDL	Driver’s license number	987654321
DRSTATE	State issuing license	TN
CARRNAME	Carrier’s name	Commercial Carrier Consultants
CARRID	Carrier’s truck ID	10144
CARRUSDOT	Carrier’s USDOT number	1628871
VIN	Vehicle Identification number	1FUJA6AV95LU33071
VID	Kernel’s vehicle ID	1004429
VLTN	Vehicle License Plate	TN20474HZ
VEHNETWT	Net Vehicle Weight	NA
VEHSTRWT	Weight on Steer Axle	NA
VEHDRVWT	Weight on Drive Axles	NA
VEHTRWT	Weight on Trailer Axles	NA
ABSWRNLP	ABS Warning Lamp Flag	NA
ABSBRKCTL	ABS Brake Control Flag	NA
ABSRTDCTL	ABS control flag	NA
ABSOFFRD	ABS Off-Road Flag	NA
MCPN	Medical Card Physician Name	Smith
MCPID	Medical Card Physician ID	998877
MCST	Medical Card State	TN
MCED	Medical Card Exam Date	39448
AID	Annual Inspection Date	39125
AIPB	Annual Inspection Performed by	Jones
AIN	Annual Inspection Number	121212
IFTAY	IFTA Year	2007
IFTASTATE	IFTA State Issued	TN
IFTAN	IFTA Number	18822045
SEQID	Unique Index Number for Each SDMS	392
DRDUTYSTATUS	Driver’s Duty Status	ON
DRDUTYTIME	Time of Last Duty Status Change	18:50:46
DRHOSDATE	Date Logged Last Duty Status Change	6/26/2007
DRHOSTIME	Time Logged Last Duty Status Change	20:28:32
DRHOS_USA607	PeopleNet HOS Info	no
DRHOSDSA_USA607	PeopleNet HOS Info	35778
DRHOSOSA_USA607	PeopleNet HOS Info	35778
PFXODO	Odometer reading	161586.80 miles
DRDUTYLOC	Location of Last Duty Status Change	0@Knoxville, TN
GPSLONG	Longitude	-84.15474
GPSLAT	Latitude	35.95472
GPSHEAD	Heading	0 deg
GPSSPEED	Speed	0 mi/h
GPSUTC	UTC Time (from GPS)	Wed Jun 06 2007 13:58:23

One of the key fields in Table 3 is the GPSUTC field. Information stored in this field provided a timestamp for any message generated by either the DAS or the kernel. Since this timestamp is taken from GPS satellites, it is universal and allows for synchronization of both messages. This, in turn, permits the comparison of the information provided by the kernel to the "ground-truth" information that was collected by the DAS system at the same time. Since the sampling rate of the DAS was 5 Hz, there is an intrinsic error of less than 0.2 seconds in the synchronization of the messages.

It should be noted that the GPSUTC value provided by the kernel is not a satellite timestamp, but rather the value of the OBC's internal real-time clock. The difference between this clock and the UTC timestamp received from GPS satellite is checked once every second; if it becomes greater than 15 seconds (configurable interval), the clock is reset to the satellite time. This is done in order to supply time as accurately as possible to other applications, even when satellite signals are degraded by obstructions or atmospheric conditions.

The test was run between 12:00:07 and 22:10:18.0 UTC (Universal Time Coordinates), corresponding to 08:00:07 to 18:10:18.0 Eastern Daylight Time (EDT). [Note: for the remainder of this chapter, all the times are shown in UTC.] During this interval, the kernel-generated 3,597 messages composed of the information shown in Table 3. This represented an average rate of one message every 10.2 seconds, as expected, based on the configuration discussed above; in the same period of time, the DAS generated 188,330 messages. Of the 3,597 messages, four had an "N/A" label in most of the fields, indicating that the kernel was not able to generate the required information; the remaining 3,593 (or 99.9 percent of the messages) always contained information in all the fields showed in Table 3.

There were 259 instances in which messages were repeated (i.e., instances when, because of communication or GPS problems, the kernel was not able to generate a new message and therefore repeated the last one that was correctly created). Those "blackout" periods, which covered 7.2 percent of the test time, resulted in 44 intervals with no updated messages. The longest blackout interval was 317 seconds, the shortest was 30 seconds, and the average was 75.6 seconds.

The blackout intervals occurred both with the truck moving and when it was stationary and were largely concentrated in two distinct periods of time. Figure 18 shows the speed profile of the test vehicle during the entire test, with the blackout periods superimposed. Some of the blackouts were explained by the area in which the truck was traveling. For example, between 14:37 and 16:21, the vehicle was traveling in the Cumberland Gap/Jellico Mountain Region (mostly going southbound on I-75) on the border between Kentucky and Tennessee; this mountainous area is known to have problems with cell-phone coverage. However, there were almost no blackout periods on the northbound leg of the trip in the same area. The other time interval with a high number of blackouts was that between 20:44 and 21:50, when the vehicle was traveling on I-75 North, between Cleveland, TN, and Knoxville, TN. This area has is not known to have particular problems with cell-phone coverage.

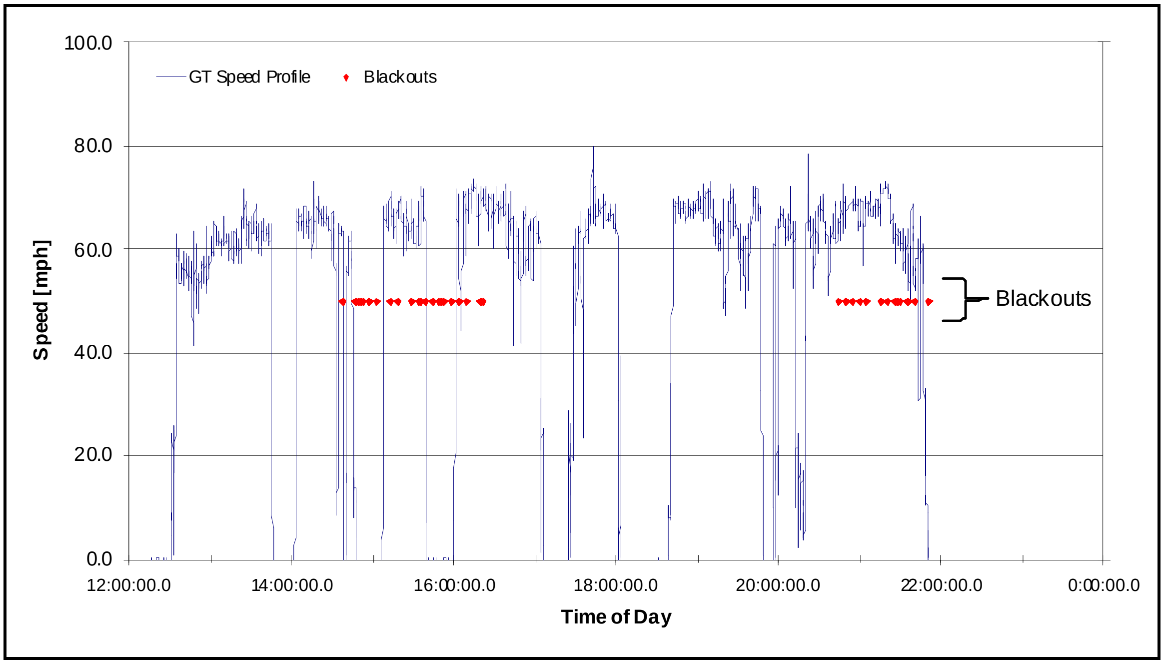

Figure 18. Graph. Test Vehicle Speed Profile and Communication/GPS Blackout Periods

3.1.3 Data Analysis

3.1.3.1 Kernel-Generated Information

In order to assess the accuracy of the information generated by the kernel, the messages that it generated were compared against "ground-truth" information collected by the DAS system. Out of the 188,330 messages collected by the comparison DAS, those with timestamps closest to the ones corresponding to the 3,593 kernel messages were selected; the four messages with "N/A" labels were eliminated from the dataset. The information contained in these messages was paired and compared for selected fields to assess the accuracy provided by the kernel.

Although the DAS system is very reliable and accurate, the information it generates could have problems, such as bad readings from the databus sensors or loss of GPS signal. Therefore, when any DAS message that was paired to a kernel message contained inaccurate[*] information in any field, it was eliminated from the database together with the corresponding kernel message. This procedure was used in order not to penalize the kernel when the ground-truth information was not collected at its highest possible accuracy level. One hundred thirteen ground-truth messages presented some problem and were therefore eliminated from the assessments.

The analysis was divided into two parts. The first part consisted of assessing information obtained from the databus sensors and location information provided by the GPS. The second part focused on the HOS and other driver-related information.

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[*] The DAS provides an error code for any field that presented any problem while a particular record was generated. These error codes were used to eliminate problematic records.

3.1.3.2 Databus and Location Information

Table 3 shows several fields related to information that can be obtained from the vehicle databus, including an ABS warning lamp flag, ABS brake control flag, ABS control flag, ABS off-road flag, and odometer reading. Because the kernel did not read any of the ABS-related information, the odometer reading was selected to represent the Databus Information category. Notice that whether only one field is used or many, the accuracy of the kernel in reading databus information is not affected, since the comparison is being made against the DAS reading the same information. Certainly, a problem would arise if the kernel were not querying the right sector of the databus, but that would result in an accuracy level of 0 percent and would rapidly be attributed to a gross reading error.

Regarding the location of the vehicle, its position in terms of latitude and longitude coordinates were used to determine the accuracy of the kernel in providing spatial/temporal information. Also related to GPS-obtained information, vehicle speed was used to determine the accuracy of the kernel in providing this type of information. While the kernel gathered this information based on its GPS, the comparison (DAS-provided) information was obtained from the vehicle databus.

In order to measure the accuracy of the kernel, the following procedure was used. First, using the timestamps added to both kernel and ground-truth messages by their respective data collection systems, the messages were paired such that their timestamps were ordered chronologically as closely as possible. A database was created with these paired messages. Second, the ground-truth messages that presented any problems (such as lack of GPS readings, out-of-bound readings, or other types of errors) were eliminated from the database, together with their paired kernel messages. Finally, the remaining records were used for the assessment of the kernel accuracy.

Two different approaches were used for this assessment. For both database and speed information, the absolute difference between the kernel (denoted by the subscript *K*) readings and ground-truth (denoted by the subscript *GT*) readings of the same field (D_{KGT}) was computed and compared against a tolerance level (*TL)* for that measure. If D_{KGT} was within the tolerance level (i.e., $D_{KGT} \leq TL$), then the kernel message was considered accurate at that level. The percentage of accurate messages at level *TL* was calculated simply by dividing the number of accurate kernel messages by the total number of kernel messages in the database.

In the case of the spatial location of the vehicle, rather than using the same procedure and comparing the latitude and longitude readings separately, the distance between the positions of the vehicle provided by the ground-truth system and the kernel (D_{KGT}) was computed using the Haversine formula (Sinnott, 1984). The rest of the procedure was the same as that used in the previous case. That is, the distance D_{KGT} was compared against a tolerance level *TL*, which allowed the determination of whether the information in the kernel message was accurate at that level. The accuracy of the kernel was then assessed as the percentage of spatially accurate messages out of the total number of kernel messages.

It should be noted that, unlike the databus information, the GPS information depends on the device used. That is, although all the GPS devices use the same satellites, they may be optimized for different situations. If a high accuracy in the horizontal plane (latitude, longitude) is desired, then the GPS device gives more weight to the satellites that are closest to the zenith. On the other hand, a higher accuracy in altitude involves using the satellites that are closest to the horizon. Since the kernel and the DAS used different GPS devices, an error may have been introduced in the assessment of D_{KGT} if these GPS devices had different optimization algorithms. The source of this error is unknown, although it is probably negligible compared to the tolerance levels used in the evaluations.

The results of the evaluations considering all of the messages collected in the test are presented in Table 4**.** For each of the categories of information presented in that table, the headers of the three right-hand columns indicate the tolerance levels used to determine the accuracy of the kernel. For the computations of the accuracy levels presented in Table 4, the total number of messages was 3,480, which is less than the 3,593 kernel messages introduced previously. This was the case because 113 ground-truth messages presented problems and were therefore eliminated from the assessments.

Table 4. Accuracy of Kernel Databus and Location Information Considering All Messages

Information Type	Tolerance Level	Number of Accurate Messages	Accuracy at Tolerance Level
Odometer	0.01 miles	934	26.8%
	0.10 miles	1,245	35.8%
	0.25 miles	2,509	72.1%
Speed	0.5 mi/h	1,361	39.1%
	1 mi/h	1,830	52.6%
	5 mi/h	3,154	90.6%
Location	250 ft	957	27.5%
	500 ft	1,070	30.7%
	1000 ft	1,169	33.6%

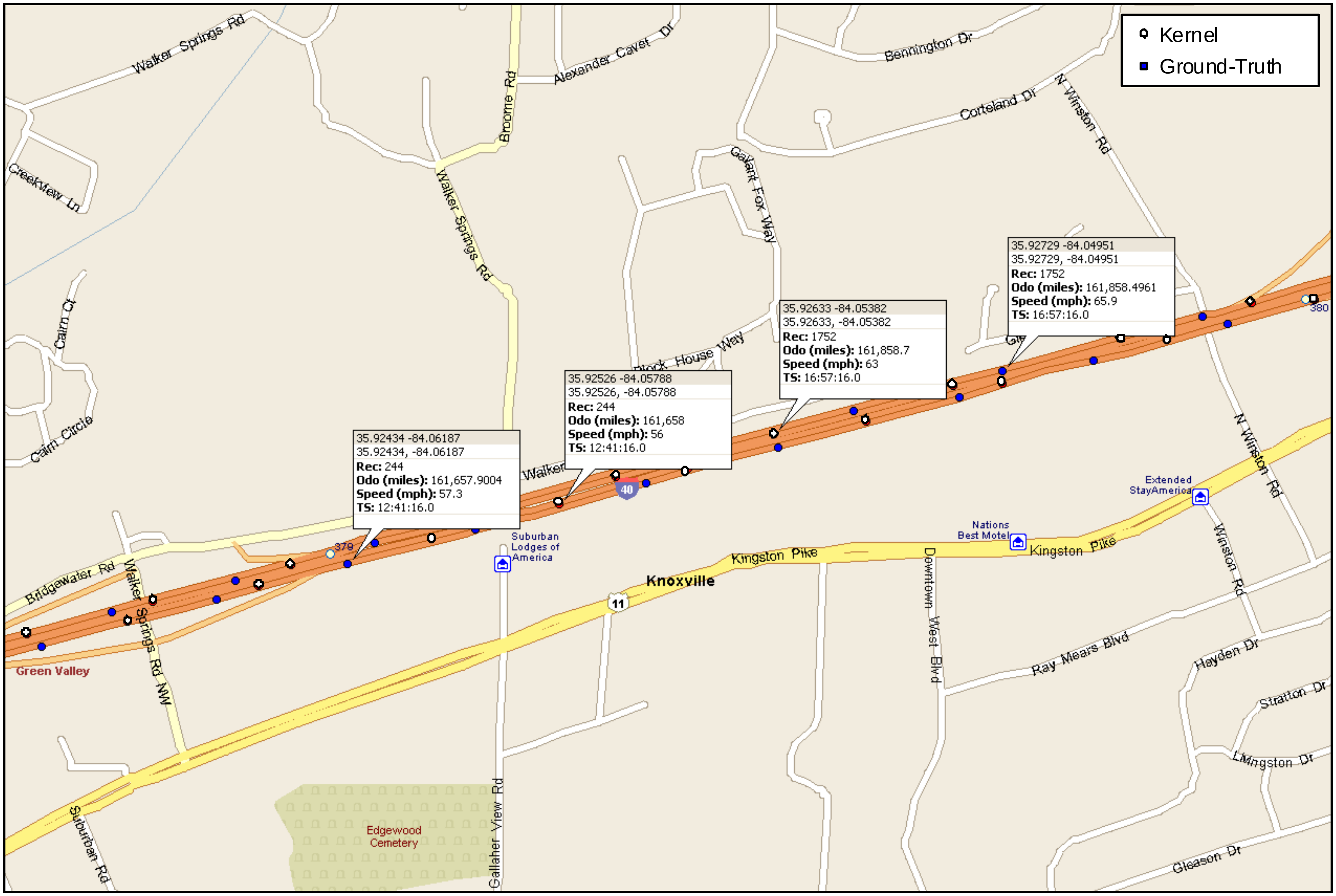
Although the tolerance levels are arbitrary, it appears from Table 4 that the accuracies of the different categories of information should be higher. In particular, Location Information seems to have a very low accuracy, even at a *TL* of 1,000 ft, and the other categories—Odometer Information and Speed Information—although not as bad as Location Information, also have very low accuracy levels. One issue that could have affected the accuracy was that of the repeated messages discussed previously. In a second round of calculations, all those repeated kernel messages (i.e., the messages provided during the blackout periods) were eliminated from the database. This reduced the total number of messages used in the accuracy assessments from 3,480 to 3,221.

The results of the new computations are presented in Table 5. Even when these repeated messages were eliminated, the accuracy levels increased only slightly in two cases, while decreasing in the other seven. This decrease in the accuracy level when apparently bad information (i.e., non-current information) is eliminated was due to the fact that a high proportion of the repeated messages occurred when the truck was stationary or traveling at a very low speed (e.g., 62 percent of the blackout messages occurred when the truck was either stationary or traveling at less than 2 mi/h). Therefore, the odometer, speed, and location readings were the same as those provided by the ground-truth messages and were counted as accurate kernel messages in Table 4. Once those messages were eliminated, the percentage of accurate messages decreased in all but one case (Odometer Information, Accuracy at TL, at 0.25 miles) as can be seen in eight of the nine cells of Table 5.

Table 5. Accuracy of Kernel Databus and Location Information Without Repeated Messages

Information Type	Tolerance Level	Number of Accurate Messages	Accuracy at Tolerance Level
Odometer	0.01 miles	822	25.5%
	0.10 miles	1,124	34.9%
	0.25 miles	2,376	73.8%
Speed	0.5 mi/h	1,243	38.6%
	1 mi/h	1,690	52.5%
	5 mi/h	2,922	90.7%
Location	250 ft	863	26.8%
	500 ft	945	29.3%
	1000 ft	1,022	31.7%

This warranted further investigation of the collected information. The messages were spatially and temporally tagged and loaded into a geographic information system (GIS) software utility (MapPoint) to visually inspect the data. Figure 19 shows this information as recorded while the test vehicle was driving in the Knoxville area during the first and second legs of the trip. The location provided by the kernel is displayed as a red dot, and the ground-truth information is displayed as a blue dot. The callout text in the four boxes show some of the information contained in each message, particularly the latitude and longitude coordinates, the record number, the odometer reading, and the timestamp. Consider, for example, Record 244. The kernel and ground-truth “bubbles” (messages) show the same timestamp, of course (since that was the common piece of information that tied those messages together). However, in all cases, the location reported by the kernel is ahead of the actual location (ground-truth location). Moreover, if the messages are matched by location and not by timestamp (recall that the ground-truth messages were collected at a rate 50 times that of the kernel), then there is always a difference of approximately 15 seconds (i.e., at the same location, the kernel indicates a timestamp that is 15 seconds earlier than the timestamp of the ground-truth message collected at that location). This time difference was consistent in terms of value and direction across all kernel-generated messages.



35.92434 -84.06187
35.92434, -84.06187
Rec: 244
Odo (miles): 161,657.9004
Speed (mph): 57.3
TS: 12:41:16.0

35.92526 -84.05788
35.92526, -84.05788
Rec: 244
Odo (miles): 161,658
Speed (mph): 56
TS: 12:41:16.0

35.92633 -84.05382
35.92633, -84.05382
Rec: 1752
Odo (miles): 161,858.7
Speed (mph): 63
TS: 16:57:16.0

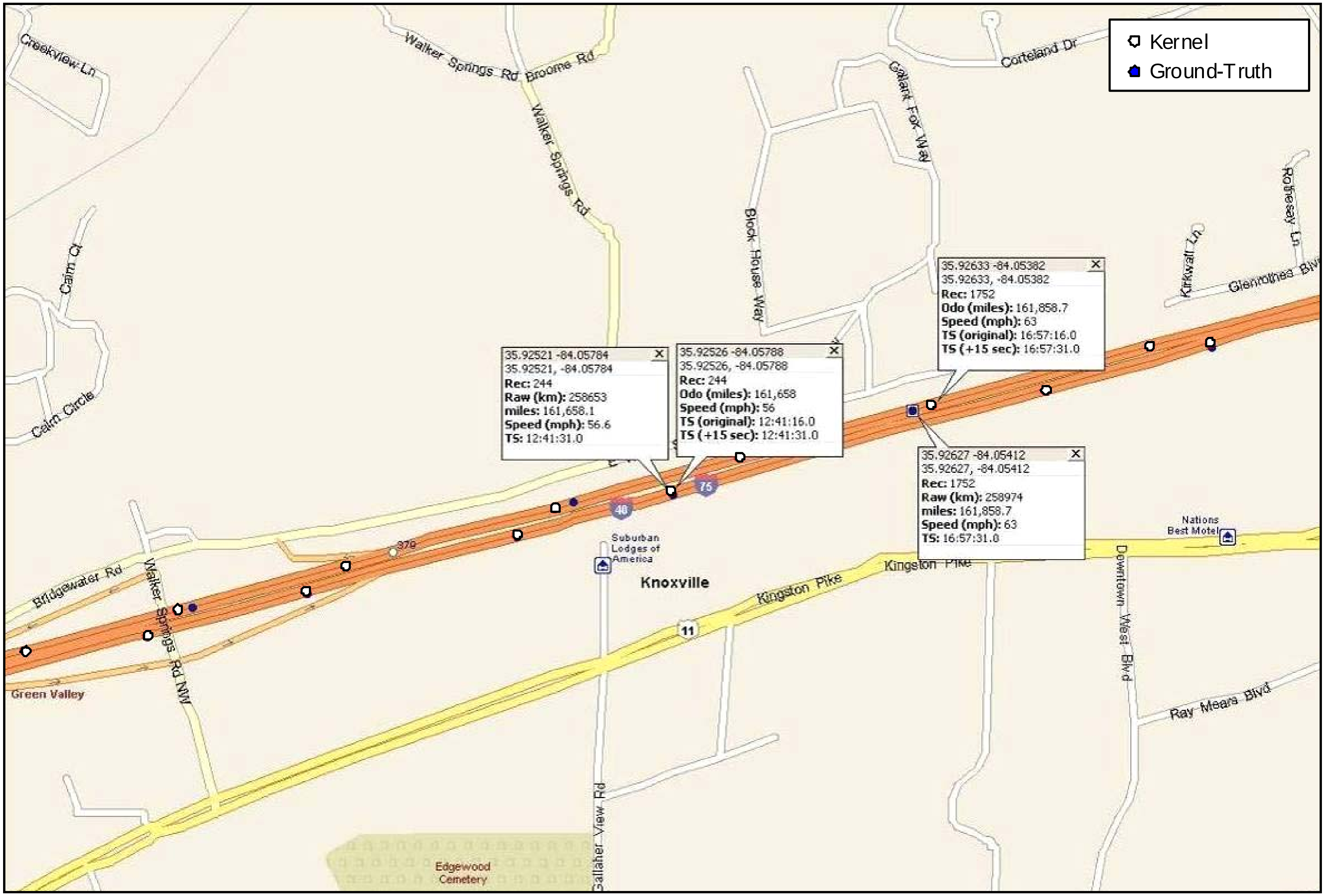
35.92729 -84.04951
35.92729, -84.04951
Rec: 1752
Odo (miles): 161,858.4961
Speed (mph): 65.9
TS: 16:57:16.0

Figure 19. Map. Vehicle Position as Provided by the Kernel and Ground-Truth Original Messages

As explained earlier, the timestamp provided by the kernel was not a satellite timestamp but rather the value of the OBC's internal real-time clock. Moreover, the difference between this clock and the UTC timestamp received from the GPS satellites was checked by the kernel at a rate of 1.0 Hz and was adjusted (i.e., reset to the satellite time) if it became greater than 15 seconds. Therefore, the observed "shift" in time was explained by the difference between the GPS time (i.e., the timestamp provided by the DAS) and the kernel's internal clock time. Since the difference never became larger than 15 seconds during the test, the kernel timestamp was never reset to the GPS time, thus generating a consistent, systematic difference between the timestamps of the kernel and the DAS.

Since the objective of this data analysis was to determine the accuracy of the information gathered by the kernel, this time shift of approximately 15 seconds was corrected and the corrected data were analyzed. The analysis resulted in significant increases in the accuracies observed in the three categories of information that were assessed. Figure 20 presents the same type of information as that displayed in Figure 19, but with the corrected data. Figure 20 graphically illustrates this increase in accuracy, while Table 6 presents the results in numerical form. The figures shown in that table were computed over a pool of 3,220 messages (one of the new ground-truth messages had to be eliminated because of reported errors in some of its fields).

It can be observed that, compared to the information presented in Table 3, all accuracy levels increased, some of them achieving values close to or at the 100 percent level. One exception was the odometer information, which did not reflect such a significant increase in accuracy. For this particular databus field, the J1587 standard indicates that the odometer data (total vehicle distance) can be read either in tenths of a mile (i.e., a resolution of 0.1 miles) or in kilometers at a resolution of 0.161 km (SAE International, 2002). While the kernel read the field in miles, the DAS did it in kilometers, introducing a small rounding error in the computations of the accuracy for this particular field. The difference, therefore, cannot be attributed to the kernel. Nonetheless, the analysis of this field was performed in order to determine whether the kernel was able to read databus information in real time, which it did successfully.



35.92521 -84.05784
35.92521, -84.05784
Rec: 244
Raw (km): 258653
miles: 161,658.1
Speed (mph): 56.6
TS: 12:41:31.0

35.92526 -84.05788
35.92526, -84.05788
Rec: 244
Odo (miles): 161,658
Speed (mph): 56
TS (original): 12:41:16.0
TS (+15 sec): 12:41:31.0

35.92633 -84.05382
35.92633, -84.05382
Rec: 1752
Odo (miles): 161,858.7
Speed (mph): 63
TS (original): 16:57:16.0
TS (+15 sec): 16:57:31.0

35.92627 -84.05412
35.92627, -84.05412
Rec: 1752
Raw (km): 258974
miles: 161,858.7
Speed (mph): 63
TS: 16:57:31.0

Figure 20. Map. Vehicle Position as Provided by the Kernel and Ground-Truth Messages That Have Been Shifted 15 Seconds

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Table 6. Accuracy of Kernel Databus and Location Information without Repeated Messages and with Time Shift

Information Type	Tolerance Level	Number of Accurate Messages	Accuracy at Tolerance Level
Odometer	0.01 miles	1,296	40.2%
	0.10 miles	2,053	63.8%
	0.25 miles	2,538	78.8%
Speed	0.5 mi/h	1,815	56.4%
	1 mi/h	2,615	81.2%
	5 mi/h	3,201	99.4%
Location	250 ft	3,217	99.9%
	500 ft	3,219	100.0%
	1000 ft	3,220	100.0%

In summary, once these corrections were made to the data provided by the kernel to account for factors that are exogenous to the investigation, for the three categories analyzed, the kernel provided information at a very good and sometimes excellent accuracy level.

3.1.3.3 Driver's Duty Status Information

The evaluation of the accuracy provided for the driver status information required a different methodology than the one used for the databus and spatial information. The driver status information, which is composed of the few discrete points that mark any change in duty status, has to be precise; otherwise it is not possible to determine HOS information.

During the test, and as discussed previously, any driver's duty status change was registered by the ride-along engineer in both the DAS and the kernel equipment. The kernel then added that information to the DRDUTYSTATUS field (see Table 3) of the message it created and repeated the information in that field until it registered a new status change. Since all the messages were timestamped, it was relatively easy to build an HOS diagram that could be compared to the one obtained by using the DAS information. Using the SDMS information in this way showed some discrepancies between the kernel and the DAS in building the HOS diagrams.

However, another field in the kernel message may be used to build an HOS diagram; this field was identified by PeopleNet as the correct field to use. The DRDUTYTIME field (see Table 3) contains time information of the last reported duty status change. This field was not used originally to construct the kernel's HOS, since at first glance it appeared to have incorrect information. Further investigation revealed that the information was not incorrect, but that it was delayed, in some cases by several hours. This was most likely due to software issues that could be corrected easily in a commercial system. Table 7 and Table 8 show the information that was derived from fields DRDUTYSTATUS (second column in these tables) and DRDUTYTIME (third column), together with the timestamp of the message that contained the new information in DRDUTYTIME (column 4) and the delay that the new information had before it was added to the kernel message (column 5). Consider, for example, row 5 in Table 7. At 15:01:15, there was a change in duty status from “Driving” to “Off Duty” for Driver 1. However, this information did not become available in the kernel messages until 19:55:23, or 4 hours and 54 minutes after the duty status change occurred. This was an extreme case; in fact, this was the maximum delay observed for Driver 1 duty status change during the test. The minimum delay was 4 minutes and 37 seconds (row 1 in Table 7) with an average delay of 3,802 seconds (just over 1 hour). For Driver 2, the maximum delay was 33 minutes and 19 seconds, the minimum was 4 minutes and 53 seconds (very close to that observed for Driver 1), and the average delay in reporting duty status change was 893 seconds (almost 15 minutes).

Table 7. Kernel Message Delays in Providing Driver 1 Duty Status Change (DRDUTYTIME Field Used)

Row No.	Driver Duty Status Changed to	Time of Driver Duty Status Change	Message TS	Delta Time	Note
1	**On Duty**	**12:26:49**	**12:31:26**	**0:04:37**	**Min. delay**
2	Driving	12:31:18	12:40:46	0:09:28	
3	On Duty	13:47:32	14:00:03	0:12:31	
4	Driving	14:02:26	16:30:56	2:28:30	
5	**Off Duty**	**15:01:15**	**19:55:23**	**4:54:08**	**Max. delay**
6	On Duty	19:51:32	20:01:05	0:09:33	
7	Driving	19:54:03	20:05:41	0:11:38	
8	Off Duty	21:52:36	22:09:06	0:16:30	

Table 8. Kernel Message Delays in Providing Driver 2 Duty Status Change (DRDUTYTIME Field Used)

Row No.	Driver Duty Status Changed to	Time of Driver Duty Status Change	Message TS	Delta Time	Note
1	Off Duty	11:46:43	12:00:16	0:13:33	
2	On Duty	11:59:15	12:22:27	0:23:12	
3	**Driving**	**15:57:46**	**16:31:05**	**0:33:19**	**Max. delay**
4	Off Duty	17:07:17	17:20:06	0:12:49	
5	Driving	17:24:23	17:35:12	0:10:49	
6	Off Duty	18:04:12	18:16:10	0:11:58	
7	Driving	18:38:03	18:45:12	0:07:09	
8	**Off Duty**	**19:45:44**	**19:50:37**	**0:04:53**	**Min. delay**

Even though there were substantial delays in reporting driver duty status changes, the information extracted from the DRDUTYTIME field (combined with the DRDUTYSTATUS field) allowed the building of HOS diagrams that were much more accurate than those built using the duty status field combined with the message timestamp. These delay problems, which were software problems, were subsequently fixed by PeopleNet. However, since the Test Plan had only one day of testing for Phase 1A, it was not possible to determine whether these issues were resolved completely. This will be done in the next phase of the project. Those HOS diagrams are shown in Figure 21 and Figure 22, with the disagreements between ground-truth and kernel data highlighted in light blue. Considering the total length of the test (i.e., 10 hours and 10 minutes), the agreements between the ground-truth and kernel diagrams amounted to 94.7 percent and 93.5 percent of that time for Driver 1 and 2, respectively. Although those accuracy levels are high, they still fall short of 100 percent accuracy.

Closer observation of the diagrams presented in Figure 21 and Figure 22 shows that most of the disagreements occur during a time period in which many "blackouts" were observed (see the "Kernel-Generated Information" subsection of section 3.1.3 and Figure 18). It is customary for devices that use wireless communication to store messages locally if the communication links are unavailable, and then to relay them later, once the communication links are reestablished. Because the observed disagreements occurred during these blackout periods, it appears that there was some software problem either in storing the information locally or in relaying that information later.

However, another disagreement occurred outside the blackout periods. In Figure 21, during the period from 13:45:15 to 14:01:38, when the truck was stopped (see Figure 18), the ground-truth data indicated that Driver 1 was "On Duty," while the kernel data showed the driver as "Driving." This could be another software issue requiring further investigation since even during the blackout periods, the discrepancy observed in Figure 22 occurred at points preceded by or followed by a stopping period. That is, the largest discrepancy occurred between 15:05:30 and 15:38:51, when the ground-truth system indicated that Driver 2 went from "On Duty" to "Driving" to "On Duty," while the kernel showed that Driver 2 was "On Duty" for the entire period. Notice that immediately before the start of this period, between 14:47:28 and 15:05:30, the truck was stopped, and it was also stopped after the end of the discrepancy period, between 15:38:51 and 16:00:14 (see Figure 18).

The two types of problems seem to be related, and are probably due to software issues whose resolution would allow the system to generate HOS diagrams with 100 percent accuracy.

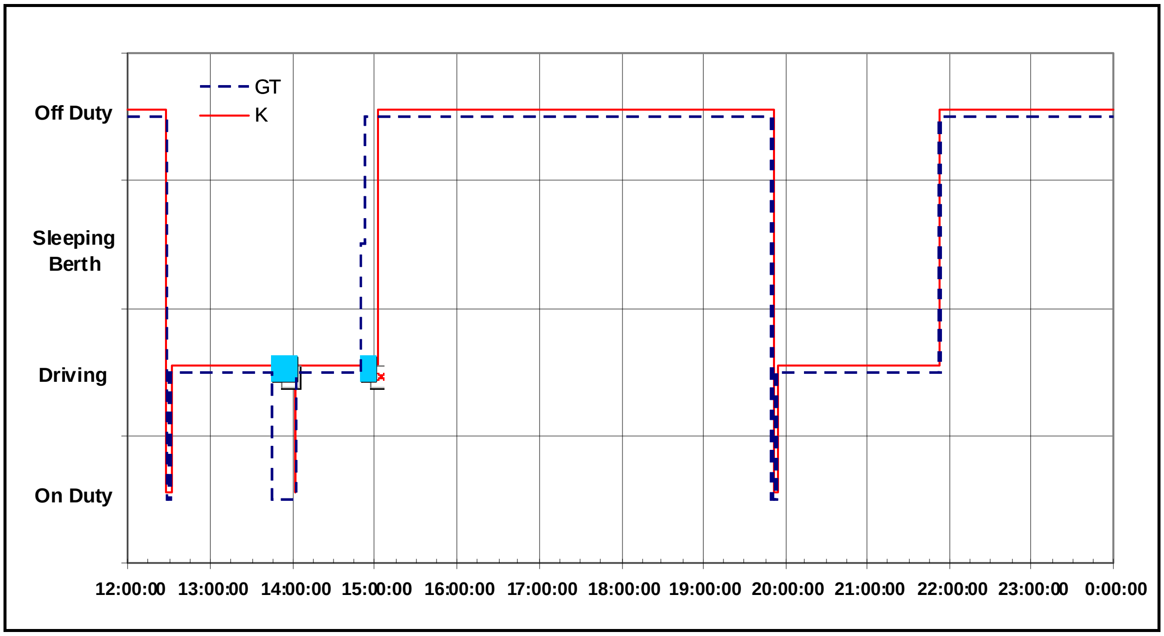

Figure 21. Graph. HOS Diagram for Driver 1
Constructed Using Kernel (K) and Ground-Truth (GT) Messages
(K DRDUTYTIME and DRDUTYSTATUS Fields Used)

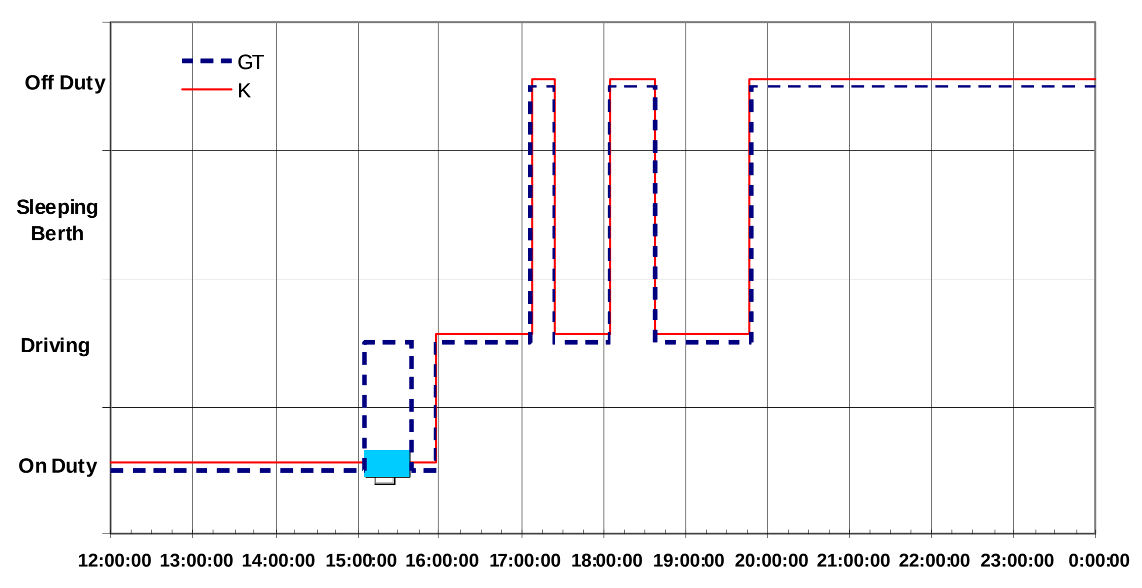

Figure 22. Graph. HOS Diagram for Driver 2
Constructed Using Kernel (K) and Ground-Truth (GT) Messages
(K DRDUTYTIME and DRDUTYSTATUS Fields Used)

3.1.4 Phase 1A Test Conclusions and Future Work

The results of the test performed in Phase 1A demonstrated that it was possible for the kernel to gather information from different sources (including EOBR and vehicle databus), assemble the required SDMS, and make it available for transmission to an RSU or MEV. The frequency at which these messages were generated was very high (i.e., one SDMS every 10.2 seconds on average) for the type of application considered here. The largest observed delay in generating a new SDMS was just over 5 minutes, which was considered to be adequate.

The accuracy of the information posted on the SDMS was measured within a certain tolerance, which was arbitrarily set at three levels. After some synchronization problems between the ground-truth and kernel messages were addressed, the information related to the spatial position of the vehicle (obtained from GPS readings) was 100 percent accurate when considering a tolerance of 1,000 ft. Speed, which was also determined via the kernel's GPS, presented an accuracy level above 80 percent when a tolerance of 1 mi/h or less was considered, and close to 100 percent with a tolerance of 5 mi/h or less. Odometer information, which was read from the vehicle's databus, was 79 percent accurate when a tolerance of 0.25 miles was considered.

The HOS information presented some problems. When a HOS diagram was built by combining driver status flags posted on the SDMS and the timestamp of that message, differences with the ground-truth's HOS were found. Those differences were substantially reduced (although not completely eliminated) when a different SDMS field was used. However, the information posted in this field, although very accurate, was not relayed in a timely fashion. Most of the observed delays were in the 5–20-minute range (which was expected), although in two instances they were measured in hours. There were also a few occasions in which a status change was either not registered or not posted in the SDMS.

Since the accuracy of the information contained in the SDMS seems to be acceptable, future work should focus mainly on the timeliness of the HOS information that is added to the message. Most of the observed problems were attributed to communication and software issues. In fact, during the pre-testing period, several related problems were identified by ORNL and addressed by the partner supplying the kernel information. It appears that some aspects of these problems were not fully resolved by the time of the test. Nevertheless, those problems do not seem to be insurmountable and should be resolved easily during the next phase.

In future tests, it is important that more detailed technical discussions be carried out between the testers (ORNL) and the developers of the system, so that there is a better understanding of the idiosyncrasies of both the DAS and the kernel. This approach would avoid such issues as reading the same field in different units (e.g., odometer) or providing timestamps that are generated by different devices (thus introducing synchronization problems).

3.2 PHASE 1B

3.2.1 Introduction

Phase 1A of the POC testing verified the kernel's ability to generate an SDMS by combining information from different sources and making that message available to be transferred to a unit outside the vehicle in which the message was generated. The focus of Phase 1B was to determine the feasibility of transferring that information under both static conditions (vehicle stationary) and dynamic conditions (traveling at up to highway speeds). Because the purpose of this POC test was to provide initial information regarding wireless inspection technology, limited testing involving several variables (such as antenna type and transmission frequency) was performed under both static and dynamic conditions. While the static tests were aimed at determining a general transmission range of the equipment used, the dynamic tests were performed to determine the feasibility of at-speed wireless safety inspections for heavy vehicles.

The wireless inspection system tested involved both an OBC mounted in the test vehicle used for Phase 1A testing and an RSU or MEV to receive the SDMS. The information generated by the kernel was received by a support computer and sent to an MCNU, supplied by TechnoCom, which transmitted the file wirelessly to a receiver at either 5.9 or 2.4 GHz via a dome antenna mounted on the right side of the truck's cab under the fairing.

The receiving system consisted of an MEV or RSU which included an antenna, a receiving MCNU, and a support computer to display the received SDMS. The MEV and RSU systems were virtually identical: the software for each was the same with slightly different setup configurations. However, the MEV antenna was mounted to the vehicle, while the RSU antenna was set up on a tripod. In order to be mobile, all of the MEV power requirements were provided by the vehicle (using AC power inverters where required), while the RSU operated on standard AC power.

A monitor and keyboard were also required to set up each MCNU upon startup; in addition, the monitor was used to display MCNU operation and to allow the test engineers to see when the MCNU had received or transmitted a file. Limited testing was performed at 2.4 GHz and 5.9 GHz, using both stick and dome antennas. While antenna placement and type remain important to the efficiency of the WRI system, this was not an area in which ORNL was tasked to do research; therefore, standard antenna placement was used (Figure 23).

Figure 23. Photo. Placement of the MCNU Dome Antenna on WRI Test Truck

3.2.2 Data Collection and Results

3.2.2.1 Static Tests

Static tests consisted of the assessment of the reliability of the wireless connection between the MEV and the test truck, as well as that of the file transfer function with both the test truck and the MEV in stationary positions. The objective of these tests was to determine a range at which the SDMS could be transmitted (although not necessarily the absolute maximum range), as well as to identify any file-transfer "dead zones" around the truck. The antenna was mounted on the tractor as illustrated in Figure 23, and the tests were conducted with a 53-ft trailer attached to the tractor.

The protocol for these tests consisted of systematically parking the MEV at 100, 200, 300, and 400 ft away from the tractor at positions that formed 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315° angles with an imaginary line defined by the longitudinal axis of the tractor-trailer combination. Figure 24 provides a diagram showing the truck placement at the center of concentric circles having radii ranging from 100 to 400 ft with an increment of 100 ft. While the truck remained at that central location during the entire test,[*] the MEV was positioned at places marked by gray dots in Figure 24. The MEV was always pointed away from the tractor-trailer in each of these positions.

Once the MEV was placed at the testing position, it made 20 attempts to "ping"[†] the OBE using the 5.9-GHz frequency. The number of successful MEV pings was noted. After that, the OBE made 20 attempts to "ping" the MEV. Again, the number of successful OBE pings was recorded. The OBE then attempted to transfer an SDMS wirelessly to the MEV. The same procedure was repeated for the remaining 31 MEV-truck relative positions.

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[*] Because of space constraints (these tests were performed at the Greene County, TN Inspection Station), the truck had to be rotated 180° to allow testing of all of the relative truck-MEV positions shown in Figure 10.

[†] A "ping" is network procedure to test whether a particular host is reachable across that network. It is performed by sending "echo request" packets to the target host and listening for "echo response" replies.

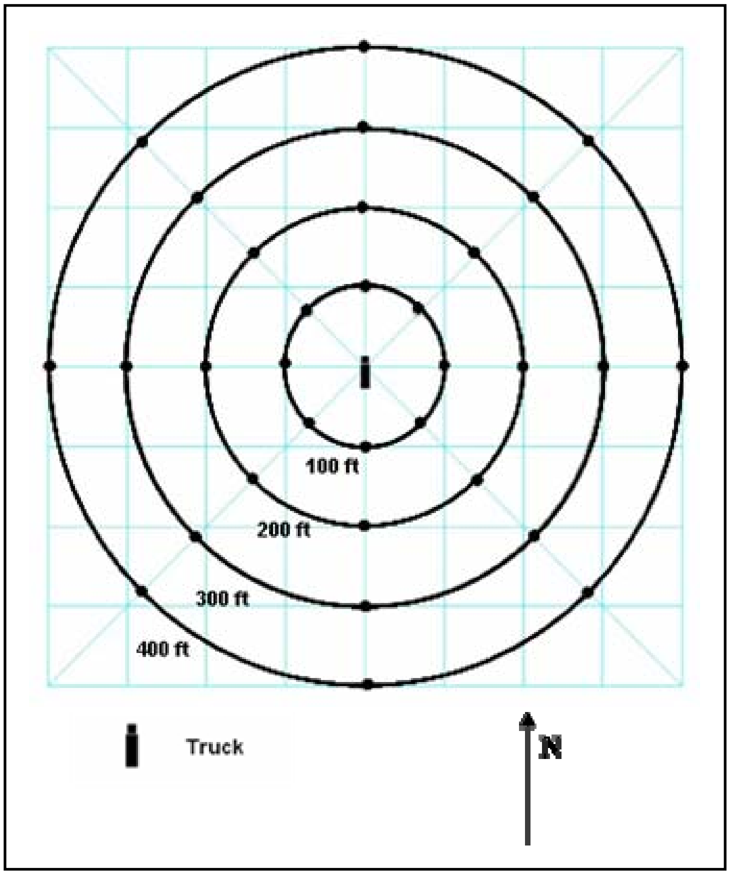


Figure 24. Location grid. Truck and MEV Positioning for Static Tests

The results of these stationary tests are graphically displayed in Figure 25**.** In that figure, the green circles indicate a successful file transfer at that location, while a gray circle shows an unsuccessful transfer. The numbers to the left and right of the circles show the number of successful MEV and OBE pings, respectively.

The SDMS was successfully transferred to the MEV at any of the four distances considered when it was located on the northwest, northeast, and east positions relative to the truck. At these positions, both the MEV and OBE pings had a success rate of 100 percent (except when the MEV was at an east position 400 ft away from the truck, where the OBE ping success rate was 95 percent). For the southeast, south, and southwest MEV positions, the success rate in pings and file transfer was 0 percent for all but the southeast and southwest positions at 100 ft from the truck. The probably reason for these results was obstruction by the trailer, which may have blocked the truck antenna. More difficult to explain are the unsuccessful file transfers and pings when the MEV was located on the west and north positions (probably the most common relative positions of truck and MEV in the field). For these instances, except for the case in which the MEV was at a distance of 100 ft from the truck, the success rates were 0 percent for all the measures considered. While it could be argued that the location of the antenna on the passenger side of the tractor may have affected the line of sight when the MEV was in the west position, it is difficult to explain why there were no file transfers or pings when the MEV was directly in front of the truck. One explanation may be that the dome antenna is directional (although no indication in this regard was given to ORNL by TechnoCom) and that it was inadvertently placed in an unfavorable position. Regardless of which explanation is most accurate, in the next phase of this project new tests should be performed to investigate these dead zones further, both statically and dynamically (i.e., at highway speeds), as this problem of dead zones was present throughout the testing.

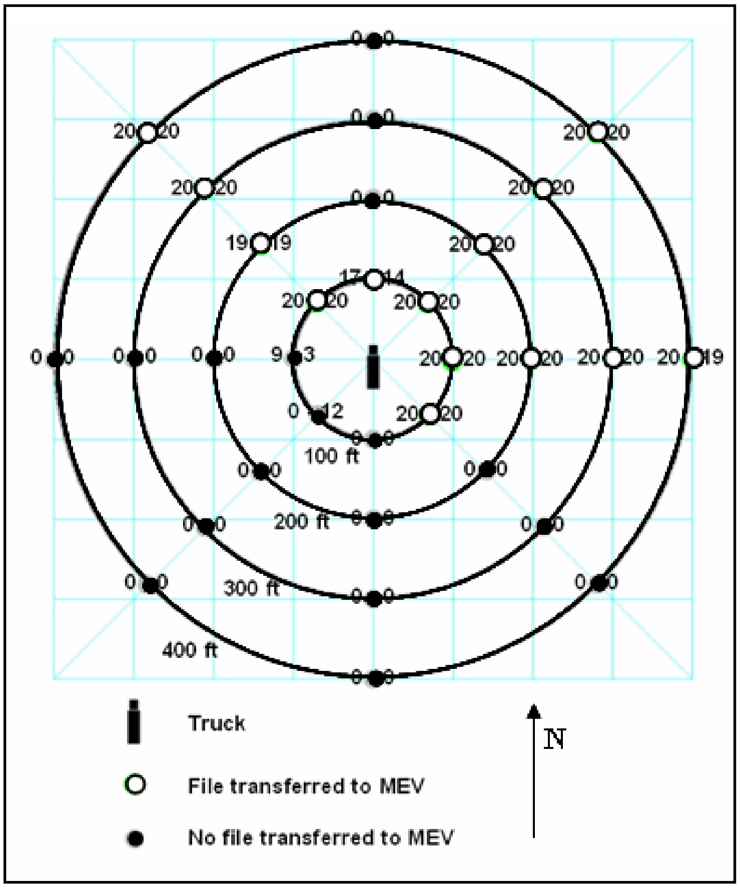


Figure 25. Location grid. File Transmission to the MEV at 5.9 GHz Using the Dome Antenna

Other static tests using the 5.9-GHz frequency were performed at the Knox County, TN, CMV Inspection Station for the purpose of verifying equipment functionality prior to dynamic testing. While the truck was in a stationary position, 10 file transfers to the RSU unit—equipped with a tripod stick antenna—were attempted with a success rate of 100 percent. Two other file transfer tests were conducted, this time between the stationary truck and the MEV. The MEV was equipped with a 5.9-GHz dome antenna centered on the roof (see Figure 29 inset). In the first case, with the MEV relatively close to the truck, all 10 SDMS file transfer attempts failed. This was attributed to interference from poles and signs (see Figure 26). When the truck was placed farther back, at about 63 ft from the MEV (in Figure 27, the truck placement would be in the bypass lane, west of the section which can be seen in the figure), the file transfer success rate was 90 percent for the 10 attempts.

Figure 26. Photo. Location of Signs at Knox County Inspection Station

3.2.2.2 Dynamic Tests

Drive-by Tests: Dynamic tests were performed at the eastbound Knox County CMV Inspection Station (Figure 27). In these tests the vehicle traveled past a roadside antenna and/or parked MEV (both a van [shown in blue in Figure 27] and a patrol car [shown as a dotted outline] were used to simulate MEVs) while traveling at 25 mi/h in the bypass lane. Tests were repeated at highway speeds of 55 mi/h on both sides of the highway. Most of the WRI testing employed a stick antenna on a tripod for the RSU, and a dome antenna on the MEV. TechnoCom supplied these antennas specifically for these units. However, some testing was also performed with the stick antenna on the MEV and a dome antenna on the tripod. In order to provide a comparison for realistic data, the dome antenna for the MEV unit was mounted on the trunk of a patrol car and that vehicle was placed in approximately the same position as the van (Figure 27) for very limited testing at 2.4 GHz.

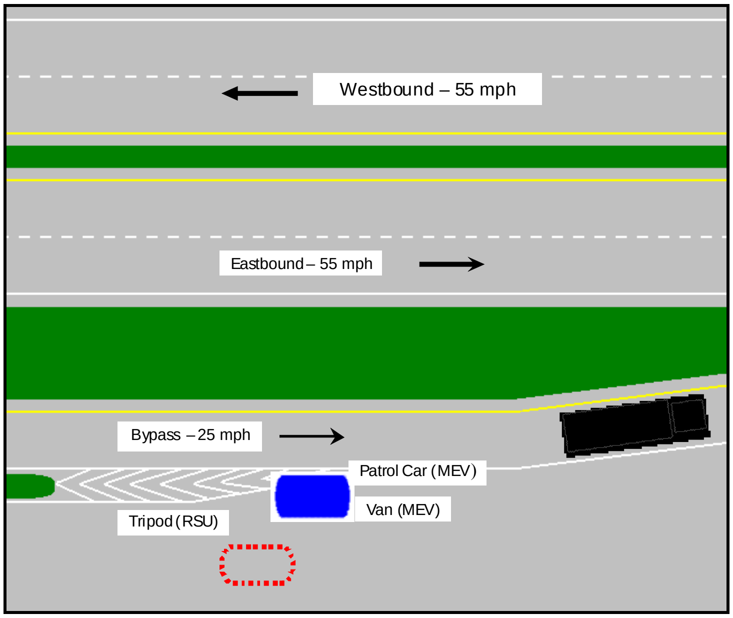


Figure 27. Diagram. Layout of Test Site at Eastbound Knox County CMV Inspection Station

Further dynamic tests of the WRI system included over-the-road tests performed on the highway with both the truck and MEV traveling at or near 55 mi/h. For these tests, the MEV traveled near the instrumented truck at various relative positions such as 12:00, 1:30, 3:00, etc (Figure 28). This test was performed at 5.9 GHz with two different dome antenna placements on the MEV: the first location was centered on the roof, and the other was laterally centered but toward the front of the vehicle (see Figure 29 inset). Two tests were performed for each position and antenna location. While both placements allowed transmission toward the front of the instrumented vehicle, the centered placement permitted transmission when the MEV was farther behind the test truck.

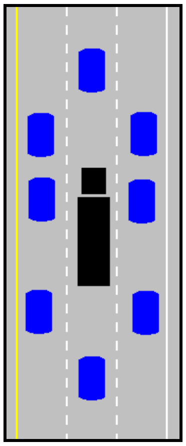


Figure 28. Diagram. MEV-Truck Positions for Over-The-Road Tests Performed at Highway Speeds

The WRI system was also tested during an interstate trip from Knoxville, TN to a CMV inspection station near Corbin, KY and back. For this test, a van (the MEV) was instrumented with two receiving systems, one using a dome antenna and the other connected to a stick antenna. During the trip to Kentucky, the wireless systems were set up for constant 5.9-GHz communication; 2.4-GHz communication was used for all transmissions during the return trip. General observations regarding transmission over the road were recorded during this trip.

The drive-by testing which made use of a tripod stick antenna for 5.9-GHz reception yielded overall positive results. As shown in Table 9, a wireless inspection could be performed each time the instrumented truck traveling east in the 25-mi/h bypass lane passed an RSU using a stick antenna or a MEV (van) instrumented with a dome antenna. The system had less success across the highway. It was observed that during the westbound testing, other vehicles occasionally came between the truck and the RSU. The stick antenna was able to complete a file transfer from the westbound side more than 80 percent of the time, while the dome antenna was unable to achieve transfer at all at 5.9 GHz.

The drive-by file transfer testing performed at 2.4 GHz yielded fairly good results (see Table 9). With the dome antenna mounted on a tripod, file transfer from the opposite side of the highway was nearly as successful as transfer from the bypass lane at 25 mi/h. For the dome-instrumented van (MEV), however, reception from the bypass lane was poor, although more inspections could be performed from across the highway. It is recommended that this surprising result be analyzed further in future tests. With the dome antenna mounted on the patrol car (MEV), files could be received in each of the three different passing scenarios (25 mi/h bypass, 55 mi/h eastbound, and 55 mi/h westbound).

Table 9. Results of Drive-by Dynamic Transmission Tests at Tested Speeds

Frequency	5.9 GHz	5.9 GHz	2.4 GHz	2.4 GHz	2.4 GHz
Antenna Type	Dome	Stick	Dome	Dome	Dome
Antenna Placement	MEV—Van	Tripod	MEV—Van	MEV—Patrol	Tripod
Bypass—25 mi/h	100%	100%	25%	100%*	83%
Eastbound—55 mi/h	67%*	N/A	N/A	100%*	N/A
Westbound—55 mi/h	0%	82%	71%	100%*	80%

*Indicates only 2 or 3 runs tested for this situation.

Relative Position Tests: The results of the 5.9-GHz at-speed tests (with the van, which served as the MEV, instrumented with a dome antenna) are shown in Figure 29. For both antenna positions tested, file transfer was successful when the MEV was positioned directly to the side of the instrumented truck and slightly ahead, as well as in the lane to either side of the truck. File transfer to the MEV positioned slightly behind the truck in the adjacent lane was accomplished only with the centered antenna placement as shown in the Figure 29 inset. A wireless inspection could not be performed either directly behind or directly in front of the instrumented truck, regardless of the MEV antenna placement. Those results were similar to those produced by the static tests discussed in the previous subsection.

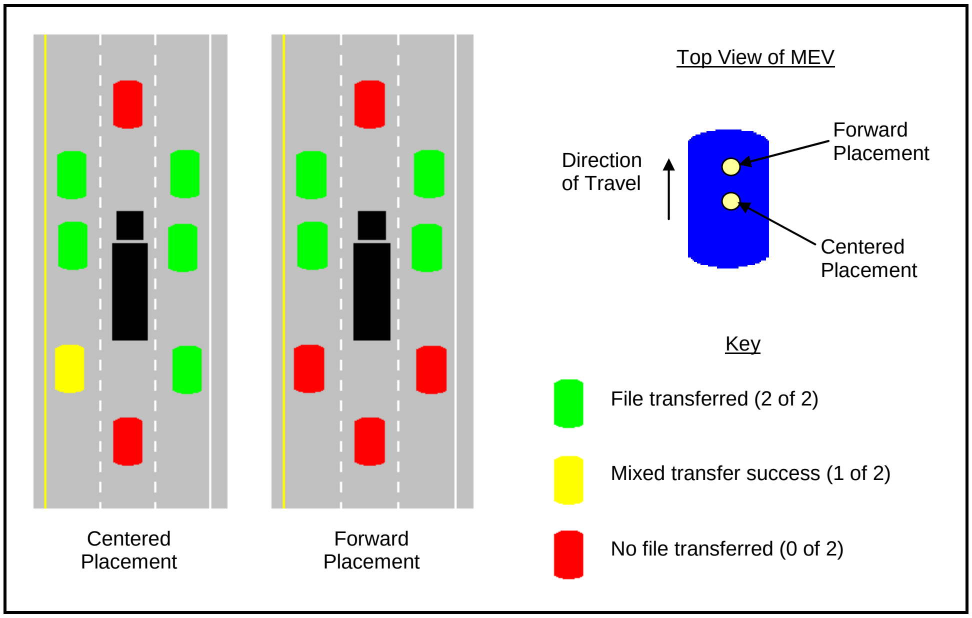


Figure 29. Combined Diagrams. Dome Antenna Placement and Results for Over-the-Road (55 mi/h) Orientation Testing at 5.9 GHz

Other Road Tests: During the trip to Kentucky (in which 5.9-GHz transmission was used), the number of files obtained by the stick antenna on the MEV was nearly four times the number obtained by the dome antenna. At 5.9 GHz, both antenna types were able to receive files when the MEV was positioned directly to either side of the truck. For the system using the stick antenna, however, file transfer was possible at many more positions. At the inspection station, the stick antenna was able to receive files from either side of the highway, but the dome antenna was unable to receive any files. At 2.4 GHz (during the return trip), the dome antenna obtained more than 4.5 times the number of files that the stick antenna did. In the instance in which there was little traffic and the MEV was ahead of the truck but slightly off-center, the system using the stick antenna could inspect the truck at a distance of more than a quarter-mile.

3.2.3 Test Conclusions and Future Work

For two antennas of the same type, the antenna mounted on the tripod received the SDMS more reliably than on the van (MEV). This result is probably because transmissions at 2.4 and 5.9 GHz are greatly improved by line-of-sight; a higher antenna placement results in fewer objects interfering with the transmission. In the bypass-lane tests, it is likely that the body of the truck itself and objects near the roadway limited the time during which transmission could occur; several pit-scale weight information signs were located along the right side of the bypass lane. The results of the dynamic orientation tests (Figure 29) indicate that a central placement of the dome antenna on the MEV roof is preferred. Both the static and dynamic tests demonstrated that there are unresolved issues regarding file transfers when the MEV is directly in front of the truck.

The results of the Tennessee-Kentucky trip confirmed that the stick antenna is very inefficient at 2.4 GHz; this was expected because the stick antenna used was designed to operate at 5.9 GHz. While the dome-type antenna was specified to operate at both 2.4 and 5.9 GHz, its performance at 2.4 GHz was much better than its performance at 5.9 GHz. The overall performance of the dome antenna when operated at 2.4 GHz was comparable to that of the stick antenna used at 5.9 GHz; however, the dome antenna seems to be the preferable choice, because of the flexibility afforded by its ability to operate at two frequencies. However, because only one frequency will ultimately be used for a WRI system, the choice of antennas should be tailored to the frequency chosen. Other factors not taken into account in this POC test that should be considered in future research include the durability of different antenna types, optimum mounting solutions, and the effect of weather and terrain.

This POC test demonstrated that the wireless inspection system tested was sufficiently robust to function as designed in real-world driving environments. Inasmuch as this testing was performed to provide a starting point for further research into wireless safety inspection methods, future work is necessary to refine the system. Regarding file transfer, reliability of this process varied with antenna type, placement, and frequency. The results of this POC test, however, demonstrate that it is possible to reliably transfer an SDMS at highway speeds.

Future work should include more extensive testing with regard to ideal antenna parameters, including type, height, and orientation. Antenna and communication requirements should be developed and refined to include required frequency (2.4 GHz vs. 5.9 GHz), antenna type, and optimal placement of antenna on each instrumented vehicle.

Ultimately, it will be necessary to test a large number of vehicles to verify system feasibility on a wider scale. Larger-scale testing should be designed to test performance when several instrumented vehicles pass an RSU. This testing will most likely involve a system that uses an inspection method that is focused (such as a directional antenna placed over a specific lane) rather than widespread (such as an omni-directional antenna with a large coverage area), and therefore more appropriate for a large number of trucks. The TechnoCom transceiver that was used has the capability of selectively communicating with one of multiple vehicles via geo-zoning, direction of travel preference, and other such methods. However, the scope of this POC did not include testing these features. Another problem which must be resolved before widespread implementation of such a wireless inspection method is the problem of how to identify visually which truck (in a group) is providing the information viewed by enforcement personnel for each wireless inspection.

4. TECHNOLOGY SHOWCASE

The FMCSA, in close partnership with TDOS, the Tennessee Department of Transportation (TDOT), and ORNL, sponsored a CMV Roadside Technology Showcase to demonstrate current and prototype large truck and bus safety inspection technologies. This event was facilitated by ORNL and was held on Tuesday, August 7, 2006, from 10:00 a.m. to 2:00 p.m., at the Greene County CMV Inspection Station, located on southbound I-81 near mile marker 21 in eastern Tennessee.

The Showcase highlighted the establishment of a permanent truck and bus roadside technology testing corridor for FMCSA, TDOS, and TDOT.

Current inspection technologies and systems showcased were:

- Inspection Selection System.
- Query Central Data Portal.
- Aspen Inspection Software.
- Driver Information Resource.
- Performance-Based Brake Testing (PBBT).
- ComVIS™ Portable Inspection Data Collection.
- PrePass™ Electronic Screening System.

Future technology inspection prototypes exhibited were:

- Smart Infrared Inspection System—captures thermal signatures of wheel components and automatically alerts inspectors to anomalies needing further attention
- WRI System—allows for the retrieval of real-time safety data pertaining to the driver, vehicle, and carrier from both a Class-8 tractor-trailer and a commercial motor coach as they pass by the inspection station

Figure 30 shows an aerial view of the Greene County CMV Inspection Station and the location of the various exhibits for the Showcase. Figure 31 and Figure 32 show example demonstrations in progress during the Showcase.

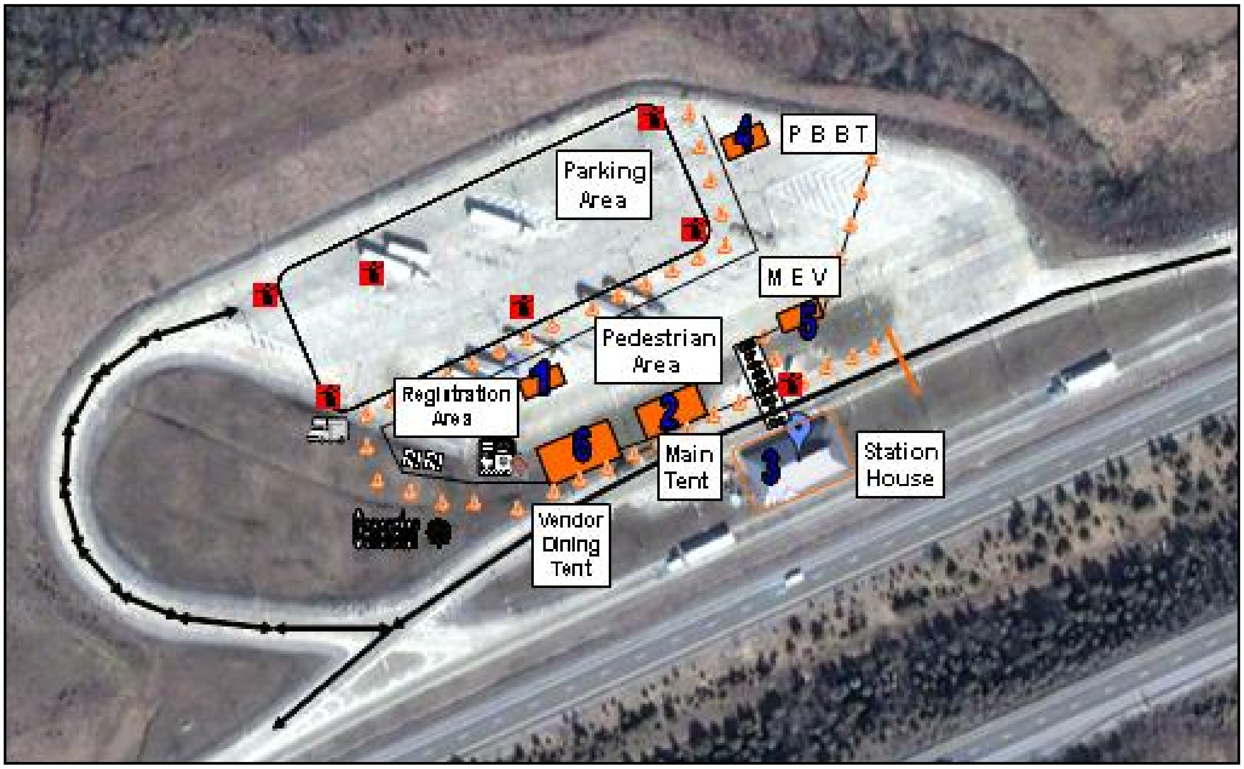


Figure 30. Aerial Photo. View of the Greene County CMV Inspection Station

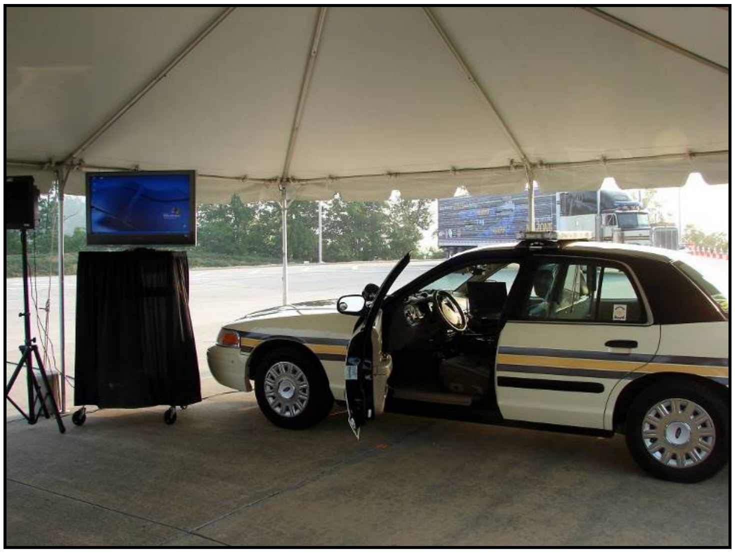


Figure 31. Photo. WRI POC MEV Ready for Demonstration

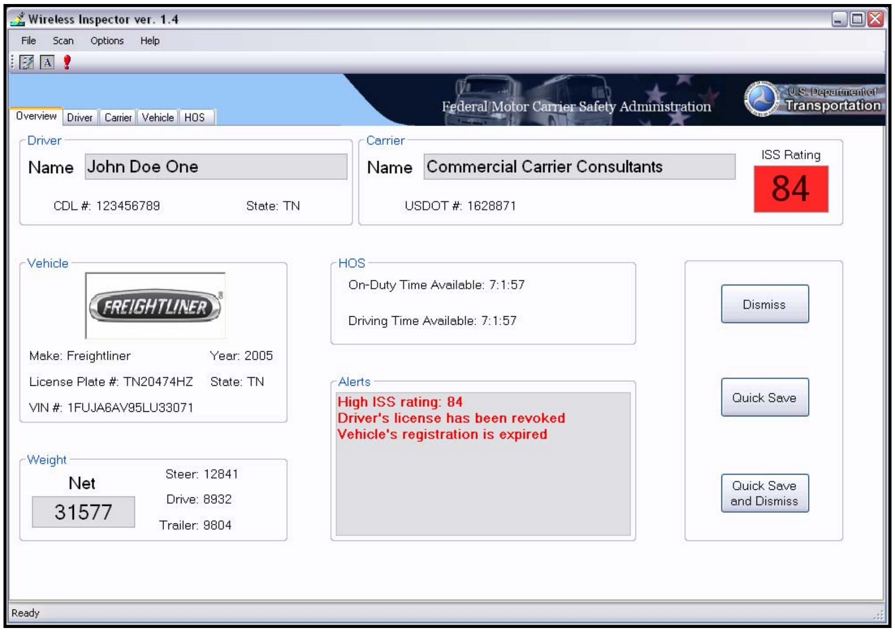
Figure 32. Photo. Wal-Mart Truck on the PBBT at the Aug 7, 2007 Showcase

5. WRI INTERFACE

A primary requirement for the Technology Showcase was the ability to format and display the data that had been wirelessly transferred from the moving vehicle to the roadside or MEV in a format that could be easily seen and understood by the viewing audience and the end-user. The WRI GUI software was designed specifically for this purpose, at the same time incorporating functionality that would be useful for an inspection official when performing wireless inspections.

The interface organizes the data to be displayed according to what is most important about the vehicle, or needs to be quickly identified, as well as according to whether the most important thing pertains to the driver, the carrier, or the vehicle itself. Therefore, five primary screens (Figure 33 through Figure 37) were designed: overview, driver status, carrier status, vehicle status, and driver HOS. The program is designed such that the user starts with the overview screen, which summarizes the identifying information of the driver, carrier, and vehicle, and provides a quick alert for any infringements identified. The remaining four screens provide more detailed information in each specific category.

The data displayed in the interface are a combination of data that have been wirelessly transferred from the vehicle and information that is acquired from a back-office database. For demonstration purposes, the kernel message was augmented with weight data obtained from the vehicle data bus through the comparison system (see section 2.2.5) before being wirelessly transferred. While some electronic databases already exist and can be manually queried by an inspection officer for a given truck, driver, or carrier, other information is not yet available in this way. Therefore, for the purposes of this POC test, a “pseudo-database” was created that contained information necessary to demonstrate how the wireless inspection system would function if the actual databases were fully networked and accessible to the WRI system.



Driver
Name John Doe One
CDL #: 123456789
State: TN

Carrier
Name Commercial Carrier Consultants
USDOT #: 1628871
ISS Rating 84

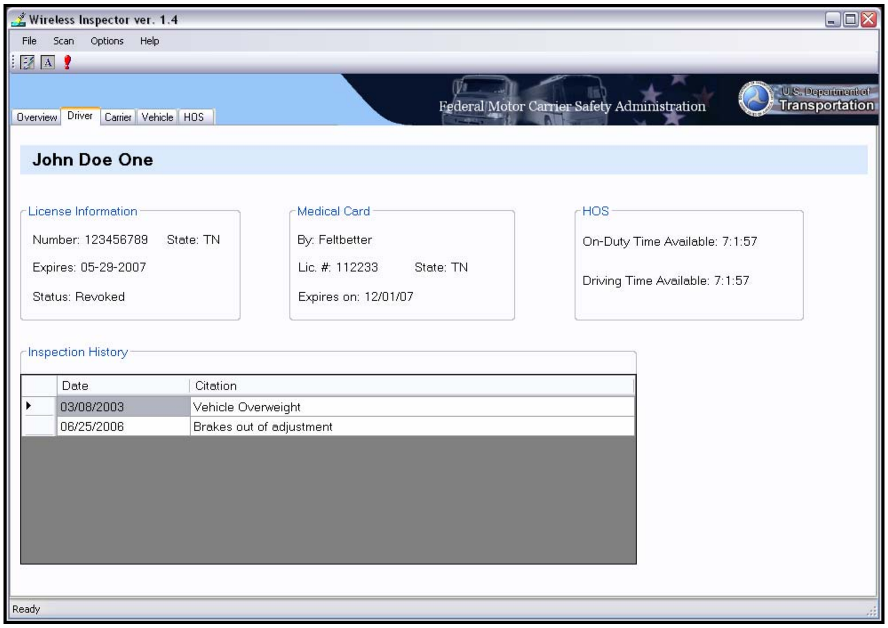
Make: Freightliner
Year: 2005
License Plate #: TN20474HZ
State: TN
VIN #: 1FUJA6AV95LU33071

HOS
On-Duty Time Available: 7:1:57
Driving Time Available: 7:1:57

Alerts
High ISS rating: 84
Driver's license has been revoked
Vehicle's registration is expired

Weight
Net 31577
Steer: 12841
Drive: 8932
Trailer: 9804

Figure 33. Screen shot. WRI GUI Overview Screen



John Doe One

License Information

Number: 123456789 State: TN

Expires: 05-29-2007

Status: Revoked

Medical Card

By: Feltbetter

Lic. #: 112233 State: TN

Expires on: 12/01/07

HOS

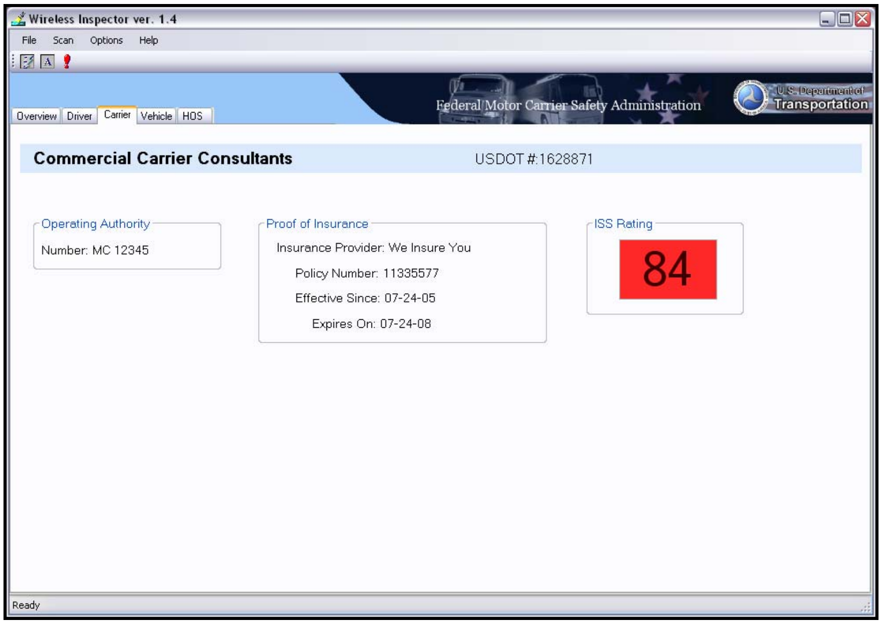
On-Duty Time Available: 7:1:57

Driving Time Available: 7:1:57

Inspection History

Date	Citation
03/08/2003	Vehicle Overweight
06/25/2006	Brakes out of adjustment

Figure 34. Screen shot. WRI GUI Driver Screen



Commercial Carrier Consultants USDOT #:1628871

Operating Authority

Number: MC 12345

Proof of Insurance

Insurance Provider: We Insure You

Policy Number: 11335577

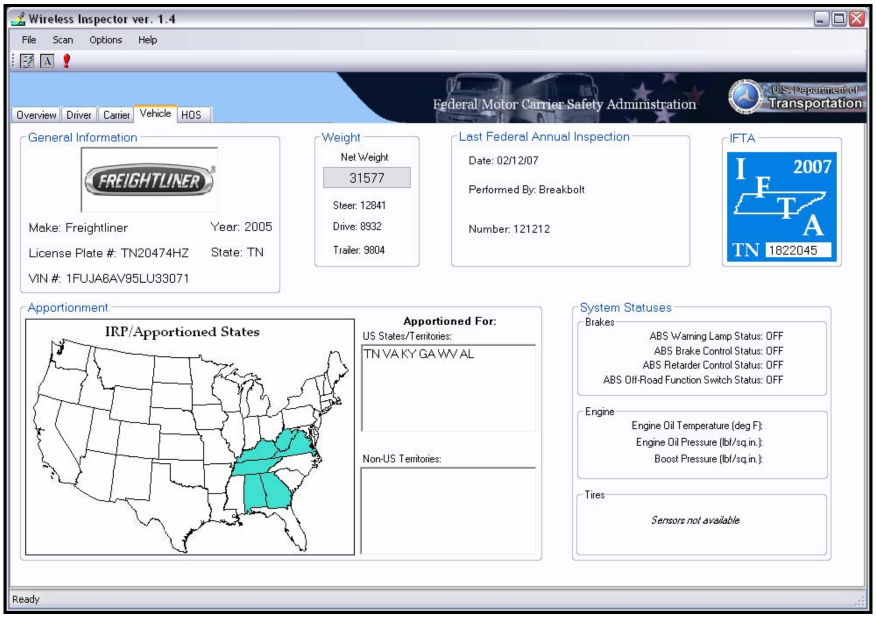
Effective Since: 07-24-05

Expires On: 07-24-08

ISS Rating

84

Figure 35. Screen shot. WRI GUI Carrier Screen



General Information

Make: Freightliner

Year: 2005

License Plate #: TN20474HZ

State: TN

VIN #: 1FUJA6AV95LU33071

Weight

Net Weight: 31577

Steer: 12841

Drive: 8932

Trailer: 9804

Last Federal Annual Inspection

Date: 02/12/07

Performed By: Breakbolt

Number: 121212

IFTA

IFTA 2007 TN 1822045

Apportionment

Apportioned For:

US States/Territories: TN VA KY GA WV AL

Non-US Territories:

System Statuses

Brakes

ABS Warning Lamp Status: OFF

ABS Brake Control Status: OFF

ABS Retarder Control Status: OFF

ABS Off-Road Function Switch Status: OFF

Engine

Engine Oil Temperature (deg F):

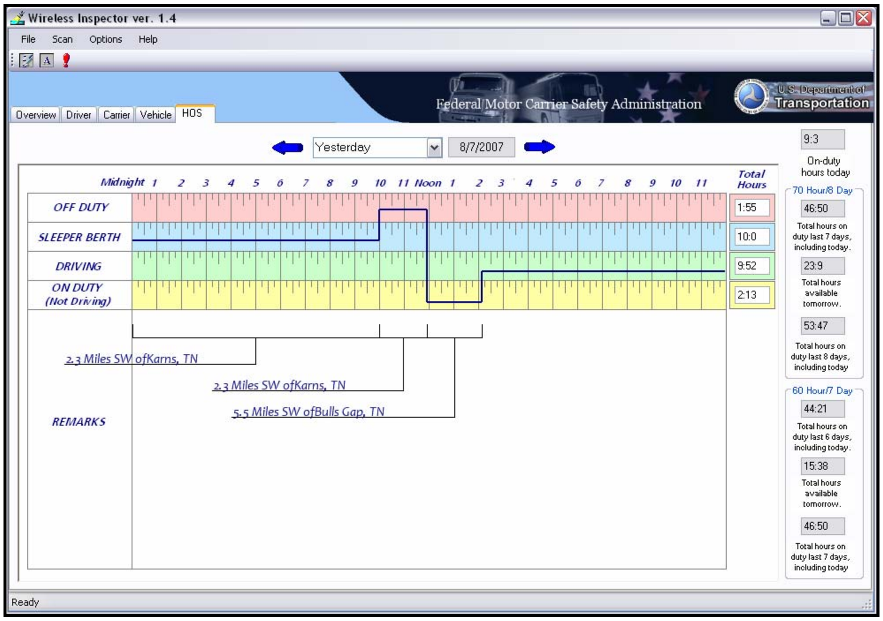
Engine Oil Pressure (lbf/sq.in.):

Boost Pressure (lbf/sq.in.):

Tires

Sensors not available

Figure 36. Screen shot. WRI GUI Vehicle Screen



Yesterday 8/7/2007

	Total Hours
OFF DUTY	1:55
SLEEPER BERTH	10:0
DRIVING	9:52
ON DUTY (Not Driving)	2:13

REMARKS

2.3 Miles SW of Karns, TN

2.3 Miles SW of Karns, TN

5.5 Miles SW of Bulls Gap, TN

9:3 On-duty hours today

70 Hour/8 Day

46:50 Total hours on duty last 7 days, including today.

23:9 Total hours available tomorrow.

53:47 Total hours on duty last 8 days, including today

60 Hour/7 Day

44:21 Total hours on duty last 6 days, including today.

15:38 Total hours available tomorrow.

46:50 Total hours on duty last 7 days, including today

Figure 37. Screen shot. WRI GUI HOS Screen

6. WRI POC PARTICIPANT QUESTIONAIRES

Although there was almost no interaction with carriers or drivers during the POC (with the exception of the Technology Showcase; see section 4.0), TDOS personnel were involved in the POC testing, were familiar with the capabilities of the system, and used the graphical user interface (section 5.0). Feedback questionnaires were developed as a part of the Test Plan for the WRI POC. The responses of the TDOS personnel and the truck and motor coach drivers for the Technology Showcase are presented in sections 6.1 and 6.2.

6.1 TDOS SURVEY

Six troopers from TDOS responded to the questionnaire regarding the WRI technology. The questions and responses are below.

Enforcement Personnel Questionnaire with Responses

Section 1: Use of the technology at the inspection station (RSU)

1. Would you find this type of device useful?

Responses: Yes: 6 No: 0 Response Not Provided: 0

Additional Comments:

None

2. Was the format of the test performed a good simulation of how the device would actually be used on the job? If not, what would have made the test more realistic?

Responses: Yes: 5 No: 0 Response Not Provided: 1

Additional Comments:

I mostly used the front page (1)
Great (1)

3. Would additional information from the screens be useful to you? If so, what data?

Responses: Yes: 1 No: 4 Response Not Provided: 1

Additional Comments:

Too much info (2)
I am fairly satisfied (1)
If co-driver is used, need to have that information so duty status would match up with time (1)

4. Was any of the information presented on the screens superfluous or otherwise not needed? If so, what data?

Responses: Yes: 1 No: 5 Response Not Provided: 0

Additional Comments:

Only need expiration date on medical card (1)
System status not needed (1)
Only date needed on last Annual Inspection (1)

5. Do you see any pitfalls or problems with such a device?

Responses: Yes: 3 No: 2 Response Not Provided: 1

Additional Comments:

The information can be changed by the company or driver (3)
The vehicle information can be wrong (1)
In order to be beneficial, the device would need to be mandatory to all motor vehicles (1)

Section 2: Use of the technology in a Mobile Enforcement Vehicle (MEV Unit)

1. Would you find this type of device useful?

Responses: Yes: 5 No: 0 Response Not Provided: 1

Additional Comments:

None

2. Was the format of the test performed a good simulation of how the device would actually be used on the job? If not, what would have made the test more realistic?

Responses: Yes: 5 No: 0 Response Not Provided: 1

Additional Comments:

I mostly used the front page (1)

3. Would additional information from the screens be useful to you? If so, what data?

Responses: Yes: 0 No: 5 Response Not Provided: 1

Additional Comments:

Too much info (2)

4. Was any of the information presented on the screens superfluous or otherwise not needed? If so, what data?

Responses: Yes: 4 No: 2 Response Not Provided: 0

Additional Comments:

Only need expiration date on medical card (1)
System status not needed (1)
Only date needed on last Annual Inspection (1)

5. Do you see any pitfalls or problems with such a device?

Responses: Yes: 4 No: 0 Response Not Provided: 2

Additional Comments:

The information can be changed by the company or driver (3)
The vehicle information can be wrong (1)
In order to be beneficial, the device would need to be mandatory to all motor vehicles (1)

6. Was the device a distraction for the Trooper?

Responses: Yes: 0 No: 5 Response Not Provided: 1

Additional Comments:

None

6.2 DRIVER SURVEYS

One tractor-trailer driver and one motor coach driver from industry responded to the questionnaire regarding the WRI technology. The questions and responses are below.

Tractor-Trailer Driver Questionnaire with Responses

1. Did the device impede your productivity?

Response: No.

2. Was the device easy to use?

Response: Yes. I have used a similar device in the past.

3. Would you object to the mandate of using such a device? Why or why not?

Response: I would be concerned about cost and the use of the information.

4. Was the device a distraction while driving? If so, how could this be combated?

Response: No.

5. Which do you feel would be the easiest interface for future designs?

a. Keypad (cell phone) **b. Touch screen** **c. Full keyboard** **d. Other _____**

Response: Voice activation for duty status changes. Keyboard for information entry.

6. Was the format of the test performed a good simulation of how the device would actually be used on the job? If not, what would have made the test more realistic?

Response: Too limited to tell.

7. What would your biggest concerns about the implementation of such a device be?

Response: Out-of-pocket cost and invasion of privacy.

Motor Coach Driver Questionnaire with Responses

1. Would you object to the mandate of having all of your buses equipped with such a device? Why or why not?

Response: As a commercial vehicle owner and operator, I would object to a proposed mandate if I am expected to bear the expense of the mandate. Small operators are at the point that they can not bear any additional cost to their operations.

2. Was the format of the test performed a good simulation of how the device will actually be used on the job?

Response: Yes, although I am sure its capabilities had to be limited for the demonstration.

3. Would the data obtained from the device be useful to you?

Response: There [are] no data (viewed in the demonstration) that we are currently not keeping (i.e., DQFs, MVRs, maintenance files, HOS status). I am sure that there are many more options that would be available to us that would be beneficial.

4. Do you see a need for such technology in order to keep a closer eye on driver activity and vehicle status?

Response: I cannot speak for other operators. As far as our operation is concerned, the safety of our passengers is the primary goal of our company. When we are mixed with other commercial vehicles on the highways, then their safe operation becomes a major factor for us. It is getting much harder to find professional driver candidates as the transportation industry grows; therefore I feel a watchful eye would be in the best interest of all parties involved.

5. Do you think your drivers would object to the use of such a device? Why or why not?

Response: Yes, drivers would object at first. But, after the initial intimidation of a change, I think they would quickly begin to realize the benefits. One area that I think would appeal to drivers is the fact that the gray areas of doubt in infractions should disappear and the enforcement officer is no longer the judge, jury, and executioner. From what I've seen, it just seems to level the playing field.

6. Do you see a value to your company from such a device?

Response: Yes, definitely. Unlike the freight haulers, our cargo is human. Anything that promotes safety and makes us look good, has to be good for us and our industry. We currently encourage our customers to go to safersys.org and review our company snapshot and safety record. Any system that would make us more visible would keep us on our toes and become one more tool for us to promote our company.

7. LESSONS LEARNED

The following is a general discussion of the lessons learned from the WRI POC. Input for this section was provided by the ORNL technical team, PeopleNet, and TechnoCom.

Several positive lessons learned during the WRI POC proved to be of benefit to the project, and many will be of benefit to future related projects.

- Private industry is willing to participate gratis in research that they find to be of value to their field of interest. This was certainly true of Air-Weigh and PeopleNet. They provided technology, software, and engineering support throughout the WRI POC. While it is difficult to put a value on this support, ORNL estimates that for the WRI POC, the value of this support was greater than $300,000.
- The State of Tennessee's Departments of Safety and Transportation and FMCSA's Tennessee-based field staff are willing to help in any way possible. Neither the POC nor the Media Event would have been possible without their support and hard work. The WRI POC can serve as a model for bringing Federal and state government and private industry together to accomplish difficult tasks in a short time within a fixed budget.
- The Greene County Tennessee CMV Inspection Station was found to be an excellent location for CMV research and technology testing. The 80-acre concrete pad, power availability, Internet access, and Interstate access made the site indispensable for this project.
- The feasibility of composing a message in real time and transmitting that message wirelessly to a fixed or a mobile station was demonstrated.
- The SDMS does not have to be a very large file in order to contain the needed vehicle, carrier, and driver information. ORNL found that a single record (a complete SDMS with one duty status change) was approximately 600 bytes. A complete, eight-day SDMS consisted of multiple records appended together equivalent to the number of duty status changes made during that eight-day period. For this case, an estimate of the SDMS total file size could be found simply by multiplying 600 bytes by the number of duty status changes made.
- The PeopleNet OBC uses an internal real-time clock that is reset to GPS once the difference between it and the GPS UTC time reaches a pre-determined value. As a result, this system is more reliable than one which relies on GPS time signals alone, because the OBC is able to continue to provide time information in the absence of the GPS signal. However, the default configuration for the time difference before time reset for the kernel was set to 15 seconds. In retrospect, the difference could have been reduced considerably, thereby preventing the 15-second position discrepancy.

Among the lessons learned there were several that could have affected the WRI POC in a detrimental way. They are:

- Greater depth of partnerships—Only one kernel provider partnership was provided. This left the WRI POC in a very vulnerable position. If the PeopleNet device had failed to gather and format the SDMS, the POC would not have been able to finish with a commercially viable system and the project would have had to rely on the ORNL-developed DAS. This was similarly true of the transceiver provider. Although TechnoCom did not participate gratis, the project budget would not have allowed for a second paid transceiver partner in the event that the TechnoCom equipment/software failed to transmit the SDMS. Such an event would have been catastrophic to Phase 1B of the POC.
- Remoteness of the Greene County, Tennessee CMV Inspection Station proved to be costly in time, manpower, and dollars. Travel time from ORNL to the site was approximately 90 minutes. Furthermore, the site is located about 30 minutes from the nearest hardware and retail stores and restaurants (food was not available on-site).
- It is very difficult to find large, flat, paved areas for CMV static and dynamic testing. The Greene County site proved to be acceptable, but required some novel testing schemes to accomplish all of the static testing called for in the test plan. A test track would have been a better option, but would have required funding for the track time, travel time, and travel expenses for the technical team.
- It is difficult and potentially unsafe to conduct some types of CMV testing at highway speeds on public roadways. It is difficult to determine vehicle separation distance and to maintain separation angle and distance. A test track is recommended for all future testing of this nature.
- The WRI POC team attempted to accomplish too much during the POC (develop the system, test the system, include a MEV, include a motor coach, include an unproven transceiver, and conduct the Technology Showcase; and demo the tractor, MEV, and motor-coach-based systems at the Technology Showcase). Given the time and budget, the number of deliverables for the POC made it uncertain that success would be achieved in all areas of the POC.
- Conducting the Technology Showcase endangered the success of the POC. A large portion of the technical team's effort went into preparing for the Technology Showcase and the vehicle perturbations (MEV and motor coach) for the Showcase. Much of the preparation for the Showcase had to be done during the POC in order to meet the Showcase date of August 7.
- The transceiver equipment requires additional analytical testing for this type of application (antenna attenuation, cable attenuation, obstruction interference, bandwidth, range, deployment methods, antenna transmission/reception angles, antenna types). A large portion of the ORNL technical team's time was spent trying to get transmission via the transceiver.

- Partners should be encouraged to install the equipment that they are providing, or at least spend a day or two on-site to assist with troubleshooting. The ORNL technical team spent a significant amount of time working through problems with the transceiver (exploring the problem, communicating with the provider, testing the problem further, trying a possible solution, etc). While in a project such as this it is not possible completely to avoid set-up and configuration problems, an on-site visit from a representative from the transceiver provider would very likely have resulted in a more efficient resolution of these problems.
- The analysis outlined in section 3.0 reveals that there was some misunderstanding as to which fields in the SDMS contained the PeopleNet-provided driver HOS data. There was also confusion as to how the J1708 odometer data are supplied and how they are formatted per the J1587 specification. Clarity in such matters before testing begins would yield results that are more accurate and hence more suitable for comparative analysis of competing vendors for future phases of this project.

8. SUMMARY OF RESULTS AND CONCLUSION

The test performed in Phase 1A showed that it was possible for the kernel to gather information from different sources (including an EOBR and a vehicle databus), assemble the required SDMS, and make it available for transmission to an RSU or MEV. The frequency at which these messages were generated was very high (i.e., an average of one SDMS every 10.2 seconds) for the type of application considered here. The largest observed delay in generating a new SDMS was just over five minutes, which was considered acceptable.

The accuracy of the information posted on the SDMS was measured within a certain tolerance, which was arbitrarily set at three levels. After some synchronization problems between the ground-truth and kernel messages were addressed, the information related to the spatial position of the vehicle (obtained from GPS readings) was 100 percent accurate when considering a tolerance of 1,000 ft. Speed, which was also determined via the GPS by the kernel, presented an accuracy level above 80 percent when considering a tolerance of 1 mi/h or less, and close to 100 percent with a tolerance of 5 mi/h or less. Odometer information, which was read from the vehicle's databus, was 79 percent accurate when considering a tolerance of 0.25 miles.

The HOS information presented some problems. When a HOS diagram was built by combining driver status flags posted on the SDMS and the timestamp of that message, differences with the ground-truth HOS were found. Those differences were substantially reduced (although not completely eliminated) when a different SDMS field was used. However, the information posted in this field, although very accurate, was not relayed in a timely fashion. Most of the observed delays were in the 5–20-minute range (which was expected), although in two instances they were measured in hours. There were also a few occasions on which a status change was either not registered or not posted in the SDMS.

For two antennas of the same type, the antenna mounted on the tripod received the SDMS more reliably than on the van (MEV). This was probably due to the fact that transmission at 2.4 and 5.9 GHz is greatly improved by line-of-sight; a higher antenna placement results in fewer objects interfering with the transmission. In the bypass-lane tests, it was likely that the body of the truck itself and objects near the roadway limited the time during which transmission could occur; several pit-scale weight information signs were located along the right side of the bypass lane. The results of the dynamic orientation tests indicated that a central placement of the dome antenna on the MEV roof was preferable. Both static and dynamic tests showed that there were unresolved issues regarding file transfers when the MEV was directly in front of the truck.

The results of the Tennessee–Kentucky trip confirmed that the stick antenna is very inefficient at 2.4 GHz; this was expected because the stick antenna used was designed to operate at 5.9 GHz. While the dome-type antenna was specified to operate at both 2.4 and 5.9 GHz, its performance at 2.4 GHz was much better than at 5.9 GHz. The overall performance of the dome antenna when operated at 2.4 GHz was comparable to that of the stick antenna used at 5.9 GHz; however, the dome antenna seems to be the preferable choice, because of the flexibility afforded by its ability to operate at two frequencies. However, because only one frequency will ultimately be used for a given WRI system, the choice of antennas should be tailored to the frequency chosen. Other factors that were not taken into account in this POC test, but that should be considered in future research, include the durability of different antenna types, optimum mounting solutions, and the effect of weather and terrain.

This POC test demonstrated that the wireless inspection system tested was sufficiently robust to function as designed in real-world driving environments. As this testing was performed to provide a starting point for further research into wireless safety inspection methods, future work is necessary to refine the system. While the reliability of file transfer varied with antenna type, placement, and frequency, the results of this POC test demonstrated that it is possible to transfer an SDMS reliably at highway speeds.

9. SUGGESTED FUTURE RESEARCH/RECOMMENDATIONS

Since the accuracy of the information contained in the SDMS seems to be acceptable, the main area on which future research should focus is the timeliness of the HOS information that is added to that message. Most of the observed problems were attributed to communication and software issues. In fact, during the pre-testing period, several related problems were identified by ORNL and addressed by the partner supplying the kernel information. It appears that some aspects of these problems were not fully resolved by the time the test took place. Nevertheless, those problems are not insurmountable, and should be easily resolved during the next phase. Also, as previously mentioned, certain delays were inherent to the system due to the back-office communication of the kernel. These delays would not be present in a commercially produced product.

Also, in future tests, it is important that more detailed technical discussions be carried out between the testers (ORNL) and the developers of the system. Such communication would facilitate a better understanding of the idiosyncrasies of both the DAS and the kernel, which would help to avoid issues such as reading the same field in different units (e.g., odometer) or providing timestamps that are generated by different devices (thus introducing synchronization problems).

Future work should include more extensive testing regarding ideal antenna parameters, including type, height, and orientation. Antenna and communication requirements should be developed and refined to include required frequency (2.4 GHz vs. 5.9 GHz), antenna type, and optimal placement of the antenna on each instrumented vehicle.

There is a need ultimately to test a large number of vehicles to verify system feasibility on a wider scale. Larger-scale testing should be designed to test performance when several instrumented vehicles pass an RSU. This testing will likely involve a system which uses an inspection method that is more focused (such as a directional antenna placed over a specific lane) rather than widespread (such as an omni-directional antenna with a large coverage area), resulting in a system which is appropriate for a large number of trucks. The TechnoCom transceiver that was used has the capability to communicate selectively with one of multiple vehicles via geo-zoning, direction of travel preference, and other such methods. However, the scope of this POC did not include testing of these features. Another problem that must be resolved before widespread implementation of a wireless inspection method is that of the ability to identify visually which truck (in a group) is providing the information viewed by enforcement personnel for each wireless inspection.

For the next phase of the program, in order to ensure greater success, it is recommended that more time be given to the formation of partnerships to provide good depth of technology. Emphasis should be placed on gratis partnerships to minimize cost and maximize industry buy-in. Each critical area of the Pilot Test (as described in section 1.1) should be identified, and when technology is present, redundancy should be emphasized as well. In the case of the WRI POC, only one kernel provider and only one transceiver provider participated. This provided no depth of options as to the method, and if either provider’s technology had failed, that would have caused the effort to fail.

It is envisioned that the future Pilot Test will involve a much greater level of complexity and many more entities. It is suggested that the Pilot Test be conducted using a “subsystems” approach with multiple teams working in parallel. Work-arounds should be planned if any teams fail their primary task. This would allow other teams to proceed, ensuring that the overall project comes to a successful conclusion. For example: If DSRC is chosen to be the communications method for the SDMS transmission, a team should be appointed to develop, test, and integrate this technology into the greater project. This team should be responsible only for the DSRC portion of the project. Further, DSRC should not be the only communications method selected. A back-up method should be explored in the event that DSRC fails to function as expected.

APPENDIX A:
WIRELESS ROADSIDE INSPECTION PROOF-OF-CONCEPT TESTING FAST TRACK PLAN DISCUSSION PAPER

WIRELESS ROADSIDE INSPECTION PROOF-OF-CONCEPT TESTING FAST TRACK PLAN DISCUSSION PAPER

Background

The I-95 Corridor Coalition wireless inspection demonstration hosted by Volvo North Americahas proven that the wireless inspection of trucks and buses is feasible with today's technology. Further, it has been shown that there is much work ahead to develop a seamless inspection system capable of gathering the inspection data of interest, transmitting it off-board in a reliable manner, and evaluating the data in real time. Dealing with the back-office and interdiction issues related to wireless inspection of commercial vehicles has, only to this point, been discussed with no hard data or experience to aid in the development of a Concept of Operations (ConOps) document. There is a need to quickly conduct a Proof-of-Concept (POC) test to demonstrate the Safety Data Message Set (SDMS) and then conduct a Pilot Test to generate thousands of inspections to aid the development and testing of back office protocols and interdiction strategies.

In order to mitigate the large development cost of vehicle-based inspection technology and to reduce the time to develop a fully functional system ready for Field Operational Testing (FOT), ORNL recommends the following "Fast Track" plan for the POC test which will help enhance the full development of the ConOps with real-world experience and will quicken the march to the Pilot Test where large numbers of actual inspections can be generated.

ORNL POC Goals

- To partner with private industry to develop the kernel of the Universal Wireless Inspection System (UWIS) at no cost to the government and make the developed system(s) available for testing in the POC.
- To partner with providers of wireless transceivers (2.4 GHz and 5.9 GHz) and integrate this wireless technology into the UWIS.
- To Demonstrate a UWIS that collects and stores predefined safety data using currently available sensors and technology; formats this data into the SDMS; and wirelessly transmits the SDMS from a commercial vehicle (truck or bus) to the roadside or to an enforcement vehicle.

ORNL POC Objectives

- Form partnerships with suppliers of technology capable of performing the needed data collection, data buffering, and formatting of the SDMS in order to have the partners develop and supply systems (kernels) for testing in the POC.
- Form partnerships with suppliers of wireless transceivers in order to secure the "best available" wireless technology and communications support.
- Define the required inputs for the UWIS based on commercially available off-the-shelf (COTS) sensor and systems technology and based on the requirements of the SDMS - driver ID and status; vehicle ID and status; and carrier ID.
- Instrument a Class-8 tractor with the partner developed and supplied kernels and transceivers for testing in the POC.

- Transmit the SDMS to the roadside via VII 5.9GHz transceiver.
- Transmit the SDMS to the roadside via an alternative frequency transceiver (currently 802.11 g; 2.4GHz).
- Perform testing of each partner kernel at the I-40/I-75 Inspection station in Knox Co. TN with the test vehicle in a static mode, traveling in the bypass lane, traveling at highway speed, and in proximity of a patrol car at highway speed.
- Capture the SDMS at the roadside and/or enforcement vehicle.

ORNL Fast Track Methodology

1) A Simple and Feasible Set of Inspection Data

Inspection data for commercial vehicles can be generated via autonomous analog and digital sensors, the vehicle's own data bus (serial CAN data), or hybrid technology, such as Electronic On-Board Recorders, that monitor sensors and/or the data bus and record/derive data of interest. The collecting of this data is not a particular technical challenge nor is dealing with the volume of the data (relative to what is currently available of an inspection nature).

It is proposed that a simple and feasible set of inspection data be defined immediately for the purposes of the POC that:

- Identifies the vehicle driver.
- Identifies the vehicle.
- Identifies the carrier.
- Gives the status of the vehicle driver.
- Gives the status of the vehicle.

As new sensors are developed and are made available and the type of inspection information desired becomes more clear (as a result of this research), additional data requirements can be added to the inspection data with little to no degradation in the confidence that a system designed to collect data of interest in the POC will be able to collect the data required in the Pilot Test and the FOT. For the POC, placeholders can be used to make the file size the same as the full SDMS.

Table 1 shows the primary categories of data in the SDMS, the technology proposed to generate the data, and the specific information to be contained in the POC SDMS.

Table 1

Category	Technology	Inspection Information
Driver ID	EOBR, laptop, PDA, GPS enabled cell phone	Driver name, CDL, state
Vehicle ID	EOBR, laptop, PDA, Vehicle data bus	VIN
Carrier ID	EOBR, laptop, PDA	DOT#, Carrier Name
Driver Status	EOBR, laptop, PDA	Hours of service; SDMS transmission history
Vehicle Status	Vehicle data bus	Available safety data from vehicle's data bus

2) Partnerships

The development cost of prototype data collection hardware can be costly ($200K to $500K for design, development, and the programming of COTS elements to collect vehicle data; cost examples from ORNL Truck Rollover, Brake Testing, and Heavy Truck Duty Cycle Projects). To mitigate these costs ORNL will partner with private industry via a Memorandum of Understanding (MOU) to have the private industry partner (partner) develop the needed technology at no cost to ORNL or the government. MOUs will be put in place with companies that ORNL already has a working relationship with and who have the interest, technical capability, and financial resources to complete the prototyping process. There is no need for a formal procurement (we have no funding for hardware development) or for an exhaustive down-selection of partners. The MOU process has been used by ORNL for its vehicle related research and FOTs to date. The MOU process is quick (~30 days for approval) and forgoing the downselection will save additional time and resources. It will however take time to draft the MOUs because they will be the guiding document for the partners and will define how the partner developed technology will operate and the roles of both ORNL and the partners in the POC phase of the program.

An MOUs will also be put in place with a transceiver provider to allow access to wireless technology, needed roadside infrastructure, and expertise relative to vehicle-to-roadside and vehicle-to-vehicle transfer of inspection data.

An MOU will be put in place with a carrier local to the Roadside Testing Laboratory to facilitate access to a test vehicle and to gather feedback and input from the carrier and driver.

3) Safety Data Message Set

The SDMS has been defined (for the moment) to be a 56Kb ASCII text file. As the POC proceeds and technical discussions begin with the partners who will provide the Universal Wireless Inspection System's kernel, the size and structure of the SDMS may change. The partners, who are already grounded in electronic on-board computer (EOBR) technology, will be able to provide input as to how we should structure the SDMS for the POC and what the packet size should be/can be acceptable for transmission.

4) Partners Will Develop Their Own Version of the Universal Wireless Inspection System (UWIS) Kernel

The selected partners from industry (EOBR providers, data acquisition manufacturers, and/or telematics providers) will develop at their own cost the data collecting, buffering, and SDMS formatting/outputting device (kernel) which will be the heart of the UWIS. The partners will be provided with the input parameters to the UWIS kernel, the sample rate, the buffer size, the SDMS format, and the Kernel output format (driven by the transceiver's input requirements). From this information they will develop their own proprietary, but universal, UWIS kernel. We will not require them to disclose their design or the internal operation/contents of their kernel. For our purposes, it will be a black box that gives the required SDMS upon request and based on the specified inputs. The kernel can be as complex or as simple as they choose while still meeting the specifications called out in the ORNL MOU.

5) ORNL Will Test the UWIS at the Tennessee-Based Roadside Testing Laboratory

ORNL will design and conduct the POC test of the UWIS at the I-40/I-75 Knoxville portion of the Roadside Testing Laboratory (RTL). ORNL will facilitate and supply the test vehicle for the POC along with "break-out" connections to all the signals related to the SDMS and to the input of the transceiver. ORNL will monitor and record the inputs to the partner developed kernels, the output of the kernels (SDMS), and the output of the transceiver at the distant end. This data will be analyzed and compared to give results based on the functionality of the kernel and the transceiver in an independent and dependent manner as called out in the next section.

6) POC to Be Done in a Phased Approach

In order to produce clear results and to move the project along at the fastest pace possible, the POC will be done in two phases: Phase 1A) testing of kernels, Phase 1B) testing of transceivers using various kernels.

Phase 1A will be conducted looking only at the input and output of each Kernel under test. Each Kernel will be tested in the same vehicle under exact conditions. Data will be recorded and analyzed.

Phase 1B will be conducted looking at the output of the Kernels and what is sent to the roadside by the transceiver. Testing of multiple transceivers will take place in Phase 1B (VII 5.9GHz, 802.11g 2.4GHz) as well as testing in various operational scenarios (vehicle-to-vehicle, vehicle-to-roadside).

7) POC Testing

Rough Outline of Events:

- It is envisioned that the POC test will involve three to five technology (kernel) providers, two wireless transceiver providers, and one fleet.
- Inputs to the SDMS and the SDMS file size and structure will be determined in final form after discussions with the partners and WRI team.
- Phase 1A — Once the UWIS kernels are developed, a date will be given for each partner to come to the RTL to oversee the integration of their system into the test vehicle and to conduct a pre-POC shakedown. The following day the POC will begin and the test vehicle will be operated in various modes of driver status (on-duty, on-duty driving, off-duty) within a 100-mile radius of the RTL for a period of 8 hours. The data collection will be continuous for the 8 hours at a sample rate of 0.2 Hz. The data will be monitored during the POC to verify collection quality and kernel operation. This will equate to 5,760 recordings of the SDMS to be compared with the input to the kernel at a given time. The target percentage of accuracy (correct data in the correct location within the SDMS) will be 99.5 percent or better for the POC. We will be able to report on this with a high level of confidence due to the large number of data points.
- Subsequent partners will follow until all kernels have been tested over a two to three week period.
- Any partner whose kernel failed to properly collect and structure the information for the POC will be given a chance to return to the RTL in 30 days for an additional 8 hrs of testing.

- The testing will be repeated. If the partner fails again. No further testing will be done and ORNL will deem this partner not viable for the POC per the MOU agreement.
- Phase 1B — Next will follow the testing of the transceivers. Again, we are expecting to have one 5.9GHz transceiver and one 2.4 GHz transceiver. Each transceiver will be tested in the following scenarios:
  - Vehicle-to-roadside (vehicle stopped at weigh station; "static test" for baseline)
  - Vehicle-to-roadside (low-speed by-pass lane, 25 MPH)
  - Vehicle-to-roadside (high-speed, 55 MPH)
  - Vehicle-to-vehicle (neither vehicle moving for baseline)
  - Vehicle-to-vehicle (low-speed, 25 MPH)
  - Vehicle-to-vehicle (high-speed, 55 MPH)
- Each transceiver will be tested with each kernel in the above scenarios. The tests will be repeated 10 or more times for each scenario. Monitoring will be done at the output of the kernel and will be compared with the SDMS received at the roadside as to content and location of data. Results from this testing will be reviewed in process. Thus, speeds, antenna locations, vehicle placement, etc. can be adjusted as needed to assess the wireless transceiver's viability in each desired scenario.
- Data from Phase 1A and Phase 1B will be analyzed and included in a final report.

8) Data Sharing with Stakeholders

In order to maintain a level playing field and defend against the appearance of favoritism, ORNL will share all test data and the test plan (as well as future vision???) with stakeholders via a website/or other administered by the FMCSA. The data will be made available as to how well each kernel collected, formatted, and output the SDMS; and how each transceiver transmitted the SDMS. Partner names may not be mentioned in the data release.

9) Teaming

ORNL will work closely with Mitretek and Volpe Center to design and conduct the POC, drawing on their expertise in system design, testing, and wireless communications.

10) POC Outputs

Below is a bulletized list of expected Outputs from the POC. It is not complete and is evolving.

- POC Test Plan
- Raw Data from POC
  - ~80 hrs of wireless vehicle inspection technology testing and some 29,400 data samples (5,760 (8hrs of kernel testing) + 60 (transceiver 1) + 60 (transceiver 2) per partner kernel
- Analyzed Data and POC Data Report
- Functional UWIS(s)
- Candidates for Pilot Test

11) POC Benefits

- Short time to technology development and demonstration (<1 yr.)

- Reduced cost due to partnerships
- Established UWIS partnerships
- Real world experience with wireless vehicle inspection for ConOps development, etc.
- Real world experience for drafting of technical requirements
- Real world experience for drafting of standards
- Wireless vehicle inspection technology maturation
- Scenario based experience with 2.4 and 5.9 GHz transceivers
- Informed decision to continue to Pilot Test (go/no-go)
- Assessment of partner interest in Pilot Test

12) POC Work Steps

- Define SDMS Inputs (complete)
- Determine Transceiver Frequency(s) (complete)
- Establish Partnerships (IP)
    - Select Partners for Initial Contact (complete)
    - Draft Partner Letter (complete)
    - Draft MOU (IP)
    - Sign MOU
- Define POC (IP)
- Define Data Collection Method (IP)
- Define Data Analysis (IP)
- Partners Develop UWIS Kernels
- Establish TDOS Roles and Secure TDOS Support
- Draft Test Plan
- Select and Secure Test Vehicle
- Instrument Test Vehicle
- Instrument Inspection Station, Roadway, and Patrol Car
- Conduct POC Phase 1A
- Collect Data and Video of Testing (if budget allows)
- Analyze Data
- Conduct POC Phase 1B
- Analyze Data
- Archive Data
- Partner Survey
- Final Report and Recommendations

13) Timeline

- Establish Partnerships (MOUs in Place) Feb 23, 07
- Kernels Developed April 27, 07
- POC 1A Complete June 29, 07
- POC 1B Complete July 27, 07
- Analysis Complete August 30, 07
- Final Report October 26 ‘07

APPENDIX B. ACKNOWLEDGEMENTS

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