Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-16/0-6867-1		

4. Title and Subtitle	5. Report Date
CONCEPTUAL DESIGN OF A CONNECTED VEHICLE WRONG-WAY DRIVING DETECTION AND MANAGEMENT SYSTEM	Published: April 2016
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Melisa D. Finley, Kevin N. Balke, Rajat Rajbhandari, Susan T. Chrysler, Chiara Silvestri Dobrovolny, Nada D. Trout, Paul Avery, David Vickers, and Cameron Mott	Report 0-6867-1
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Texas A&M Transportation Institute College Station, Texas 77843-3135	11. Contract or Grant No. Project 0-6867
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Texas Department of Transportation Research and Technology Implementation Office 125 E. 11th Street Austin, Texas 78701-2483	Technical Report: February 2015–December 2015
	14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

Project Title: Connected Vehicle Wrong-Way Driving Detection and Mitigation Demonstration

URL: http://tti.tamu.edu/documents/0-6867-1.pdf

16. Abstract

This report describes the tasks completed to develop a concept of operations, functional requirements, and high-level system design for a Connected Vehicle (CV) Wrong-Way Driving (WWD) Detection and Management System. This system was designed to detect wrong-way vehicles, notify the traffic management entities and law enforcement personnel, and alert affected travelers.

To accomplish the project goals, the research team reviewed the state of the practice regarding intelligent transportation systems and CV technologies being applied as WWD countermeasures and the WWD crash trends in Texas from 2010 to 2014. The research team also identified the user needs associated with the implementation of a CV WWD system and preliminary ways to connect with law enforcement. The research team conducted one-on-one surveys to assess motorist understanding of wrong-way driver warning messages that were designed to be displayed on dynamic message signs. The research team also investigated the use of roadside alert (RSA) messages to provide warning to CVs about approaching wrong-way drivers.

The research team recommended the development of a proof-of-concept test bed at an off-roadway location before implementing a model field deployment of the system on an actual roadway in Texas. The purpose of the test bed is to provide an offline location for the research team to test and fine-tune the system components and operations prior to installing them on the open roadway. A need also exists to conduct additional human factors studies to determine motorist needs, comprehension, and interpretations of RSA data elements in a WWD context. It is also important to understand how motorists will respond to the information contained in potential RSAs. The lessons learned from the deployment in the test bed environment would be used by the research team to determine the design considerations for a model field deployment of the system.

17. Key Words	18. Distribution Statement
Wrong-Way Driving, Wrong-Way Countermeasures, Wrong Way Detection Systems, Connected Vehicles, Dynamic Message Signs	No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia 22312 http://www.ntis.gov

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	214	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

CONCEPTUAL DESIGN OF A CONNECTED VEHICLE WRONG-WAY DRIVING DETECTION AND MANAGEMENT SYSTEM

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Report 0-6867-1
Project 0-6867
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Texas Department of Transportation
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Federal Highway Administration

Published: April 2016

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT.

This report does not constitute a standard, specification, or regulation. This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Melisa D. Finley, P.E. (TX-90937).

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGMENTS

This project was conducted in cooperation with TxDOT and FHWA. Darrin Jenson of TxDOT served as the project manager. The following TxDOT employees served on the project team: Michael Chacon, Jianming Ma, John Gianotti, Martin Gonzalez, Maurice Johnson, Omar Madrid, and Roy Parikh. The authors gratefully acknowledge the assistance and direction that these individuals provided over the course of the project.

The research team also received input from an Expert Advisory Panel comprised of experts in their field of practice. Members of the Expert Advisory Panel were:

- Natalie Bettger, North Central Texas Council of Governments.
- Walton Fehr, USDOT OST-R ITS Joint Program Office.
- Calvin Harvey, Harris County Toll Road Authority.
- Eric Hemphill, North Texas Tollway Authority.
- Jan-Niklas Meier, Volkswagen Group of America.
- Chiu Liu, California Department of Transportation.
- Jeffrey Shaw, Federal Highway Administration.
- Derek Vollmer, Florida Department of Transportation.
- Captain Adolph Zuniga, San Antonio Police Department Traffic Section.

The authors would also like to acknowledge the contributions of Roma Stevens, Steve Venglar, Scott Cooner, Sandra Stone, Hassan Charara, David Florence, and the many other Texas A&M Transportation Institute staff that assisted with various aspects of this project.

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LIST OF ABBREVIATIONS

ADAS	Advanced Driver Assistance Systems
ADOT	Arizona Department of Transportation
ATMS	Advanced Traffic Management System
AVL	Automatic Vehicle Location
BAC	Blood Alcohol Concentration
BSM	Basic Safety Message
CAD	Computer-Aided Dispatch
CCTV	Closed Circuit Television
CFX	Central Florida Expressway Authority
ConOps	Concept of Operations
CRIS	Crash Records Information System
CV	Connected Vehicle
CVRIA	Connected Vehicles Reference Implementation Architecture
DSRA/WAVE	Dedicated Short Range Communications for Wireless Access in Vehicular Environment
DMS	Dynamic Message Sign
DPS	Department of Public Safety
DSRC	Dedicated Short Range Communication
EAM	Emergency Agent Module
ESP	Emergency Service Provider
ETA	Estimating Time of Arrival
FHWA	Federal Highway Administration
FDOT	Florida Department of Transportation
GIS	Geographic Information System
HCTRA	Harris County Toll Road Authority
HAM	Highway Agents Module
HOT	High Occupancy Toll
HOV	High Occupancy Vehicle
IEEE	Institute of Electrical and Electronics Engineers
ITE	Intuition of Transportation Engineers
ITIS	International Traveler Information System
IAM	Interface Agent Module
ITS	Intelligent Transportation System
MoDOT	Missouri Department of Transportation
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
OBE	Onboard Equipment

OEM	Original Equipment Manufacturers
OVW	Oversized Vehicle Warning
PIO	Public Information Officer
POD	Portable Onboard Device
PoE	Power Over Ethernet
PVD	Passive Vehicle Detection
RRFB	Rapid Rectangular Flashing Beacon
RSA	Roadside Alert
RSE	Roadside Equipment
RSU	Roadside Unit
RTI	Radio Tomographic Imaging
SAE	Society of Automotive Engineers
SAPD	San Antonio Police Department
SET-IT	Systems Engineering Tool for Intelligent Transportation
SwRI	Southwest Research Institute
SWIW	Spot Weather Impact Warnings
TAMU	Texas A&M University
TMC	Traffic Management Center
TMDD	Traffic Management Data Dictionary
TME	Traffic Management Entity
TTI	Texas A&M Transportation Institute
TxDOT	Texas Department of Transportation
US DOT	United States Department of Transportation
VAM	Vehicle Agents Module
VCR	Videocassette Recorder
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
WWD	Wrong-Way Driving

CHAPTER 1: INTRODUCTION

STATEMENT OF THE PROBLEM

According to the National Highway Traffic Safety Administration (NHTSA) Fatality Analysis Reporting System database, approximately 360 fatalities occur every year due to wrong-way driving (WWD) crashes on controlled-access highways (*1*). WWD crashes occur when a motorist either inadvertently or deliberately drives in the opposite direction of travel on a divided roadway. Even though WWD crashes are infrequent, they remain a serious problem because the resulting crashes often result in fatalities or serious injury to the persons involved.

Since the mid-1960s, agencies around the country have deployed combinations of traffic control devices (e.g., DO NOT ENTER and WRONG WAY signs, pavement markings, and directional route markers) to prevent drivers from entering freeway facilities in the wrong direction. More recently, agencies have leveraged traditional intelligent transportation system (ITS) infrastructure (e.g., cameras, radar, or loop detectors) to detect wrong-way drivers and notify traffic management centers (TMCs). However, most of these systems lack the ability to provide specific vehicle location information and real-time warnings to right-way drivers. In addition, the process still relies on manual inputs from operators and traditional methods of information exchange between TMC and law enforcement personnel. Connected vehicles (CVs) and their integration with transportation infrastructure provide new approaches to WWD detection, warning, verification, and intervention that will help practitioners further reduce the occurrence and severity of WWD crashes.

GOAL OF THE PROJECT

The goal of this project was to develop a concept of operations, functional requirements, and high-level system design for a Connected Vehicle WWD Detection and Management System. This system will detect wrong-way vehicles, notify the Texas Department of Transportation (TxDOT) and law enforcement personnel, and alert affected travelers. For this project, the system boundaries were identified as high-speed, controlled-access, freeway-type facilities. These included the main lanes of TxDOT freeways and major toll facilities, as well as their entrance and exit ramps. System boundaries *do not include* frontage roads, cross-street approaches of frontage road intersections or the intersection itself, or urban roadways operated by municipalities. The system was also not designed for multi-lane, divided highways without access control.

CONTENTS OF THIS REPORT

Chapter 2 documents the state of the practice regarding ITS and CV technologies being applied as WWD countermeasures. Chapter 3 contains information about the WWD crash trends in Texas from 2010 to 2014. Chapter 4 details the user needs associated with a CV WWD Detection and Management System, and Chapter 5 documents the concept of operations for such a system. Chapter 6 and the appendix detail the development of the system's functional requirements. Chapter 7 explores the need for emergency service provider integration and preliminary connectivity concepts for emergency service providers. Chapter 8 contains the high-level system design. Chapter 9 documents the findings from one-on-one surveys to assess motorist understanding of wrong-way driver warning messages that were designed to be displayed on dynamic message signs (DMSs). Chapter 9 also contains information on the use of roadside alert (RSA) messages to provide warning to CVs about approaching wrong-way drivers. Chapter 10 summarizes all research tasks and provides recommendations for the next steps toward the implementation of a CV WWD Detection and Management System in Texas.

CHAPTER 2: STATE OF THE PRACTICE

In order to determine the state of the practice, the research team reviewed and documented national and international ITS and CV technologies being applied as countermeasures for WWD. The following sections document the findings of these activities.

INTELLIGENT TRANSPORTATION SYSTEM WWD APPLICATIONS

One scenario for mitigating WWD events leverages traditional ITS infrastructure, in which sensors (e.g., cameras, radars, or loop detectors) are used to detect a vehicle going in the wrong direction, triggering an alert that targets both the wrong-way driver and nearby right-way drivers via existing ITS infrastructure (e.g., blank-out signs, DMSs, and flashing light emitting diodes [LEDs] around the border of signs). Figure 1 depicts this scenario. Many state transportation agencies and toll road agencies have implemented WWD applications using traditional ITS technologies.

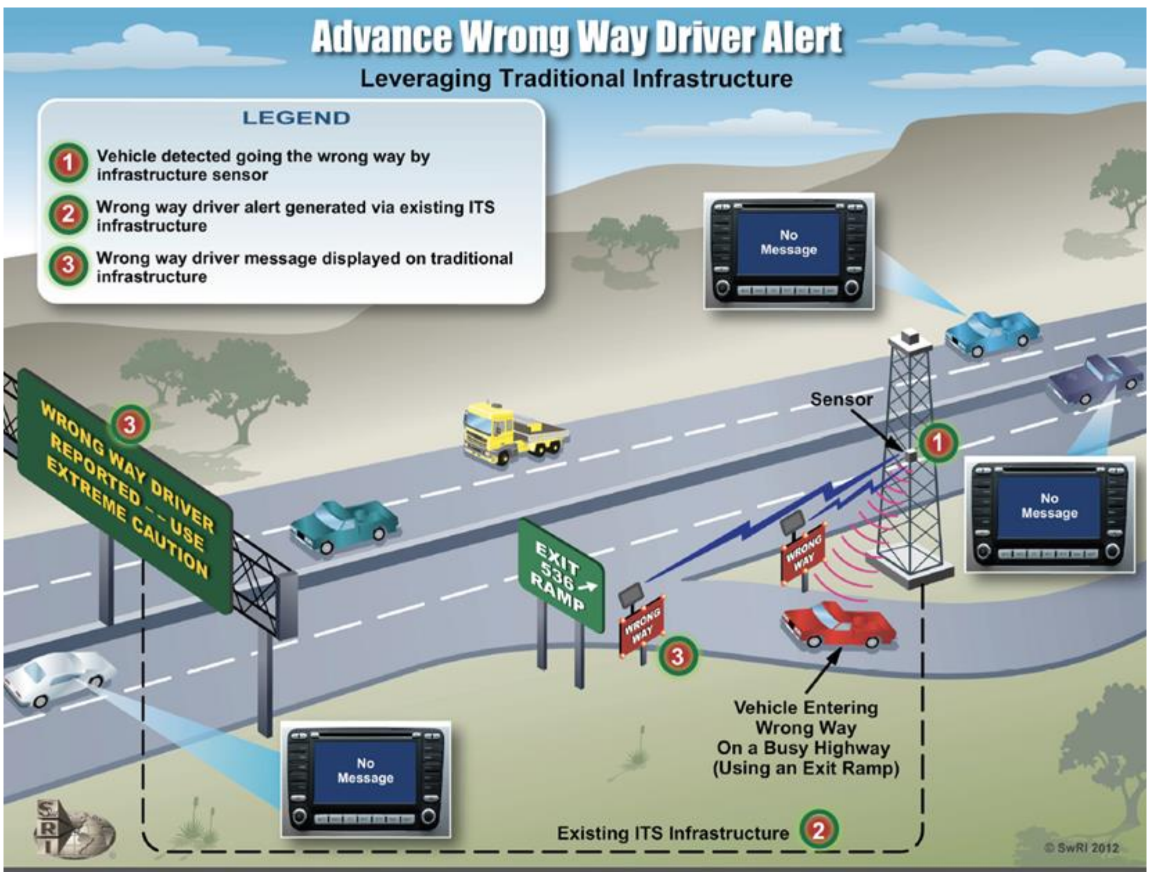


Figure 1. WWD Detection and Notification Leveraging Traditional Infrastructure.

Weaver was one of the pioneers in the field of WWD detection on freeway ramps. He developed a system that could be diagrammed using just five representative icons (Figure 2), which is essentially an AND gate architecture used to determine the direction of travel for vehicles passing over two detectors set a certain distance apart (*2*). Each detector when triggered will fire a pulse for a set duration, and by carefully selecting this duration for the two detectors, the system can determine the direction of a vehicle and issue an alert if the vehicle is traveling in the wrong direction.

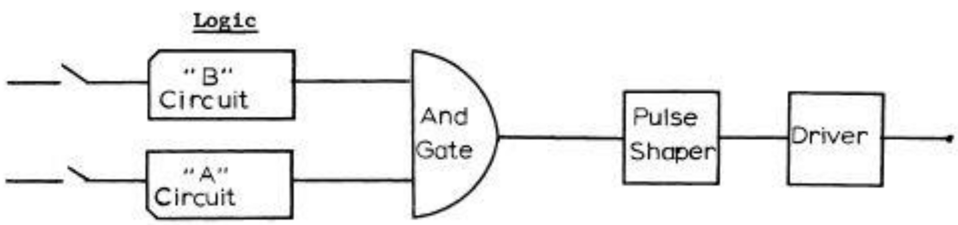


Figure 2. Weaver's Detection System Design (*2*).

Generally, it is preferable to detect the wrong-way vehicle at the beginning of the exit ramp so that the errant driver can be alerted and hopefully correct the wrong maneuver. In addition, public agencies are notified at the point of entry (i.e., the earliest possible time). In 1994, Woods identified the optimal locations for wrong-way detection units for high-occupancy vehicle (HOV) lanes (*3*). As shown in Figure 3, the area adjacent to the wedge island was the ideal location for wrong-way detection because the driver's attention at this location was on negotiating the curve. If the driver is alerted at this point, he/she can change the direction of the vehicle before entering the roadway. The alternate location for the detection areas was just after the entry in to the HOV lane. The main advantage of the alternate location was that more detectors and display boards could be placed in this area. The main disadvantage of the alternate location was that the attention of the driver would be on the lane rather than on the communication device placed adjacent to the lane.

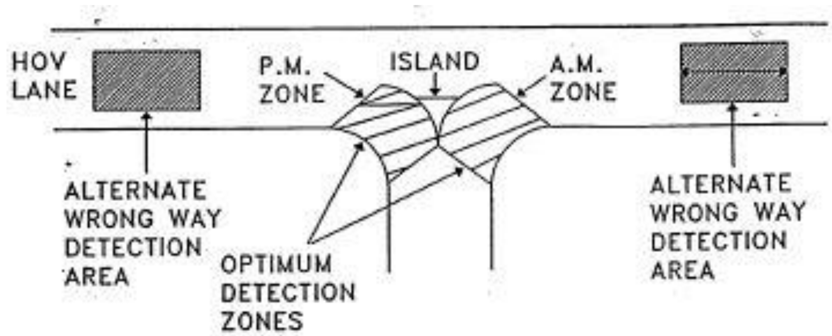


Figure 3. Optimal and Alternate Detection Areas (*3*).

In 2004, Cooner et al. compiled a report on countermeasure findings for wrong-way movement on freeways, which included several ITS applications (*4*). In New Mexico, a directional traffic sensor system was developed and put into place on the Interstate 40 exit ramp near Albuquerque. The system is shown in Figure 4. When the system detects a wrong-way driver, red lights flash on the WRONG-WAY side of the sign to warn the errant driver and yellow lights flash on the STOP AHEAD side of the sign for drivers going the correct direction. The system works by using loop sensors, a modified 3M Canoga TMI C400 vehicle detector, and warning signs.

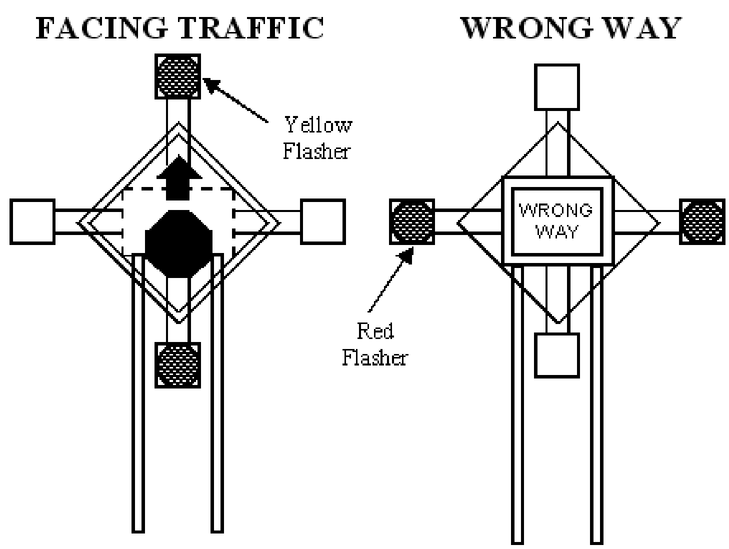


Figure 4. Diagram of the New Mexico Directional Traffic Sensor System (*4*).

Washington State created two warning systems at two freeway ramp locations to show the advantages of ITS wrong-way signing. One system included a solar-powered vehicle detection system to power LED signs, flashers, video camera, and a videocassette recorder (VCR). The other system was powered by traditional sources. Wrong-way drivers were warned with a flashing red WRONG WAY message (Figure 5). The VCR recorded the reported incidents for further review (*4*).

Figure 5. Washington State Wrong-Way ITS System on an Exit Ramp (*4*).

At one bridge in Florida, loop detectors were used for wrong-way vehicle detection. This system notified a nearby police substation when a wrong-way driver was detected and alerted motorists going in the proper direction through a signal system located over the roadway (*4*). Caltrans reported using in-pavement warning lights that were activated by wrong-way vehicles to warn errant drivers (*4*).

In 2004, some of the advertised wrong-way detection products included an acoustic traffic sensor being made by SmarTrek that was designed to detect wrong-way drivers on exit ramps using the passive acoustic detection of motor vehicles and a video wrong-way detection systems being made by ASCOM, Traficon, and Peek (*4*).

In 2008, a study by Shehata et al. discussed Automatic Incident Detection (AID) systems used in Intelligent Transportation Systems and false alarms due to environmental conditions (*5*). Video-based AID systems are able to detect traffic abnormalities on a specific roadway section from a live video feed. WWD is an example of a roadway anomaly that could be detected by AID. However, one of the most recurrent and critical problems with AID systems is the generation of false alarms, which can reach 60 to 80 percent of total alarms. The main reason for such a high frequency of false alarms was related to the environment (i.e., weather conditions) in which they are used. Shehata et al. discussed the nature of problems associated with operating AID systems outdoors due to shadows, snow, rain, and glare. For example, the presence of glare in the scene could trigger a false alarm. Particularly, moving glare, which is commonly caused by vehicle headlights, can cause false alarms in incident detection systems where wrong-way vehicle detection is implemented.

In October 2008, the Harris County Toll Road Authority (HCTRA) began to operate a wrong-way driver detection system on a 13.2-mile portion of the West Park Tollway, a controlled-access roadway (i.e., freeway) in Houston. The system uses Doppler radar vehicle sensors supplemented with in-pavement loop sensors at 14 points along the tollway (Figure 6). TMC personnel receive wrong-way movement detections and monitor the system 24 hours a day and seven days a week. Once a wrong-way vehicle is detected, operators at the TMC can immediately dispatch law enforcement officers and monitor the vehicle's location and attributes via closed-circuit television (CCTV) and a geographic information system (GIS) map. The operators use the TMC software to warn other motorists of the wrong-way vehicle using DMSs (*6*). According to Zhou et al., dispatchers use global position system (GPS) technology to position law enforcement officers ahead of the wrong-way driver (*7*). Current methods to stop wrong-way vehicles include driving parallel to the wrong-way driver and warning them with lights, sirens, and spotlights or by getting ahead of the driver and forcing the driver to pull over. If this approach is unsuccessful and the wrong-way driver passes the officers, the officers may deploy tire deflation techniques, like portable spikes, to slow or stop the vehicle.

The HCTRA wrong-way driver detection system deployment incorporated a number of innovative aspects including site-specific design, configuration, and communications dispatch and response protocols. The original cost in 2007 was $337,000 (about $25,530 per mile). In 2011, HCTRA spent an additional $175,000 to enhance the system, which increased the cost per mile to approximately $38,788. Figure 6 shows the components and locations of the current detection system, as well as the other countermeasures that HCTRA implemented. The following features have been added since implementing the system in 2008 (*6*):

- Once the alarm is activated, the nearest CCTV camera automatically pans toward the detection site so that TMC operators can track a wrong-way vehicle and relay information to first responders.

- Warning messages conveyed to other drivers on DMSs can be displayed in automated incident response plans based on the direction of travel and location of the detection.
- LED in-ground lighting was installed to warn motorists at Post Oak and Richmond Avenue.
- WRONG WAY signs with flashing LEDs around the border were installed at locations that have a higher rate of incidents.
- Through attrition, radar sensors were replaced by in-ground puck loop systems. In 2014, three sites were using the puck system.

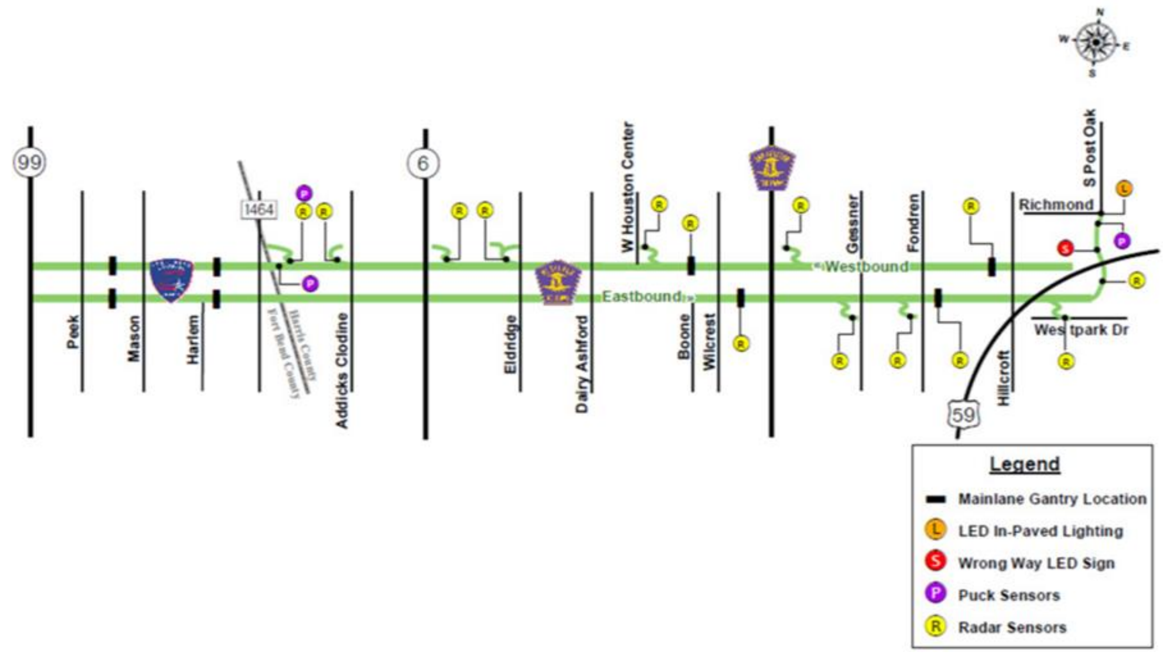
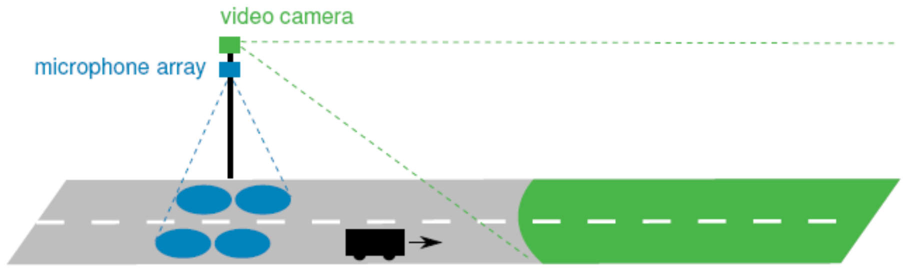
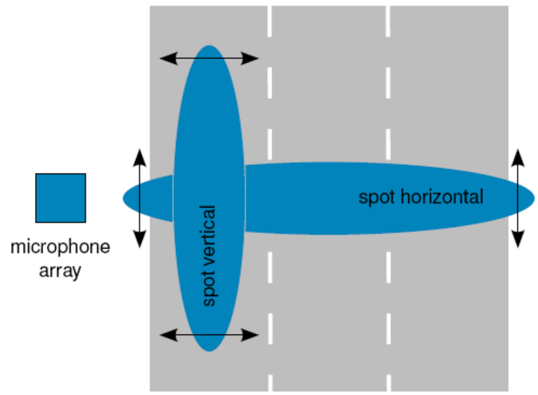


Figure 6. West Park Tollway Wrong-Way Detection Sensors (HCTRA) (*6*).

In 2010, Pucher et al. presented methods for detection and tracking based on audio-video sensors (Figure 7) (*8*). To mitigate the complexities between video detection of cars and trucks, different strategies were adopted. For video car detection, classifier grids were used. For scene calibration, the ground plane surface was noted. With the knowledge of the captured detection footage and the ground place surface, a car moving in the wrong direction could be detected. More complex features were required for video truck detection.



a) Audio-Visual Highway Monitoring Scenario.

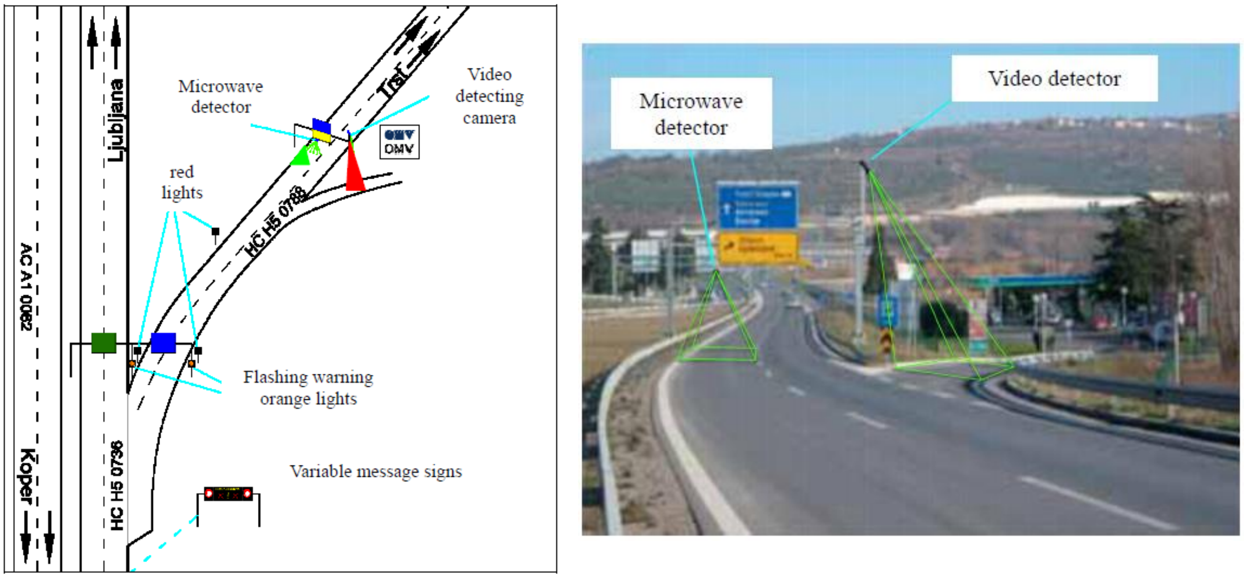


b) Beam Steering Using Horizontal and Vertical Arrays.

Figure 7. Scenario for Audio-Visual Highway Monitoring (*8*).

For the audio detection system, a cross-shape microphone array was used to perform horizontal and vertical beam steering (Figure 7b). A horizontal array was positioned to form a narrow beam across both lanes, while vertical line arrays were placed to form beams in the lanes. Using the arrays and variable digital time delays, an algorithm can determine vehicle direction. Based on two trials, researchers found that about 97 percent of vehicles were detected. In addition, the direction of the vehicle was correctly detected for at least 98.6 percent of the vehicle.

In 2010, Babic et al. suggested four basic categories of countermeasures for WWD, including the implementation of dynamic detection and alarm signs, and the development of vehicle stopping systems, which could be coupled with detection devices (*9*). Babic et al. also reported on an experimental dynamic microwave/video wrong-way detection system that was installed on an exit ramp of a Koper freeway H5-Trieste (Figure 8). The system includes one microwave- and one video-detector, which were employed to monitor a single lane. Specifically, the microwave detector (green mark in Figure 8a) was located on the overtaking lane of H5 exit ramp and was used to detect wrong-way motorists coming from Bivje. The video detector (red mark in Figure 8a) was located at the entrance lane to the gas station, and was used to detect wrong-way motorists coming from the gas station. The system is connected to the TMC. A DMS, two orange lights (for correct motorists), and two red lights (for wrong-way motorists) were positioned approximately 1000 ft before and at the entrance of the exit ramp, respectively.



(a) Aerial View. **(b) On-Road View.**

Figure 8. Layout of the Wrong-Way Detection System in the Area of Exit Ramp H5 for Trieste (*9*).

When a vehicle going in the wrong direction passed under either the radar or the video camera system, a wrong-way alarm was triggered and the event appeared on a large display in the TMC. At the same time, the DMS above H5 freeway automatically set the speed limit to 37 mph (60 km/h) and displayed DRIVE CAREFULLY. If the operator of the TMC confirmed the presence of wrong-way vehicle using the video surveillance system, the alarm was confirmed and the message on the DMS automatically changed to WRONG WAY DRIVER.

Babic et al. also described a new light-radar ITS system proposed by Jarc et al. for automatic detection and reporting of wrong-way highway entry (*9*, *10*). The system employs one or more Doppler radars to detect wrong-way motorists at the exit ramp. When a wrong-way vehicle was detected, the system activated luminous signals (Figure 9) to warn the driver going in the wrong direction. If the wrong-way driver did not stop, the system was designed to send an alarm message via a suitable communication channel at hand on the location to the regional TMC, where an operator could take actions, such as close roads via DMSs.

Figure 9. Proposed Light Signalization (*9*).

An example of an installation with three detectors is shown in Figure 10. Multiple detectors properly spread along the exit ramp were strongly suggested to reduce false alarms, through redundancy, and to monitor the entire ramp length. As illustrated in Figure 10, radar detector 1 (yellow area) was directed toward the junction of the exit ramp and the local road and served to detect only approaching WWD vehicles. If radar 1 detected a wrong-way vehicle, the system activated four flashing lights, which were located at each corner of the sign shown in Figure 9. These lights could be powered by the electrical network or by use of batteries and solar panels. If the driver observed the warning sign and corrected their direction of travel, radar 2 (orange area) would detect the behavior. If the driver does not observe the warning sign and continues in the wrong direction, the vehicle will be detected by radar 3 (red area). At this point, the system would send a high priority alarm message to the regional TMC.

In a recent case study conducted in the Czech Republic, Feix described a system where the detector system was installed at the toll station. In addition to truck tracking and weighting, the existing sensors could also assess whether the vehicles were traveling in the same direction (*11*). If a wrong-way vehicle is detected, information is sent to the National Traffic Information Center, where traffic on all Czech Republic roads is constantly monitored. An operator would verify the reality of the alarm with the use of surveillance cameras and track the wrong-way vehicle's movements. The operator would then post a warning message on an information sign in the path of the wrong-way vehicle. The other drivers proceeding in the right direction were also warned of the wrong-way vehicle via special radio reports, latest navigation systems or radio data systems, or mobile phones. Police, Integrated Rescue System, and road workers of the motorway management and maintenance department of the Road and Motorway Directorate also receive information about the wrong-way vehicle. In 2013, it was reported that this system was able to identify seven to ten wrong-way drivers per month (*12*).

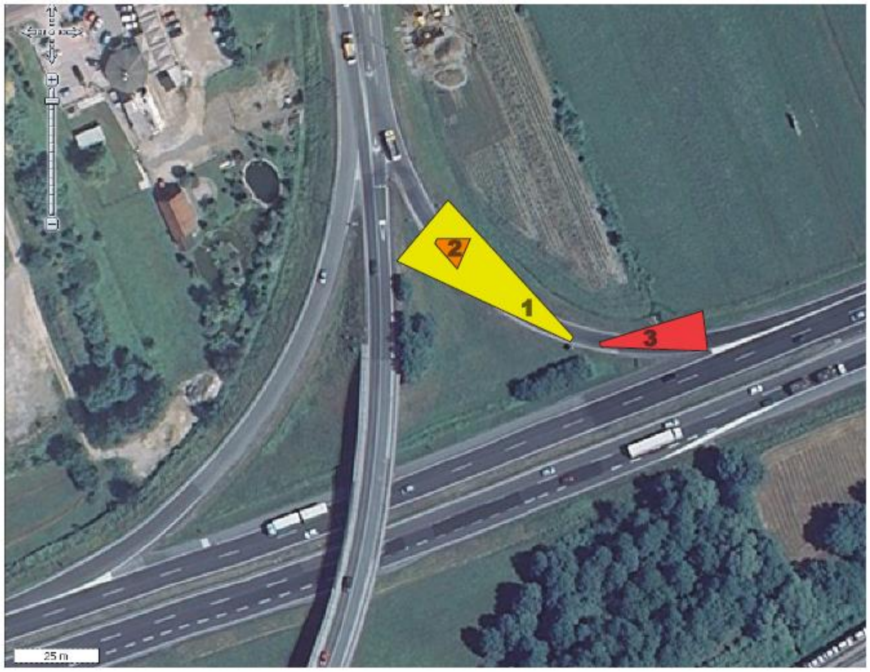


Figure 10. Example of System Layout with Three Radar Detectors (*9*).

Since 2012, the TxDOT San Antonio District has been implementing various ITS technologies to detect and warn wrong-way drivers. Along the US 281 test corridor, automatic detection of wrong-way drivers and the communication of their presence on a specific exit ramp were envisioned as an intrinsic element of countermeasure deployment. Since a sign-support-mounted radar sensor was readily available from an equipment manufacturer, that device was chosen for implementation on the US 281 exit ramps. Power for the radar sensor derived from the same solar power array used for the WRONG WAY signs with flashing red LEDs around the border. Radios were used to transmit radar readings (essentially speed, where negative values represent wrong-way drivers) from the radar sensors to the nearest TMC communications hub. However, the following issues were encountered during implementation that has impeded continuous activation of the exit ramp radar speed sensors to date:

- In July 2011, it was determined that TxDOT would engage Southwest Research Institute (SwRI) to incorporate the wrong-way driver detection from the radar sensor into the TxDOT Lonestar Advanced Traffic Management System (ATMS). Necessary changes to Lonestar were completed by December 2011.

- Installation of radar speed sensors at the US 281 exit ramps began in summer 2012. Communication from US 281 radar sensors back to the TMC was enabled late in summer 2012, but false detections resulted in TMC personnel deactivating the radar-produced WWD alerts for the US 281 ramps.
- From fall 2012 to March 2013, TxDOT and SwRI consulted with the radar sensor manufacturer to reposition and recalibrate the sensors. While some improvements were made, the number of false detections remained too high. Therefore, the radar-related wrong-way warnings continued in deactivated status.
- Throughout the remainder of 2013, SwRI studied the exit ramp radar sensor installations for TxDOT, and in April 2014 suggested that two radar sensors per ramp may be needed so that the second radar could authenticate the primary radar's wrong-way detection. Other alternatives identified included the use of a different (though substantially higher-cost) radar unit with reduced false detection issues or the pursuit of an altogether different wrong-way vehicle detection technology.

The US 281 corridor was also supposed to include four wrong-way detection and warning systems on the freeway main lanes that consisted of another vendor's radar sensors and detector-activated illuminated signing (only illuminated when a wrong-way vehicle was detected). The radar sensors would provide an alarm notifying TMC operators and law enforcement dispatchers of the presence of a wrong-way vehicle at that location. The illuminated signing would provide a warning to the wrong-way driver. Due to funding limitations, the main lane systems on the US 281 corridor have not been implemented. However, TxDOT obtained separate funding to install two main lane systems at other locations: one on I-10 at Callaghan in December 2013 and one on I-35 at Judson Road in March 2014.

As mentioned previously, the TxDOT Lonestar ATMS was enhanced to receive wrong-way driver detections from infrastructure-based devices. SwRI added a notification system for WWD detection events, which caused alerts to appear on TMC operators' workstations as well as sending an email . Reports can also be generated for WWD detection events. Figure 11 shows the Lonestar ATMS WWD alert data flow. Figure 12 shows an example of a WWD event alert sent from Lonestar. Figure 13 shows an example of a WWD event email sent from Lonestar.

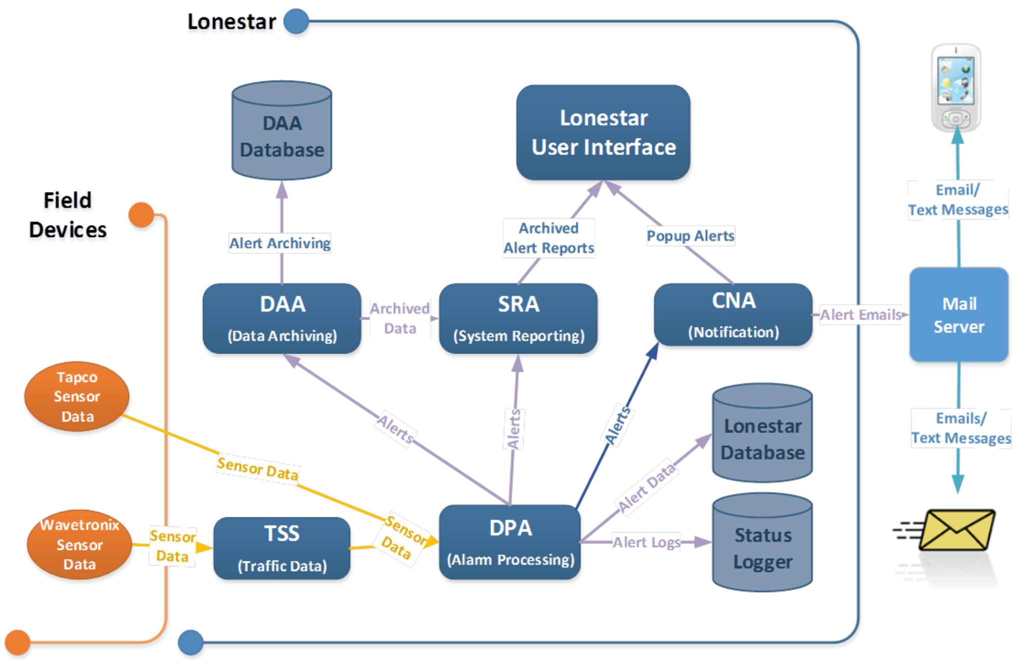


Figure 11. TxDOT Lonestar ATMS WWD Alert Data Flow.

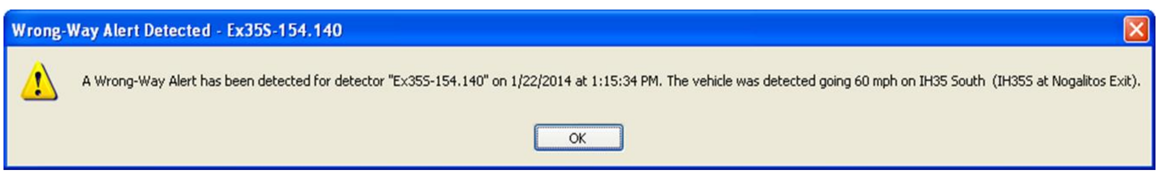


Figure 12. Example of TxDOT Lonestar ATMS WWD Event Alert.

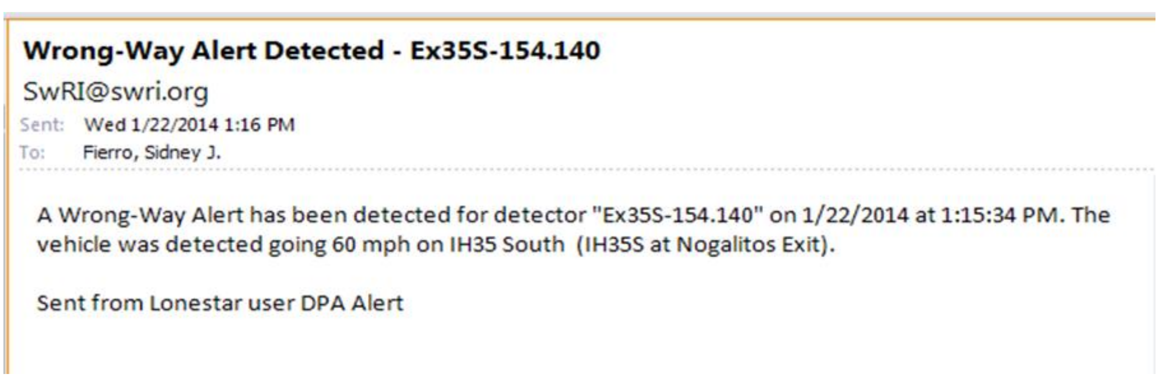


Figure 13. Example of TxDOT Lonestar ATMS WWD Event Email.

The TxDOT Lonestar ATMS does not currently have CV capabilities. However, a CV subsystem was designed and deployed by SwRI for the Florida Department of Transportation (FDOT) Sunguide ATMS software for the 2011 ITS World Congress in Orlando. Florida and

Texas have a sharing agreement for the ATMS software with SwRI as the integrator, and there is currently a plan to integrate a similar CV module into the TxDOT Lonestar ATMS in the future.

In 2013, Simpson completed a research study for the Arizona Department of Transportation (ADOT) where she discussed various concepts for detection of a wrong-way vehicle at freeway ramps to determine the viability of existing detector systems (*13*). This study also focused onevaluating the capabilities of different technologies, determining the effectiveness of the wrong-way detection system in real-world environments, and providing insight into the operational feasibility of wrong-way detection. Five technologies were evaluated including microwave sensors, Doppler radar, video imaging, thermal sensors, and magnetic sensors. Table 1 compares these devices and their effectiveness.

- Microwave Sensors – A low power, fan shaped microwave motion sensor signal (with varying frequency) is sent continuously onto the road surface which paints an elliptical footprint. If a vehicle passes by, the energy is reflected back from the vehicle. The characteristics of the energy reflected back are thus processed. The detector can recognize the presence of vehicle through the detection of motion. Thus with the motion sensor signal and the characteristics of the energy reflected, a wrong-way vehicle is detected.
- Doppler Radar – High frequency signals are emitted on to the road surface. When a wrong-way vehicle passes by, from the frequency received back from the reflected surface of the vehicle (be it a wrong-way or a right-way) the direction and speed of the vehicle can be determined from the Doppler shift of the frequency.
- Video Imaging – Videos captured by the cameras are analyzed and run through sophisticated algorithms and software. The software is programmed to detect/recognize the wrong-way movement and trigger the sensors when a wrong-way vehicle passes by. To communicate the wrong-way detection information with the TOC, this system uses modem.
- Thermal Sensors – The method used is the same as video imaging except that heat is used instead of light. The detected video from the thermal sensors can be transmitted using communication technologies.
- Magnetic Sensors – Magnetic sensors (battery operated) are embedded in the road surface. When a wrong-way vehicle passes through the location and causes a disturbance in the earth's magnetic field, the magnetic sensors send the disturbance in the earth's magnetic

field's data via radio to the field sensors. The data received are then processed for speed and direction of the vehicle using sophisticated algorithms at the road side controller, thereby confirming a wrong-way vehicle.

Table 1. Summary of Test Results for the Controlled Test Procedure (*13*).

Test	Device Type				
	Microwave	**Radar**	**Video**	**Thermal Sensor**	**Magnetic Sensor**
Detect Wrong-Way Vehicle	X	X	X	X	X
Response Time	X	X	X	X	X
Non-Intrusive	X	X	X	X	
Minimal Maintenance		X			X
Night Operations	X	X		X	X
Communication	X		X		X
Ease of Installation	X	X	X	X	
No Missed Calls	X			X	
No False Alarms		NA		NA	X
Dual Function			X		X
Low Cost	X				

Also in 2013, Matsumoto et al. presented a system developed to detect and warn wrong-way drivers (*14*). The system consisted of a warning provision unit for drivers and an image processing unit to detect wrong-way drivers. The system integrated the camera unit (basic sensing unit) and the core image processing unit, while an image processing sensor was used for information collection. With this structure, the system maintained the original functional requirements, but at the same time it reduced costs for the units and devices as well as initial costs. All of the equipment was installed on the same equipment pole (Figure 14) thus conserving space when compared to other types of sensors (i.e., optical and ultrasonic).

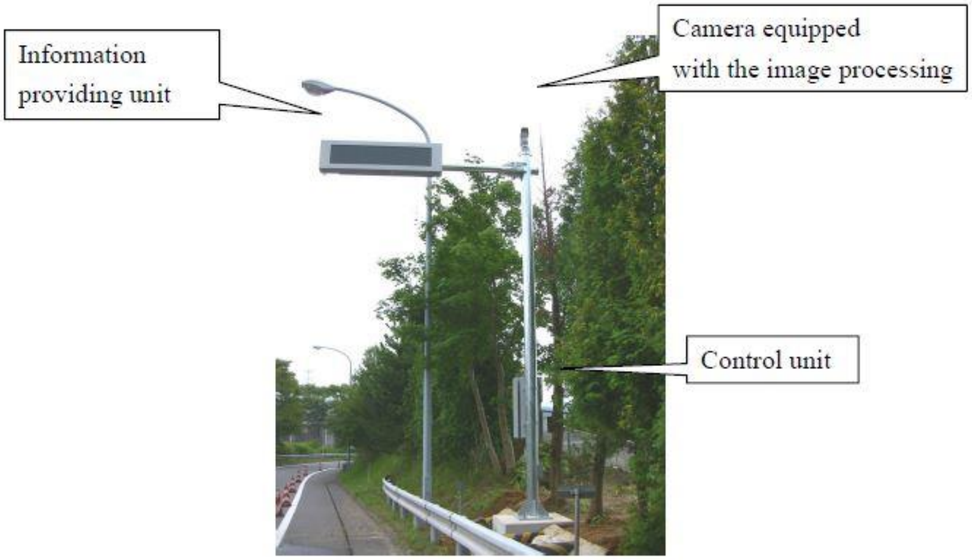


Figure 14. Information Providing Unit and Its Installation Arrangement (*14*).

Traditional vehicle sensors typically used for detecting wrong-way vehicles (e.g., optical, ultrasonic, and road embedded loop-coil) have a narrow measurement range and one sensor head is typically required for each travel lane. In contrast, an image-processing sensor can support a wide measurement range (i.e., multiple road lanes with the use of only one camera) with a capability of detecting vehicles up to approximately 500 ft away from the camera. In addition, when a wrong-way vehicle is detected, this system allows for recording of footage before and after the detection (up to 120 seconds per one recording). This footage maintains a record of the driver behavior that led to wrong-way entry and can be used for future analysis of such cases and determination of the effectiveness of implemented countermeasures. It also allows vehicle size (small or large) detection and can send footage data with addition of an appropriate optional function.

False wrong-way driver detection cases were confirmed during field tests conducted in 2011 in 21 locations under the management of the Niigata Operation Base. False detection was attributed to three specific causes:

- Road Reflection – Especially during rainy nights, road reflection significantly affects the spread of the taillights of vehicles going in the right direction. When the right-way vehicle's brakes are applied, the light is detected by the camera and incorrectly detects this movement as that of a wrong-way vehicle.

- Snowfall – White snowflakes falling on the black road surface can be mistakenly detected as a vehicle. Although precautions were taken for this type of false detection, the image processing did not work properly in certain local conditions.
- Oncoming vehicle's headlights – Approximately 90 percent of false detection cases were caused by headlights of oncoming vehicles. This is typical where entry and exit ramps are adjacent to each other and the headlights of oncoming vehicles reflect into the detection area.

During a one-year period, this study confirmed that 13 wrong-way drivers safely corrected their behavior and went back to the right direction, demonstrating that warning provisions were effective. While this system worked under extreme cold weather conditions (e.g., −86°F), false detections due to rain, fog, and snowfall did occur.

More recently, pilot projects intended to prevent WWD crashes were launched in Florida and Missouri. The Missouri Department of Transportation (MoDOT) has launched its pilot on the I-44 freeway near St. Louis where 25 crashes caused by wrong-way drivers were recorded in the last eight years (*15*). This pilot study involves the installation of solar-powered signs equipped with a sensor that can identify a wrong-way vehicle at the exit ramp. Once an errant driver is detected, the signs flash and law enforcement agencies are notified. Testing will be conducted both during the day and at night.

FDOT is testing new signs and equipment to deter wrong-way drivers after recording 24 wrong-way crashes within the period between 2010 and 2012, including 22 fatal crashes between 2009 and 2013 (*16*). Radars and cameras are being used to detect a vehicle driving in the wrong direction, and once detected the system will activate LED lights on a solar-powered sign. If the wrong-way vehicle continues to go past the sign, the radar will send an alert and email photos of the vehicle to the Florida Highway Patrol's command center and to the Turnpike's TMC in Pompano Beach. Overhead DMSs can be programmed by the traffic managers to alert motorists of the potential wrong-way driver.

The Central Florida Expressway Authority (CFX) is planning to install and evaluate the use of rapid rectangular flashing beacons (RRFBs) as a WWD countermeasure at five ramps along SR 408 and SR 528 (Figure 15) (*17*). At each of these sites, WRONG WAY signs will be equipped with RRFB and radar detection. When a wrong-way vehicle is detected, the RRFB will flash in the attempt to warn the driver, and it will also send an alert to the nearby TMC. A radar detector will be located on the main roadway downstream of the ramp and will be used to detect whether the vehicle corrects itself or continues to drive in the wrong direction. Detection data will be collected and analyzed to determine the effectiveness of the technology at reducing WWD.

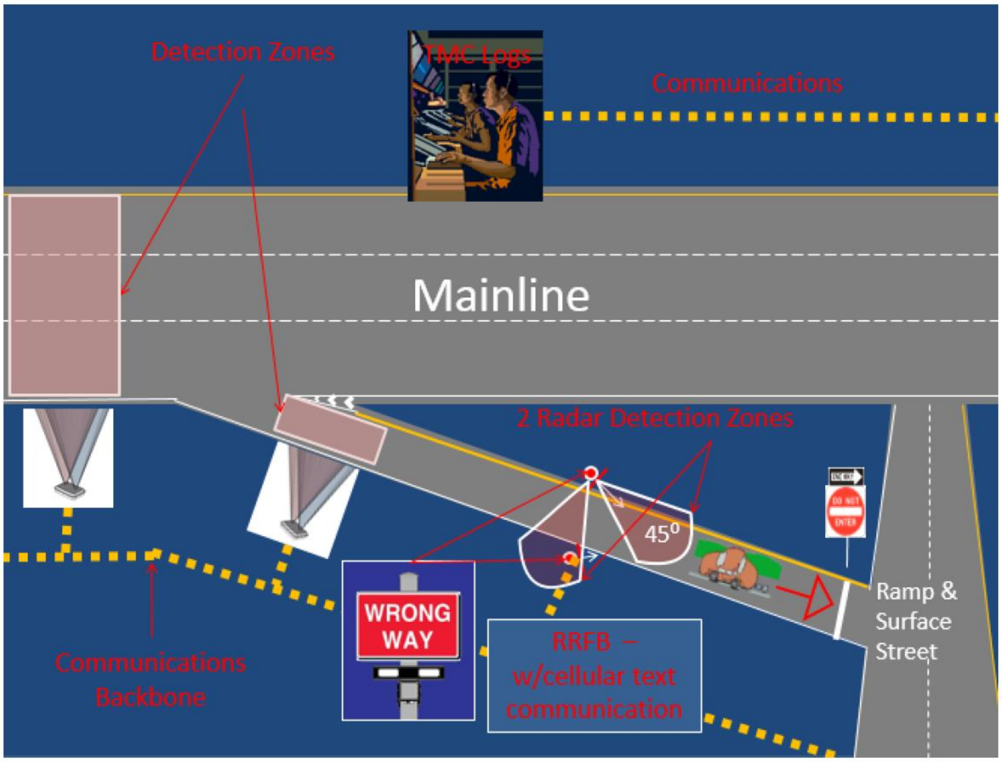


Figure 15. Conceptual Setup of RRFBs and WWD Detection Devices (*17*).

CONNECTED VEHICLE WWD TECHNOLOGIES

While traditional ITS infrastructure (e.g., sensors and signs) is currently being implemented to detect wrong-way vehicles and alert both wrong-way and right-way drivers, these systems still rely on some human interaction, especially with respect to verification of the event, activation of some system components (e.g., DMSs), exchange of event information between entities (e.g., TMC personnel and law enforcement), and dispatch of law enforcement to the scene. Other scenarios for mitigating WWD events use vehicle-to-infrastructure (V2I) and/or vehicle-to-vehicle (V2V) technologies, which further reduce the need for human interaction with the system. Figure 16 depicts an example of V2I technologies detecting and alerting a wrong-way driver, as well as warning right-way vehicles in the path of the wrong-way driver. Figure 17 provides an example of V2V technologies disseminating a basic safety message (BSM) to right-way drivers in the path of the wrong-way driver. These are just a few connected vehicle scenario concepts that can be applied to WWD detection.

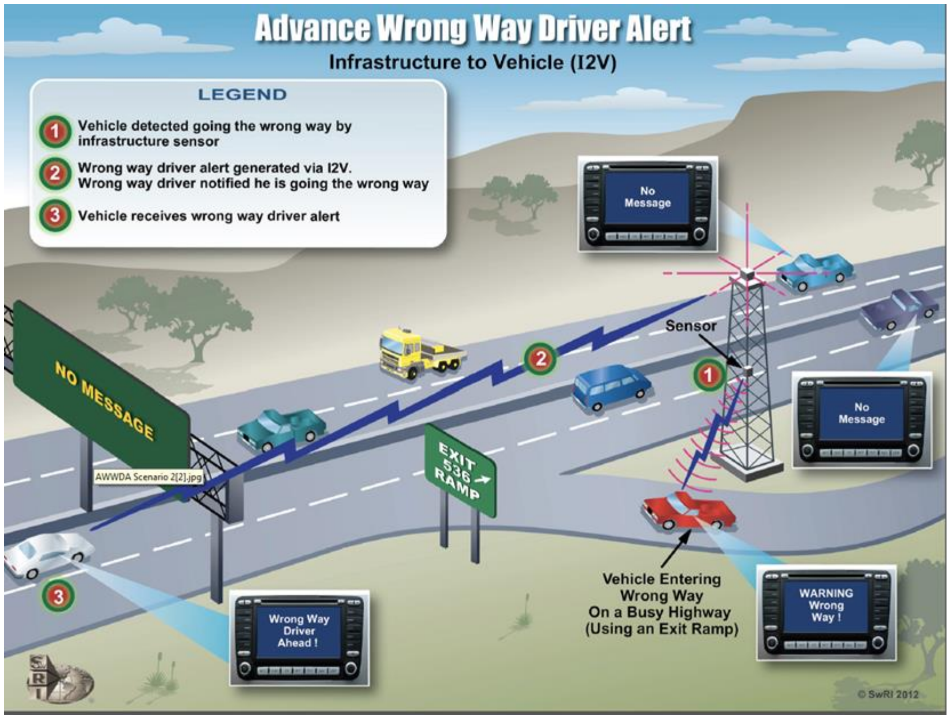


Figure 16. Example of V2I Wrong-Way Driver Technology.

Figure 17. Example of V2V Wrong-Way Driver Technology.

In 2007 in Germany, the BMW Group Research and Technology developed a new driver assistance program to reduce the 1800 wrong-way drivers reported every year (*18*). This program "uses the car's navigation system to automatically recognize when a driver is about to join a road in the wrong direction by navigation data." The road sections on which the wrong-way driver was moving were highlighted and the system was capable of reporting information such as position, direction, and speed of the wrong-way vehicle. As long as the driver keeps driving in the wrong direction, such information can be viewed in the Heads-up Display (HUD) at regular intervals. The wrong-way driver was warned by a series of audible and visual signals in the instrument cluster or HUD.

The program was also capable of warning other motorists within a range of approximately 2000 ft (approximately 610 meters) by using V2V technology. Two communication channels were employed to transmit wrong-way driver information. The V2V channel (also called Car2Car) was used for close-up identification of vehicles in the immediate area. In order to communicate information to vehicles in a wider area, a V2I communication channel was used instead. The BMW Group Research and Technology developed different frequency levels of audible and visual warning signals to differentiate between wrong-way drivers in the area and wrong-way drivers in immediate proximity. The wrong-way vehicle sends its position to a service center, which supplies the other vehicles with the information. The service center also sends information to the police and to the media directly. The message can be fed into the "warning chain" so that radio traffic bulletins can relay the message to drivers outside the range.

In 2012, Zeng et al. discussed the potential of connected vehicles for wrong-way warning system application (*19*). The system consisted of roadside units (RSUs), an onboard unit (OBU), a detection unit, and a GPS. When a wrong-way vehicle passes by, the RSU sends a message to vehicles in the vicinity equipped with OBUs, which may then display a message to the drivers using some display mechanism (Figure 18). Figure 19 represents a flow chart illustrating the operations of the system. However, this system relies on having all vehicles equipped with OBUs, which may not be practical for some time. Therefore, researchers illustrated a sequence of events for when the WWD vehicle is and is not equipped with an OBU (Figure 20).

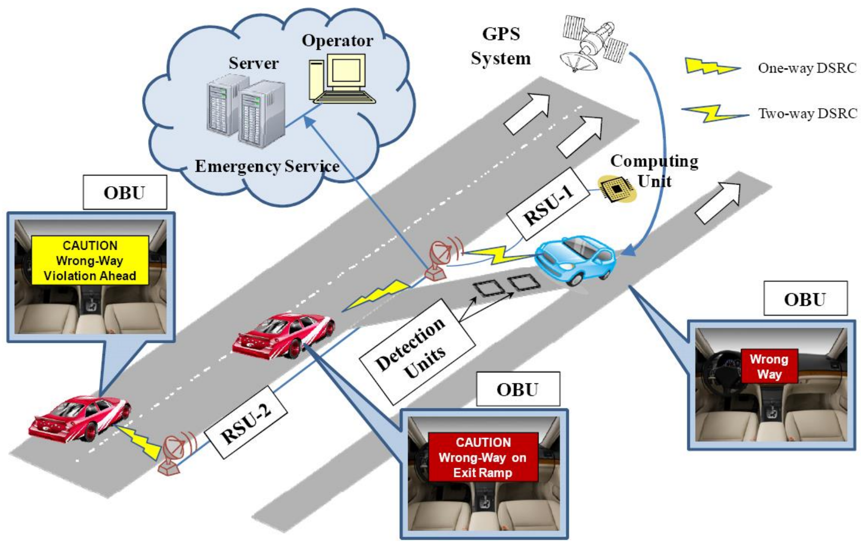


Figure 18. Concept of Wrong-Way System (*19*).

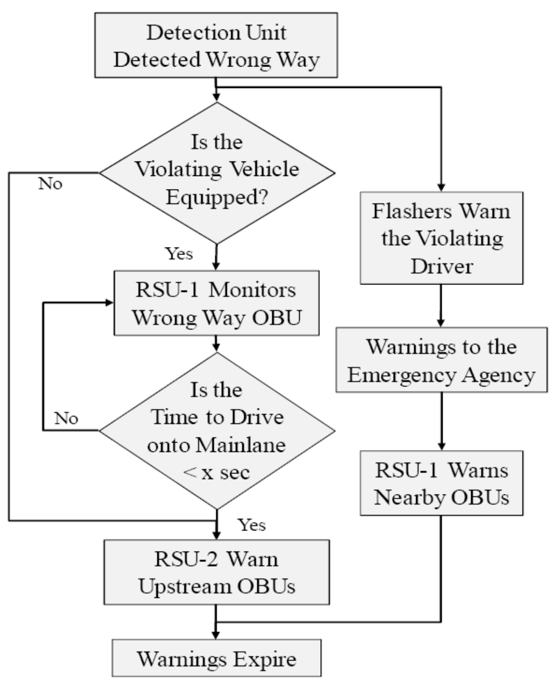
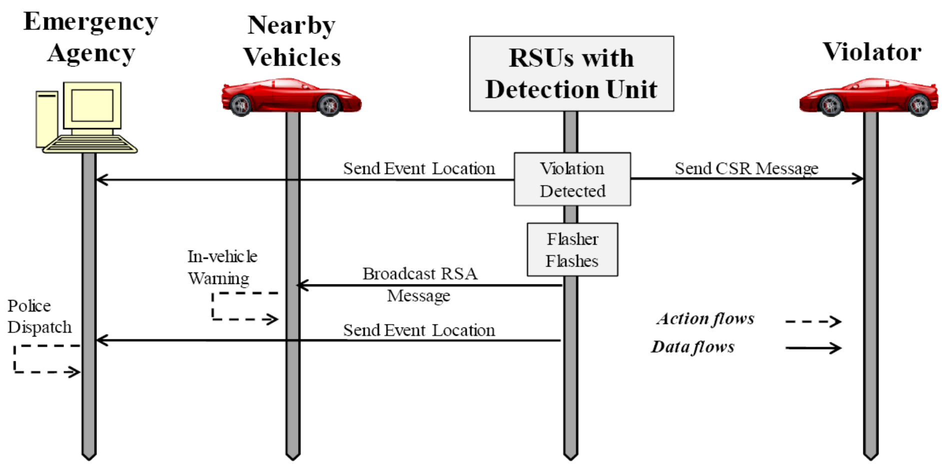
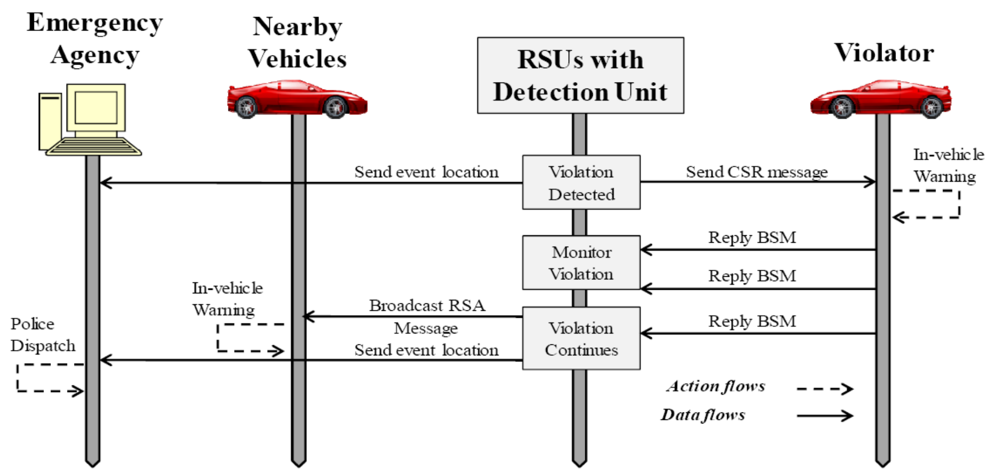


Figure 19. System Flow Chart for Wrong-Way Warning (*19*).



a) Non-Equipped Vehicle.



b) Equipped Vehicle.

Figure 20. Data and Action Flows for Wrong-Way Warning (*19*).

In Spain, an agent-based paradigm to detect wrong-way drivers was proposed by Conesa et al. and was based on V2I communication (*20*). The basic configuration included aligning emitters along the roadway that communicate through a wireless receiver with the electronic control unit inside the vehicle (Figure 21). More specifically, the researchers proposed to divide the road into several transversal stripes using signal emitters placed along the road. When the vehicle collects these signals, it determines the order in which the transversal stripes are being crossed, defining if there is an infringement of the direction of the traffic flow. The authors suggest that past studies and applications, together with the limited costs associated, make it possible to use signal emitters based on Institute of Electrical and Electronics Engineers (IEEE) Wireless 802.15.4 technology to effectively create the transversal stripes. The emitters will emit two neighboring signals: an input and an output which would define two of the three transversal stripes required. The third stripe will be determined by the absence of either the input or output signal.

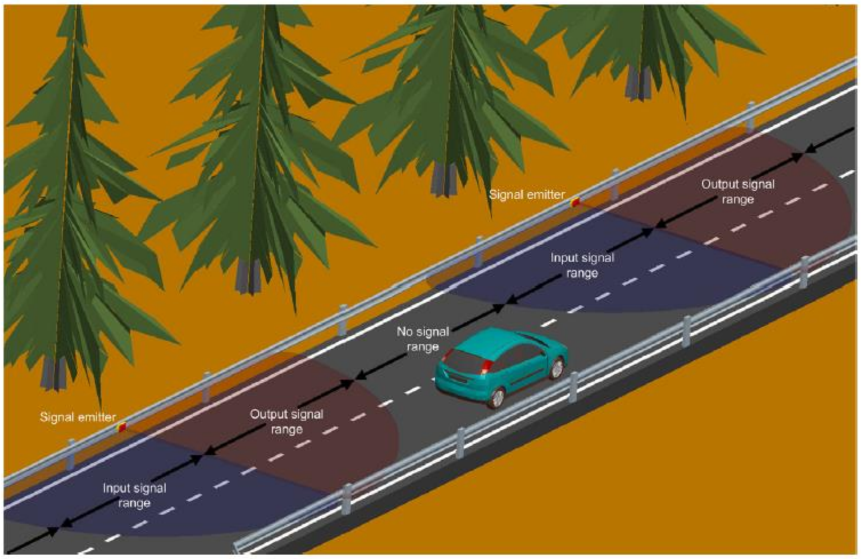


Figure 21. Method Proposed for Defining the Transversal Stripes (*20*).

Within this paradigm, a vehicle would be equipped with an electronic control unit that includes a wireless receiver, which analyses the order in which the emitter signals are received; detecting any violation of the direction of traffic flow. Conesa et al. describe in detail the architecture based on multiple agents that simulate the proposed system (Figure 22) (*20*). This architecture is divided into four modules: the Interface Agent Module (IAM), the Highway Agents Module (HAM), the Vehicle Agents Module (VAM), and the Emergency Agent Module (EAM).

In 2013, Oorni and Schirokoff introduced the iMobility project to promote energy efficiency and maintainable mobility, with a special focus on cooperative ITS systems (*21*). For WWD specifically, a system was described that detects errant vehicles with a roadside monitoring system, such as cameras combined with machine vision algorithms or video surveillance by a human user. The driver is warned with an audible sound or by other means from the vehicle. The location of the wrong-way driver is communicated to other motorists through V2I with roadside ITS stations. These ITS stations can also send messages to the TMC, which can alert more drivers through other roadside units. Malone et al. provided an illustration of likely the technical architecture of the system (Figure 23) (*22*).

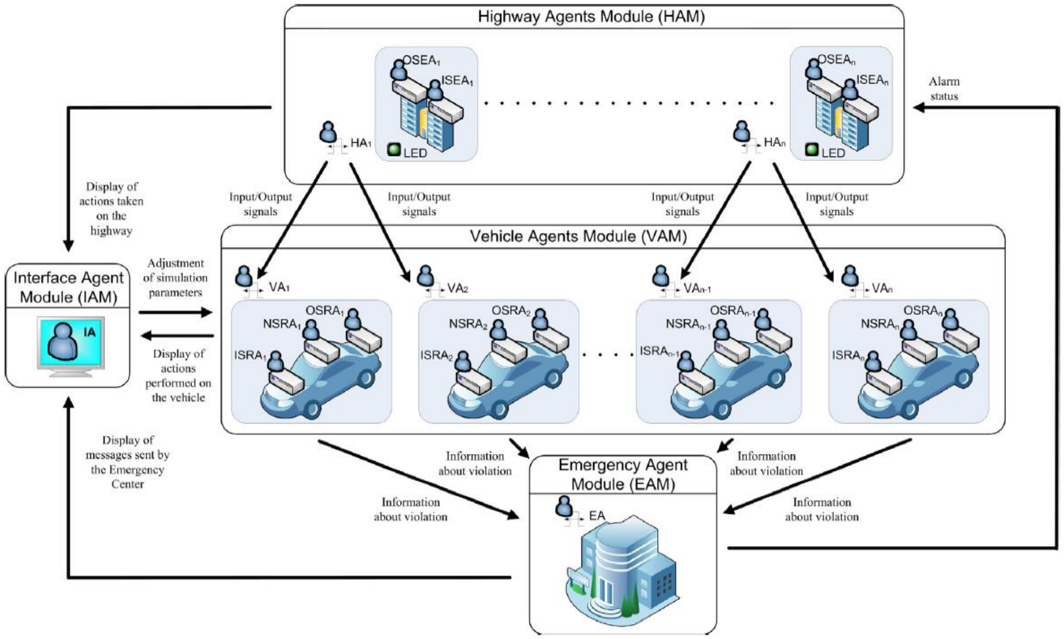


Figure 22. Functional Diagram of the Agent-Based Architecture (*20*).

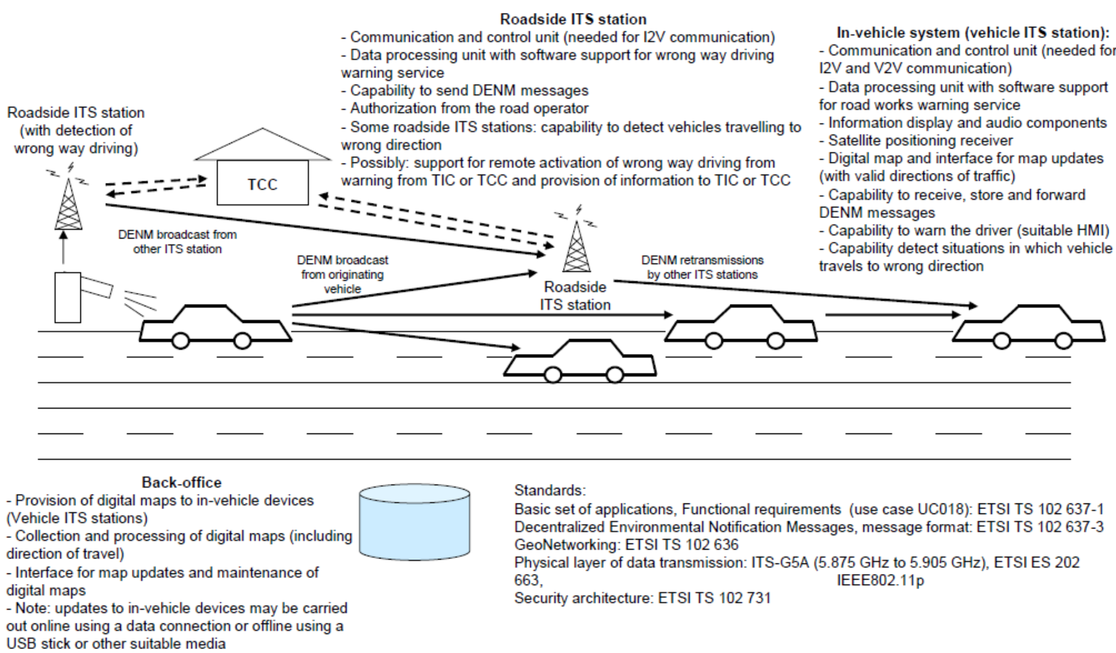


Figure 23. WWD – Simplified Technical Architecture (*22*).

The automotive industry in Europe (especially in Germany) has made note of WWD crashes and are developing wrong-way warning modules as part of advanced driver assistance systems (ADAS). These systems are designed to have different levels of warning depending upon the situation and vehicle manufacturer. Depending upon the vehicle make and model, the ADAS uses a car's navigation system and accurate road geometry or a camera mounted behind the windshield to recognize road signs (e.g., WRONG WAY) to detect when the vehicle has entered the roadway in the wrong direction and immediately warns the driver of the vehicle using either the navigation display or some other form of display (Figure 24). The warning can be supplemented with an audible signal. If the driver of the vehicle continues driving in the wrong direction, the wrong-way driver information system can also use V2V communications to warn other vehicles when a wrong-way driver is approaching on the same road. Additional tactile warnings, such as vibration of the driver seat and steering wheel, and tightening of the seat belt might also be engaged if the driver continues to drive in the wrong direction. The wrong-way driver's information system can also use V2I communications to send wrong-way vehicle information to a traffic management center (*23*, *24*).

Figure 24. Wrong-Way Warning Display on Navigation System (*23*).

Other examples include a system developed by Continental that recognizes and sends a warning to a driver who is about to enter the highway in the wrong direction (*24*). In 2013, Mercedes-Benz developed a windscreen-mounted camera that detects when a vehicle is about to go in the wrong direction by scanning for no entry signs (*25*). The driver is warned accordingly through acoustics and visuals on the instrument board (Figure 25).

Figure 25. WWD Warning Introduced by Mercedes Benz (*25*).

In 2014, Xing reported on some ITS countermeasures for wrong-way crashes in Japan. General applications included on-board navigation systems, high-tech sensing programs, vehicle safety technologies, and V2I communication (*26*). These countermeasures were found to be effective for older drivers and drivers with dementia—two categories that each made up about 30 percent of the total number of wrong-way crashes in Japan. At that time in Japan, the three main types of ITS technologies being adopted were:

- Roadside wrong-way warning system with different sensors.
- Autonomous WWD alert system using GPS and digital map technology.
- A wrong-way warning system using V2I communications through dedicated short range communications (DSRC).

The efficacy of these technologies was still being studied at the time of the report.

A new ITS-based, wrong-way entry warning system was recently placed at Porter Avenue (Exit 9) along I-190 in Buffalo, New York (*27*). It consists of Doppler radar detection and programmable message LED message boards, which can display various colors, messages, and shapes. Once a wrong-way driver is detected, the driver receives a sequence of messages in the following order: WRONG-WAY, STOP, and PULL OVER. The ITS warning system can send alerts to the TMC, state police, and to other message signs with similar technology. Each sign costs $10,000, and there is an option for the system to be solar powered. Since it was only recently implemented, there are no data on the effectiveness of the system. Figure 26 shows the message signs and warning messages used.

Figure 26. New York Thruway Wrong-Way Entry ITS Warning System (*27*).

In 2014, Haendeler et al. proposed a new passive vehicle detection (PVD) technology to detect driving direction based on roadside radio sensors (*28*). The system contains six radio modules assembled to the existing delineators and uses the radio tomographic imaging (RTI) principle. In the event of WWD, the local and wide area warnings are activated. In the field tests, all of the road users were alerted of the wrong-way driver within 6.65 seconds. Figure 27 shows the technology implementation.

Figure 27. System Architecture of the New Wireless Detection and Warning System for Wrong-Way Drivers (*28*).

SUMMARY

Currently several transportation agencies, including TxDOT, are implementing systems to detect wrong-way vehicles using traditional ITS infrastructure (e.g., cameras, radars, or loop detectors). While some of these systems automatically activate blank-out signs and/or lights to alert the wrong-way driver, the remainder of the process requires a high level of human interaction. TMC personnel must verify the event, monitor the event, continually provide critical information to law enforcement, and use ITS infrastructure, when available, to warn right-way drivers of the potential hazard. Currently, none of the ITS technologies being used allow for automated (without human interaction) tracking of the wrong-way vehicle upon detection, automated dispatch from roadside detection units to emergency vehicles, or automated warning to right-way drivers. It is anticipated that CV WWD applications that use V2I and/or V2V technologies will allow for the automation of these components and thus reduce the need for human interaction with the system.

CHAPTER 3: ANALYSIS OF WWD CRASHES IN TEXAS

As part of a recent Texas A&M Transportation Institute (TTI) study researchers obtained and analyzed the TxDOT-reportable wrong-way crashes on Texas freeways from 2007 to 2011 (*6*). In addition, researchers compared wrong-way crashes by major roadway, county, city, and TxDOT district to identify trends. Researchers also analyzed driver characteristics, including blood alcohol concentration (BAC) levels, for wrong-way crashes. For this project, researchers obtained and analyzed the TxDOT-reportable wrong-way crashes on Texas freeways from 2010 to 2014 to update the general trends and identify potential model field deployment sites for future phases of this project.

DATASET

Researchers obtained the wrong-way crash data from the Crash Records Information System (CRIS). Researchers used the CONTRIB_FACTR_ID variable to identify wrong-way-related crashes. This variable is defined as "the factor for the vehicle, which the officer felt contributed to the crash." The dataset lists up to three contributing factors and up to two possible contributing factors for each crash (up to five overall). A contributing factor code of 69 represents "wrong side—approach or intersection," 70 represents "wrong side—not passing," and 71 represents "wrong-way—one way road." While code 71 best represents wrong-way crashes on freeway, researchers included the other two codes in order to capture all possible wrong-way crashes.

Researchers used the FUNC_SYS_ID to extract wrong-way crashes on freeways (i.e., controlled-access highways). A functional system code of 1 represents rural interstates, 11 represents urban interstates, and 12 represents other urban freeways. Researchers also used the TxDOT reportable flag variable in this dataset (TxDOT_Rptable_Fl = Y) to identify crashes that occur on a roadway and result in injury, death, or at least $1,000 in damage. In summary, to obtain the freeway wrong-way crash database the following CRIS codes were used:

- CONTRIB_FACTR_1_ID = 69, 70, or 71.
- CONTRIB_FACTR_2_ID = 69, 70, or 71.
- CONTRIB_FACTR_3_ID = 69, 70, or 71.
- CONTRIB_FACTR_P1_ID = 69, 70, or 71.

- CONTRIB_FACTR_P2_ID = 69, 70, or 71.
- FUNC_SYS_ID = 1, 11, or 12.
- TxDOT_Rptable_Fl = Y.

Using these codes, researchers identified 1293 wrong-way crashes in the CRIS database. Researchers then used the latitude and longitude data associated with each crash and the Google® Fusion Table tool to create a map that showed the location of each crash. A visual inspection of the crash locations revealed that 106 of the crashes were not on freeway facilities. Therefore, researchers removed these crashes from the dataset; yielding 1187 wrong-way crashes in the final dataset. These TxDOT reportable wrong-way crashes on Texas freeways involved 2551 vehicles and 3726 persons (crashes involved more than one vehicle and person).

The process used by researchers to obtain the crash database in this study was different from the process used in another recent study (*6*). The main difference was that the charge category and road classification variables were not used. Continual refinement and updates to the CRIS database have revealed that the contributing factor and functional system variables are more reliable. The change in variables resulted in slightly different numbers for the wrong-way crashes reported in 2010 and 2011 between the two studies.

RESULTS

General Trends

Researchers then created a heat map (see Figure 28) with the Google® Fusion Table tool to visualize wrong-way crashes on freeways in Texas. This map shows that most wrong-way crashes in Texas occur in urban areas (86 percent). Table 2 contains freeway wrong-way crash statistics from 2010–2014, and Figure 29 shows the trend of total, injury, and fatal wrong-way crashes by year on freeways. These data exhibit typical crash data trends; some years exhibiting increases and some exhibiting decreases. Overall, there was a slight increase (12 percent) in total wrong-way crashes during the study period, but wrong-way crashes still represent less than 1 percent of all traffic crashes on freeways. Fatal wrong-way crashes remained relatively constant at about 30 each year and represented 1 percent of all fatal crashes on freeways.

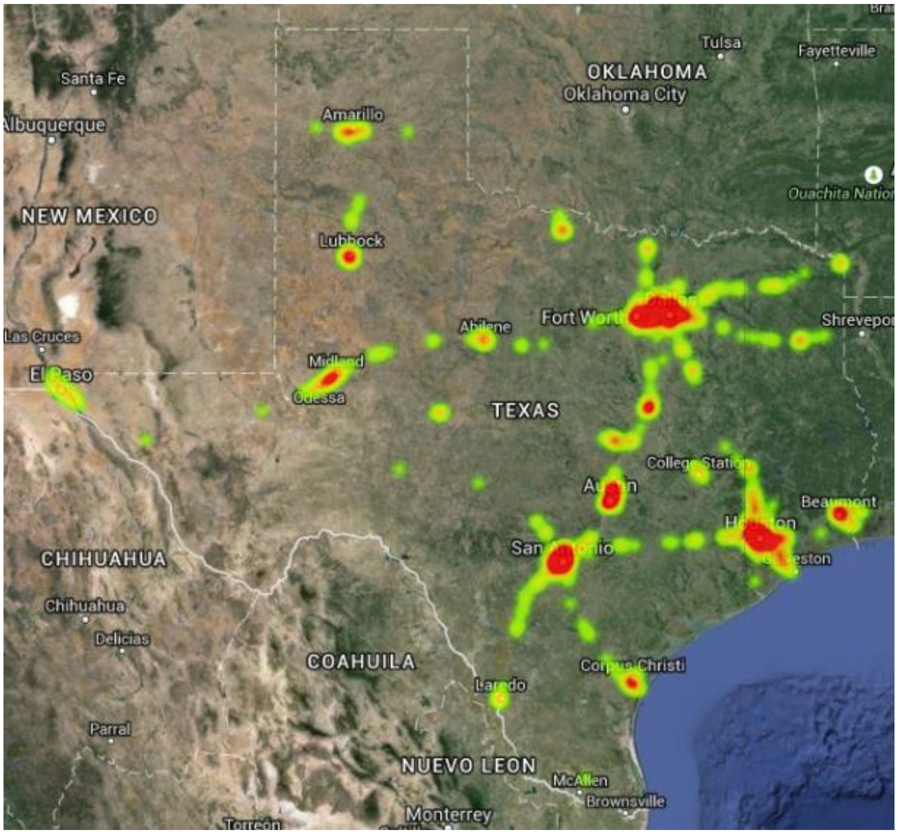


Figure 28. Heat Map of Texas Freeway Wrong-Way Crashes (2010–2014).

Table 2. Freeway Wrong-Way Crashes as a Percentage of All Traffic Crashes, by Severity.

Year	2010	2011	2012	2103	2014	Overall
All Traffic Crashes[1]	392,004	384,439	417,702	445,792	476,466	2,116,403
Freeway Wrong-Way Crashes[2]	226	207	259	243	252	1187
Percent Freeway Wrong-Way Crashes	< 1	< 1	< 1	< 1	< 1	< 1
All KABC Crashes	144,655	142,461	155,337	157,502	161,864	761,819
Freeway Wrong-Way KABC Crashes	131	124	157	141	143	696
Percent Freeway Wrong-Way KABC Crashes	< 1	< 1	< 1	< 1	< 1	< 1
All K Crashes	2781	2803	3037	3055	3154	14,830
Freeway Wrong-Way K Crashes	24	32	26	27	30	139
Percent Freeway Wrong-Way K Crashes	1	1	1	1	1	1

K = killed; A = incapacitating injury; B = non-incapacitating; C = possible injury; O = not injured/property damage only; U= unknown severity.

[1] All crashes included KABCOU on all roadways.

[2] Wrong-way crashes represent those on freeways only.

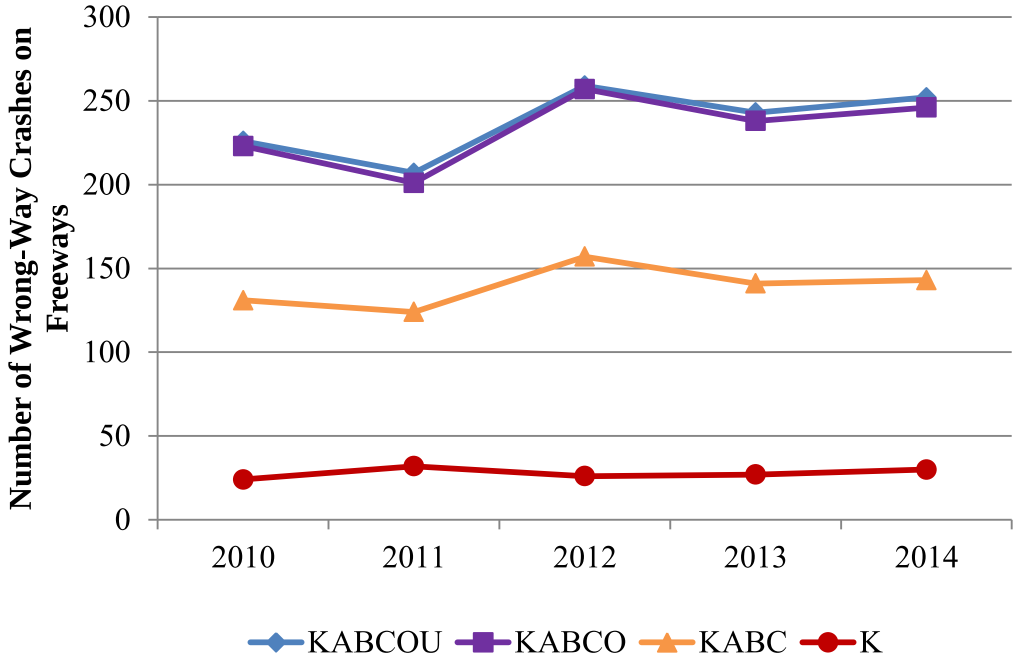


Figure 29. Freeway Wrong-Way Crash Trends (2010–2014).

Roadway and District Trends

In an effort to identify specific roadways and areas where wrong-way crashes are more prevalent, researchers compared wrong-way crashes by roadway and TxDOT district to identify trends. Table 3 lists the top 10 freeways with the highest number of wrong-way crashes. Overall, these 10 freeways represent approximately 56 percent of all wrong-way crashes and 63 percent of all fatal wrong-way crashes in Texas. This table no longer includes US 281. Previous research using crash data from 2007–2011 had shown that US 281 was ranked number eight in the state (*6*). Since March 2012, TxDOT has implemented various WWD countermeasures and detection systems on a portion of US 281 in San Antonio and a 38 percent reduction in WWD events in the corridor has been attributed to these measures (*6*).

Table 4 lists the top 10 TxDOT districts with the highest number of wrong-way crashes. As expected, districts with major metropolitan areas top the list (i.e., Houston, Dallas, San Antonio, Fort Worth, and Austin). Overall, these 10 districts represent approximately 82 percent of all wrong-way crashes and 69 percent of all fatal wrong-way crashes in Texas.

Table 3. Top 10 Freeways with Highest Number of Wrong-Way Crashes (2010–2014).

Highway System	Highway Number	Non-fatal	Fatal	Total	Percent Total Crashes[a]	Percent Fatal Crashes[b]
I	35	130	19	149	13	14
I	20	93	18	111	9	13
I	10	88	16	104	9	11
I	45	86	8	94	8	6
I	30	53	15	68	6	11
I	410	32	3	35	3	2
I	35E	27	1	28	2	1
I	610	24	5	29	2	3
US	290	24	1	25	2	1
US	75	22	2	24	2	1
Total		579	88	667	56	63

I = Interstate; US = United States
[a] Percent computed out of all wrong-way crashes (n = 1187).
[b] Percent computed out of all fatal wrong-way crashes (n = 139).

Table 4. Top 10 TxDOT Districts with Highest Number of Wrong-Way Crashes (2010–2014).

TxDOT District	Non-fatal	Fatal	Total	Percent Total Crashes[a]	Percent Fatal Crashes[b]
Houston	221	28	249	21	20
Dallas	173	15	188	16	11
San Antonio	140	23	163	14	17
Fort Worth	100	9	109	9	6
Austin	65	5	70	6	4
Waco	43	3	46	4	2
Odessa	39	3	42	4	2
Beaumont	38	5	43	4	4
Corpus Christi	26	3	29	2	2
Lubbock	28	1	29	2	1
Total	873	95	968	82	69

[a] Percent computed out of all wrong-way crashes (n = 1187).
[b] Percent computed out of all fatal wrong-way crashes (n = 139).

SUMMARY

Overall, there was a slight increase in total wrong-way crashes from 2010 to 2014 in Texas. However, wrong-way crashes still represent less than 1 percent of all traffic crashes on freeways. The majority of wrong-way crashes on freeways occur in urban areas. As expected, TxDOT districts with major metropolitan areas have the highest occurrence of wrong-way crashes. The research team will use the crash trends presented herein coupled with more detailed crash analysis for the top four districts and information about existing ITS and CV infrastructure, the ATMS used, roadway infrastructure, current and planned construction, and general knowledge of the area to identify potential roadway corridors where a model field deployment of a CV WWD system could be implemented in future phases of this project.

CHAPTER 4: NEEDS ASSESSMENT

In developing any type of advanced system, one of the first steps in the system engineering process is to conduct a needs assessment, which identifies and documents the "gaps" between current conditions and the future desired conditions or "wants" associated with a new system or application. Part of the project planning process, the needs assessment provides the foundation for developing the concept of operations for a CV WWD application for TxDOT.

In conducting a needs assessment for a CV WWD application, the research team performed two distinct activities:

- An assessment of potential CV applications and technologies for use with a WWD system.
- The identification of user needs associated with detecting, warning, and intervening in a WWD event.

The purpose of this technical memorandum is to provide a summary of the findings associated with these activities.

BASIC INFORMATION EXCHANGE MESSAGES USED BY CVS

In developing a CV system, it is important to understand the types of information that can be exchanged by equipped vehicles. The exchange of information is governed by different standards – some standards deal with the physical nature in which data are exchanged, others deal with content of the information that is exchanged. Society of Automotive Engineers (SAE) Standard J2735 *Dedicated Short Range Communications (DSRC) Message Set Dictionary* specifies a message set, and its data frames and data elements specifically for use by CV applications using 5.9 GHz Dedicated Short Range Communications for Wireless Access in Vehicular Environments (DSRC/WAVE, referenced in this document simply as DSRC) communications systems. Although the scope of this standard is focused on DSRC, the message set and its data frames and data elements have been designed, to the extent possible, to be of potential use for applications that may be deployed in conjunction with other wireless communications technologies. The following is a brief description of the message sets that are most applicable to developing a CV WWD application.

Basic Safety Message

The BSM is a fundamental building block of CV applications. The BSM integrates with onboard equipment and provides basic information about the motion and location of the vehicle. BSM data elements are broadcast from the vehicle 10 times per second. It is used in a variety of applications to exchange safety data regarding vehicle state. The BSM contains two parts. Part I is a mandatory part to the BSM (that means that every CV conforming to the standard must provide it). The data elements contained in Part II of the BSM are optional and may not be included by every automobile manufacturer. Part I contains the following information:

- Position of the vehicle – This data frame contains information used to describe the current position of the vehicle and includes the following data elements:
  - Latitude – This data element represents the geographic latitude of an object, expressed in 1/10th integer microdegrees.
  - Longitude – This data element represents the geographic longitude of an object, expressed in 1/10th integer microdegrees.
  - Elevation – This data element represents the geographic position above or below the reference ellipsoid (typically WSG-84), expressed to a resolution of 1 decimeter.
  - Position accuracy – This data element is a 4 octet field of packed data consisting of various parameters of quality used to model the accuracy of the positional determination with respect to each given axis.
- Motion of the vehicle – This data frame contains information used to describe the current motion of the vehicle and include the following data elements:
  - Speed – This data element represents the speed value in unsigned units of 0.02 meters per second combined with a 3 bit element describing the stat of the transmission.
  - Heading – This data element represents the current heading of the sending device, expressed in unsigned units of 0.0125 degrees from North.
  - Angle – This data element represents the rate of change of the angle of the steering wheel, expressed in signed units of 3 degrees/second over a range of 381 degrees in either direction.

    - Acceleration characteristics – This data frame is a set of acceleration values used to describe the longitudinal, lateral, and yaw associated with the vehicle's motion.
    - Status of the braking system – This data frame conveys a variety of information about the current brake and system control activity of the vehicle. Each of the first four bits indicates whether the brakes are active for a given wheel on the vehicle. Other bits are used to indicate the status of the traction control system, the anti-lock brake system, the stability control system, the brake boost system, and the auxiliary brake system.
- Vehicle size characteristics – This data frame contains information used to describe the size of the vehicle. It includes two data elements:
    - Vehicle width – This is a data element that represents the width of the vehicle expressed in centimeters.
    - Vehicle length – This data element represents the length of the vehicle measured from the edge of the front bumper to the edge of the rear bumper expressed in centimeters.

Roadside Alerts

RSA messages are used to send alerts for nearby hazards to travelers. Typically, these messages are used to provide simple alerts to travelers, through both in-vehicle display devices and with portable devices. Generally, these messages are intended to provide warning and alert information about roadway hazards that may affect travel, and not V2V communications, mayday, or other safety applications. Typical example messages would be "bridge icing ahead," "train coming," or "ambulance operating in the area." A full range of typical phrases are supported, but those dealing with mobile hazards, construction zones, and roadside event are the ones that are most frequently expected to be found in use.

Generally, RSA messages are generated by a traffic management entity either at a TMC or by a roadside infrastructure device. In generating an RSA, it is presumed that each receiving device can determine its own position and heading and can determine whether or not the message is applicable to itself, but this is not a requirement to receive or understand these messages. It is also not a requirement of the vehicle (or device) to have any knowledge of the roadway itself to understand and use the message. The typical RSA message contains the following types of information:

- Event type – This is an integer code that equals to a specific type of alert, danger, or hazard identified in the SAE J2450.2 ITS Phrase Lists. This data element is a mandatory component of an RSA message.
- Description – This is a sequence of up to eight additional ITS codes that can be used to further describe the event, give advice to drivers, or recommend a course of action to drivers in response to the event. This data element is a mandatory component of an RSA message.
- Priority – This is a field in the RSA message that is used to describe the urgency of the message, in relative degree of merit compared with other similar messages of this type. This data element is an optional component of an RSA message.
- Heading – This field in the RSA message is optional is intended to provide the heading and direction of travel for which the message is applicable.
- Extent – This field in the RSA message is optional and is intended to provide the spatial distance over which the message application should be presented to the driver.
- Position – This field in the RSA message is optional and intended to provide information about the position, heading, rate of speed, etc., of the event in question. This field can also be used to describe the position information for stationary and wide area events as well.

RSA messages have a rigid content and the standard does not allow free-form text to be used. The basic message types themselves are represented by a standard code sent only in their integer representation formats, which each interval has as specific message (e.g., "accident" has an ITS Phase code of 513, "follow-detour-signs" = ITS Code 8452). SAE J2540.2 contains a complete list of codes that are currently being used to generate an RSA. To promote inoperability, this list of codes is national in scope, and does not allow local additions.

Map Message

The map message is an important message that relates all the other types of potential messages. The map message is used to describe the physical geometry and pathway on which the vehicle can travel. Various types of map messages are sent to the vehicle, depending upon the type of application needing the physical description of the roadway. For example, for traffic signal applications, the map information would contain the information related to an intersection. Likewise, for a curve warning application, the map data would contain information related to the geometry of the curve (centerline points, approach speeds, etc.). For a WWD application, the map data would need to contain the information related to the physical nature of the freeway (e.g., the spline related to the centerline of the roadway, the number of lanes, and the location of entrance and exit ramps).

ASSESSMENT OF POTENTIAL CONNECTED VEHICLE APPLICATIONS AND TECHNOLOGIES

Recent CV research programs funded by the United States Department of Transportation (US DOT) have documented four general types of CV applications: safety, mobility, environmental, and support. To assist agencies with developing and deploying CV applications, the USDOT has developed the Connected Vehicle Reference Implementation Architecture (CVRIA) (*29*). Using the stakeholder involvement, existing connected vehicle documents, concepts of operations, systems requirements, and standards, the CVRIA provides reference implementation architectures for different types of connected vehicle applications. These reference implementation architectures form the basis for integrating CV implementations into the National ITS Architecture and are intended to illustrate the types of data flows and interfaces that will be needed for different types of CV applications. In total, reference implementation architectures have been developed for 83 different CV applications. Table 5 shows the total number of reference implementation architectures developed for each type and group of potential CV applications.

Table 5. CV Application Types and Groups as Defined by US DOT (*29*).

Type	Group	Number of Applications
Environmental	AERIS/Sustainable Travel	15
	Road Weather	6
Mobility	Border	1
	Commercial Vehicle Fleet Operations	2
	Commercial Vehicle Roadside Operations	1
	Freight Advanced Traveler Information Systems	2
	Miscellaneous	1
	Planning and Performance Monitoring	1
	Public Safety	4
	Traffic Network	4
	Traffic Signals	5
	Transit	8
	Traveler Information	3
Safety	Transit Safety	2
	V2I Safety	12
	V2V Safety	11
Support	Core Services	5
	Security	1
	Signal Phase and Timing	1

Shading indicates groups with relevance to WWD.

TTI experts conducted a high-level assessment of the applications listed in Table 6 to rate the relevance of the US DOT applications to WWD. They used the following criteria for rating each application:

- *High* – Those applications whose structure, technologies, or operating concept appeared to have direct relevance to how a WWD application might be developed.
- *Marginal* – Those applications where some part of the application, technology or concept of operation could potentially be used in the design and/or operations of a WWD application.
- *Limited* – Those applications where the research team felt the structure, technologies, or concept of operations had little or no direct relevance to developing a WWD application.

The application groups shaded in Table 5 are those that the research team deemed as having relevance to developing and implementing a wrong-way vehicle application. The following sections summarize the research team's assessment of the applicability of each of the applications listed in Table 6.

Table 6. Applications Examined for Applicability to a WWD Event.

CV Application	Applicability to WWD Application		
	High	Marginal	Limited
Public Safety Mobility Applications			
Advanced Automatic Crash Notification Relay	✓		
Emergency Communication and Evacuation			✓
Incident Scene Pre-arrival Staging Guidance for Emergency Responders			✓
Incident Scene Work Zone Alerts for Drivers and Workers		✓	
V2I Safety Applications			
Curve Speed Warning		✓	
Oversized Vehicle Warning	✓		
Pedestrian in Signalized Crossing			✓
Railroad Crossing Warning			✓
Red Light Violation Warning			✓
Reduced Speed Zone Warning		✓	
Restricted Lane Warning		✓	
Spot Weather Impact Warning	✓		
Stop Sign Gap Assist			✓
Stop Sign Violation Warning			✓
Warnings about Hazards in a Work Zone			✓
Warnings about Upcoming Work Zone		✓	
V2V Safety Applications			
Blind Spot Warning + Lane Change Warning			✓
Control Loss Warning			✓
Do Not Pass Warning		✓	
Emergency Electronic Brake Light			✓
Emergency Vehicle Alert		✓	
Forward Collision Warning		✓	
Intersection Movement Assist			✓
Pre-crash Actions		✓	
Situational Awareness		✓	
Tailgating Advisory			✓
Vehicle Emergency Response		✓	

Public Safety Mobility Applications

Within the Public Safety Mobility group, four applications were identified by US DOT as being potential near-term applications to support public safety agencies, such as law enforcement, emergency medical services, fire, and others. These applications would be installed in public safety vehicles and are intended to assist these agencies in performing several of their critical transportation functions.

Advanced Automatic Crash Notification Relay

Application Group: *Public Safety Mobility*

Description: Formerly known as "Mayday Request," this application provides the capability for a vehicle to automatically transmit an emergency message when the vehicle has been involved in a crash or other distress situation. An automatic crash notification feature transmits key data on the crash recorded by sensors in the vehicle (e.g., deployment of airbags) without the need for involvement by the driver. The emergency message is broadcast to passing vehicles that are equipped with the appropriate communication hardware, which can then relay the message to other vehicles, as well as roadside "hotspots" (i.e., roadside equipment). Once received by an emergency response organization (either through emergency vehicles or through the roadside equipment), the appropriate response to the vehicle situation is executed. This application allows a vehicle to forward mayday requests even in areas where no V2I capabilities exists.

Applicability to WWD: *High* – This application shows the potential for using other CVs to forward or "spread the word" about an event (in this case a collision) to an emergency service provider. A similar concept of using other CVs as the communication pathway to notify law enforcement and transportation entities could be employed to provide notification and alerts of potential WWD events.

Emergency Communications and Evacuations

Application Group: *Public Safety Mobility*

Description: The emergency communications and evacuation (EVAC) application contains multiple functions to support the efficient evacuation of special-needs and non-special-needs evacuees within a jurisdiction, as well as provide real-time communication on evacuation instructions and routing guidance that accounts for current road and traffic conditions. This application integrates several existing emergency communication and evacuation functions including mass warning and notification, computer-aided dispatch/automated vehicle location, traffic information, etc.

Applicability to WWD: *Limited*

Incident Scene Pre-Arrival Staging Guidance for Emergency Responders

Application Group: *Public Safety Mobility*

Description: This application provides situational awareness to and coordination among emergency responders upon dispatch, while en-route to establish incident scene work zones, upon initial arrival and staging of assets, and afterward if circumstances require additional dispatch and staging. The application collects a variety of data from emergency, traffic, and maintenance centers. The application includes a vehicle and equipment staging function that supplies the en-route responders with additional information about the scene of an incident that they can use to determine where to stage personnel and equipment prior to their arrival on-scene. The application also includes a dynamic routing function that provides emergency responders with real-time navigational instructions to travel from their base to their incident scene, accounting for traffic conditions, road closures, and snowplow reports if needed. In addition, the application includes emergency responder status reporting—the function which continuously monitors the location of the en-route responders—as well as vehicles already on-scene. The function develops and maintains the current position of the responder's vehicle and provides updates for estimating time of arrival (ETA) to other applications.

Applicability to WWD: *Limited*

Incident Scene Work Zone Alerts for Drivers and Workers

Application Group: *Public Safety Mobility*

Description: This application employs communication technologies to provide warnings and alerts associated with incident zone operations. In-vehicle messaging could be used to provide drivers with merging and speed guidance information around an incident. Another aspect of this application would provide in-vehicle scene alerts to drivers, both for the protection of the drivers as well as the incident zone personnel. This application would also provide alerts using an infrastructure-based warning system for on-scene workers as the vehicle approaches the scene.

Applicability to WWD: *Marginal* – This application could be used to provide warning alerts associated with wrong-way events that have terminated or resulted in a crash.

V2I Safety Group

V2I safety applications involve the wireless exchange of critical safety and operational data between vehicles and roadway infrastructure, intended primarily to avoid motor vehicle crashes. US DOT has identified twelve potential near-term V2I safety applications. The following provides a high-level assessment of the applicability of the concepts used in these applications to address a potential WWD event.

Curve Speed Warning

Application Group: *V2I Safety*

Description: This application allows a CV to receive information as it is approaching a curve along with the recommended speed for the curve. The application would provide the driver with a warning or alert regarding the curve and its recommended speed. In addition, the vehicle can provide additional warning actions if the actual speed through the curve exceeds the recommended speed.

Applicability to WWD: *Marginal* – A similar concept could be used to alert drivers that they are potentially entering the roadway in the wrong direction. The vehicle would need to have an understanding of the ramp/roadway geometries and then relate the direction of travel of the CV to the intended direction of travel of the roadway geometrics.

Oversized Vehicle Warning

Application Group: *V2I Safety*

Description: The oversized vehicle warning (OVW) application uses external measurements taken by roadside infrastructure, and transmitted by the vehicle, to support in-vehicle determination of whether an alert/warning is necessary. In this application, specific infrastructure equipment is used to detect and measure the height and width of approaching vehicles. The infrastructure component of the application transmits the vehicle measurements, along with bridge, overpass, or tunnel geometry to the OVW vehicle application. The vehicle application utilizes these data to determine whether or not the vehicle can clear the bridge or tunnel. If deemed necessary, the driver is alerted to the impending low height and/or narrow horizontal clearance upstream of a decision point, enabling the vehicle to reroute and avoid a collision. If the vehicle driver ignores the alert and continues along the route, the vehicle will generate a warning indicating an impending collision at a point near the bridge or tunnel approach. To support unequipped vehicles, the infrastructure will display warning or reroute information when the measurements indicate that a vehicle does not have adequate height or width clearance. This application could be expanded to consider overweight vehicles as well.

Applicability to WWD: *High* – This application concept could be directly applied to the issue of WWD detection and management. Like with an OVW application, external measurement taken by infrastructure devices and information transmitted by the CV could be used to detect a WWD vehicle. Messages could be issued to other CVs upstream of the potential wrong-way vehicle to warn them and recommend an appropriate course of action. Warning alerts could also be issued to the CV if it is the vehicle traveling in the wrong direction. Infrastructure devices could also display warnings or rerouting information to unequipped vehicles.

Pedestrian in Signalized Crosswalk Warning

Application Group: *V2I Safety*

Description: This application provides information from infrastructure devices indicating the possible presence of pedestrians in a crosswalk at a signalized intersection. The infrastructure-based indication could include inputs of pedestrian sensors or simply an indication that the pedestrian call button has been activated. This application has been defined for transit vehicles, but can be applicable to any class of vehicle.

Applicability to WWD: *Limited*

Railroad Crossing Warning

Application Group: *V2I Safety*

Description: This application provides alerts and/or warning information to drivers who are approaching an at-grade railroad crossing if they are on a crash-imminent trajectory to collide with a crossing or approaching train. This application involves the integration of both vehicle-based and infrastructure-based technologies. The roadside equipment (RSE) sends detailed geometric information about the intersection, as well as information about whether a train is approaching or blocking the intersection. The geometric information could be obtained from an RSE at the intersection or obtained from an RSE at some earlier point in the vehicle's trip. The information about the approach or presence of a train would be obtained from the infrastructure via a connection between the rail infrastructure and the RSE. The information received from the RSE at the intersection could be augmented with road surface information or other weather-related data.

Applicability to WWD: *Limited*

Red Light Violation Warning

Application Group: *V2I Safety*

Description: This application enables a CV approaching an instrumented signalized intersection to determine if it appears likely that the vehicle will enter the intersection during a red signal indication. The application, located on the vehicle, would use the speed and acceleration profile, along with the signal timing and geometry of an intersection to determine if the red indication would be active when the vehicle arrived at the intersection. If the vehicle determines that it is likely to enter the intersection on red, a warning is provided to the driver through an onboard device. Another usage of this application might be at a railroad crossing where the vehicle would enter the crossing when the railroad crossing gates have been activated.

Applicability to WWD: *Limited*

Reduced Speed Zone Warning

Application Group: *V2I Safety*

Description: This application provides CVs that are approaching a reduced speed zone with information on the zone's posted speed limit and/or if the configuration of the roadway is altered (e.g., lane closures and lane shifts). The application, which is embedded in the vehicle, uses information about revised speed limits along with information about applicable roadway configuration changes to determine whether to provide an alert or warning to the driver. To provide warnings to non-equipped vehicles, infrastructure equipment would measure the speed of approaching vehicles and if greater than the posted reduced speed, provide warnings on infrastructure-based signs.

Applicability to WWD: *Marginal* – This application targets both equipped and non-equipped vehicles in the same application. The application uses both on-board equipment and infrastructure-based equipment to notify both equipped and non-equipped of a change in travel conditions or approaching hazard.

Restricted Lane Warning

Application Group: *V2I Safety*

Description: This application provides the CV with restriction information about the travel lanes, such as if the lane is restricted to HOV, transit, or public safety vehicles only, or has defined eco-lane criteria. The CV can use this information to determine if the vehicle is in a lane that has lane restrictions.

Applicability to WWD: *Marginal* – An application developer might use a similar concept to determine if the CV is traveling in the wrong direction. Information about the appropriate direction of travel would need to be communicated to the vehicle, which could then determine if it is traveling the wrong direction.

Spot Weather Impact Warning

Application Group: *V2I Safety*

Description: The spot weather impact warning (SWIW) application is intended to provide alerts to drivers concerning the presence of unsafe weather conditions at specific points downstream of the vehicle's current location. These conditions may include high winds, flooding, ice, or fog. The application uses a standalone road weather information system to warn drivers about inclement weather conditions that may impact travel. Real-time weather information is collected via a weather/roadway condition monitoring system or via vehicle-based sensor data. The information is processed to determine the nature of the alert or warning that is communicated to the CVs. For non-equipped vehicles, the alerts or warnings are provided via roadway signage. In addition, the roadway equipment may calculate the appropriate speed for current weather conditions and provide this information directly to the CV or via roadway signage.

Applicability to WWD: *High* – This application would serve as a model for developing a WWD application. A standalone external detection system could be used to detect the potential of a WWD event. The vehicle could process alerts issued by the infrastructure to warn approaching CVs about a potential wrong-way event. Non-equipped vehicles would receive alerts or warning via roadside information devices.

Stop Sign Gap Assist

Application Group: *V2I Safety*

Description: This application is intended to improve safety at non-signalized intersections where only the minor road has posted stop signs. This application includes both onboard (for CVs) and roadside signage warning systems (for non-equipped vehicles). The application will help drivers on a minor road stopped at an intersection understand the state of activities associated with the intersection by providing a warning of unsafe gaps on the major road. The application collects data from available sensors and computes the dynamic state of the intersection in order to issue appropriate warnings and alerts.

Applicability to WWD: *Limited*

Stop Sign Violation Warning

Application Group: *V2I Safety*

Description: This application is intended to improve safety at unsignalized intersections with posted stop signs. The application warns approaching drivers that they may violate an upcoming stop sign based on their current speeds and distance to the stop sign. The application in the vehicle would need to have detailed information about the geometry of the intersection.

Applicability to WWD: *Limited*

Warnings about Hazards in a Work Zone

Application Group: *V2I Safety*

Description: This application is intended to provide warnings to maintenance personnel within a work zone about potential hazards. The application would enable vehicle or the infrastructure to provide warnings to workers about vehicle movements that might create an unsafe condition (e.g., a vehicle moving at a high rate of speed or entering the work area).

Applicability to WWD: *Limited*

Warnings about Upcoming Work Zone

Application Group: *V2I Safety*

Description: This application is intended to provide information to CVs about conditions that exist in an upcoming work zone. The application provides approaching vehicles with information about work zone activities that may result in unsafe conditions to the vehicle, such as obstructions in the vehicle travel lanes, lane closures, lane shifts, speed reductions, or vehicle entering/exiting the work zone.

Applicability to WWD: *Marginal* – A similar concept could be applied to WWD events. The application would provide alerts to CVs of a potential WWD event downstream of the current position of the vehicle. WWD alerts could potentially include information about which lanes are closed (due to the wrong-way event), potential speed reductions, or other actions to be taken in response to a wrong-way event.

Vehicle-to-Vehicle Safety Applications

In addition to V2I applications, V2V safety applications could potentially be applied to WWD events. These applications rely on the direct exchange of information between vehicles with little or no involvement from the infrastructure. It should be noted that these applications are mostly likely going to be developed by original equipment manufacturers (OEMs) and/or after-market providers, and not likely the state departments of transportation, like TxDOT.

Blind Spot Warning and Lane Change Warning

Application Group: *V2V Safety*

Description: This application is intended to warn the driver of a vehicle during a lane change attempt if the blind-spot zone into which the vehicle intends to switch is, or will soon be, occupied by another vehicle traveling in the same direction. The application would provide advisory information that is intended to inform the driver that another vehicle in an adjacent lane is positioned in a blind-spot zone of the vehicle even if a lane change is not being attempted.

Applicability to WWD: *Limited*

Control Loss Warning

Application Group: *V2V Safety*

Description: This application enables a vehicle to broadcast a self-generated, control loss event to surrounding vehicles. Upon receiving control loss event information, the receiving vehicle determines the relevance of the event and provides a warning to the driver, if appropriate.

Applicability to WWD: *Limited*

Do Not Pass Warning

Application Group: *V2V Safety*

Description: This application is intended to warn the driver of a vehicle during a passing maneuver attempt when a slower moving vehicle, ahead and in the same lane, cannot be safely passed using a passing zone which is occupied by a vehicle in the opposite direction of travel. In addition, the application provides advisory information that is intended to inform the driver of the vehicle that the passing zone is occupied when a vehicle is ahead and in the same lane even if a passing maneuver is not being attempted.

Applicability to WWD: *Marginal* – In a passing maneuver, a vehicle could be considered a WWD vehicle as it is traveling the wrong direction in a lane. While the scope of this project is to develop an application for divided roadways where travel in the opposing is not permitted, the final application will need to be able to distinguish between a passing maneuver and a WWD maneuver if it is to be deployed on undivided roadways or in situation where the vehicle must travel on both types of facilities.

Emergency Electronic Brake Light

Application Group: *V2V Safety*

Description: This application enables a CV to broadcast a self-generated emergency brake event to surrounding vehicles. Upon receiving the event information, the receiving vehicle determines the relevance of the event and, if appropriate, provides a warning to the driver in order to avoid a crash. This application is particularly useful when the driver's line of sight is obstructed by other vehicle or bad weather conditions (e.g., fog or heavy rain).

Applicability to WWD: *Limited*

Emergency Vehicle Alert

Application Group: *V2V Safety*

Description: This application provides drivers with alerts regarding the location of and the movement of public safety vehicles responding to an incident. These alerts are intended to provide warning alerts so the driver does not interfere with the emergency response. This application is expected to receive information about the location and status of nearby emergency vehicles responding to incident.

Applicability to WWD: *Marginal* – This application might also provide alerts associated with emergency vehicles responding to a WWD event. This application would provide information about when emergency vehicles are trying to respond to, intercept, and detain a wrong-way driver.

Forward Collision Warning

Application Group: *V2V Safety*

Description: A forward collision warning application is intended to warn the driver of the vehicle in case of an impending rear-end collision with another vehicle ahead in traffic in the same lane and direction of travel. The application uses data received from other vehicles to determine if a forward collision is imminent. The application is expected to advise drivers to take specific action in order to avoid or mitigate rear-end vehicle collisions in the forward path of travel.

Applicability to WWD: *Marginal* – One would expect that a forward collision warning system would be activated in WWD events, especially if a crash is imminent. A test case should be developed that would explore the alerts provided by a forward collision warning applications during a wrong-way event. Note that the time-to-collision algorithms for these systems generally assume a stationary or moving-in-same-direction object in determining the time to collision. It is unknown at this time how the fast closing speed of a WWD may impact how forward collision systems will behave.

Intersection Movement Assist

Application Group: *V2V Safety*

Description: The intersection movement assist application warns the driver of a vehicle when it is not safe to enter an intersection due to high collision probability with other vehicles at stop sign controlled and uncontrolled intersections. This application can provide warning information to vehicle operational systems which may perform actions to reduce the likelihood of crashes at the intersection.

Applicability to WWD: *Limited*

Pre-Crash Actions

Application Group: *V2V Safety*

Description: This application enables a vehicle to mitigate the injuries in a crash by activating countermeasures in the vehicle when a crash is about to happen. This application uses information from a forward collision warning application to determine that a crash is imminent, activating countermeasures that could include air bag pre-arming, pyrotechnic, and non-pyrotechnic seat belt pre-tensioning, bumper extension or lowering, and emergency brake assist.

Applicability to WWD: *Marginal* – This application has the potential to reduce the severity of crashes associated with a WWD event. This application would most likely activate just immediate to a collision, but it would not reduce the likelihood or prevent a WWD crash from occurring.

Situational Awareness

Application Group: *V2V Safety*

Description: This application would determine if road conditions measured by other vehicles represents potential safety hazard for vehicles containing the application. This application requires that other vehicles broadcast relevant road condition information. The application supports the capability for CVs to share situational awareness information even in areas where no roadside communication infrastructure exists.

Applicability to WWD: *Marginal* – This application can be useful to vehicles that are not fully equipped with sensors, and do not have the capability of providing alerts back to motorist in their vehicles. Vehicles equipped with situational awareness applications could be used to assist in detecting potential wrong-way vehicles.

Tailgating Advisory

Application Group: *V2V Safety*

Description: This application uses information from other vehicles to determine if the vehicle is too close to another vehicle in front of it. This feature enables the host vehicle to warn the driver if the vehicle is following another vehicle too closely, creating an unsafe driving condition.

Applicability to WWD: *Limited*

Vehicle Emergency Response

Application Group: *V2V Safety*

Description: This application provides public safety vehicles with information from a CV involved in a crash. Emergency responders need information about the vehicle involved in a crash to respond safely and effectively to the vehicle crash. Information about air bag activations can provide useful input to ambulance personnel. In addition, information about the power system of the vehicle (e.g., hybrid, electric, or internal combustion engine) can affect the response.

Applicability to WWD: *Marginal* – This application would most likely be activated if a wrong-way event ended in a collision. This application would not likely prevent a wrong-way event/crash from occurring.

ASSESSMENT OF USER NEEDS FOR PRIORITY WRONG-WAY APPLICATIONS

One of the first steps in developing any new system or application is to conduct an assessment of the user needs. A needs assessment includes identifying potential stakeholders who will own, operate, maintain, use, interface with, benefit from, or otherwise be affected by the system, eliciting their needs, desires, and constraints for the system, and consolidating those needs into a document which can then be used in the development of a concept of operations.

Identification of Stakeholders

In developing user needs, the research team identified three primary stakeholders to be considered in developing a wrong-way vehicle application. The roles and responsibilities of these stakeholders during WWD events are discussed below.

Traffic Management Entity

The traffic management entity (TME) stakeholder is the agency generally responsible for operating and maintaining the roadway facilities. TMEs are generally state or local department of transportation, or mobility authorities responsible for operating toll road facilities. Generally, a TME is responsible for deploying, operating, and maintaining traffic detection and traveler information infrastructure. A TME generally operates their facilities through a TMC. For the purposes of this project, a TME is assumed to already have a traffic management capabilities and infrastructure already in place, and is responsible for installing and operating roadside equipment that can communicate and extract data from CVs.

Emergency Service Provider

Emergency service providers (ESPs) are another critical stakeholder group that will be impacted by the development of a CV WWD Detection and Management System. This stakeholder group consists primarily of law enforcement agencies, since they are generally considered to be first responders to WWD events. Their primary mission is to intercept and stop a WWD vehicle, and they are responsible for other law enforcement activities that occur after the vehicle has been stopped (e.g., issuing citations, conducting field sobriety tests, apprehending violators, or conducting collision investigations). Examples of typical ESPs include the following:

- County or municipal law enforcement agencies.
- Texas Department of Public Safety (DPS).
- Contract law enforcement agencies used by toll road operators.
- Fire departments and other emergency medical services providers.

Motorists

Two subcategories of motorists are assumed for this project: vehicles with and without CV technology. A CV-equipped vehicle includes technology that allows the vehicle to communicate and share data with surrounding CV-equipped vehicles and infrastructure and potentially with personal communication devices within the vehicle. CV technology enables a vehicle to monitor and share data regarding its location, speed, heading, recent path history, and a variety of event-specific alerts.

Using location information along with underlying map data, CV technology can determine if a vehicle is traveling in the wrong direction and provide a warning message. CV-equipped right-way vehicles can also receive warning messages related to the wrong-way vehicle using V2V communication methods. Warning messages may be communicated to wrong-way and right-way drivers using graphical, auditory, or tactile technology. These alerts can also be sent to nearby CV-equipped infrastructure devices using V2I communication methods.

A non-CV driver is one that operates a vehicle without CV technology. This type of vehicle would not have any means of alerting the driver regarding a potential wrong-way maneuver or the danger related to an approaching wrong-way driver. These drivers must receive warnings or notifications through external traveler information system (e.g., DMS, lights on signs, and blank-out signs). For a non-CV to provide data to the system, it must be detected through infrastructure-based traffic detection systems.

Current WWD Response Protocols

The following section provides a general description of the current response protocols by stakeholders in response to a WWD event. This is intended to represents the highest level of response currently performed by TMEs. The response protocol is divided into the following functional areas:

- Detection of the presence of wrong-way vehicle and event.
- Verification and monitoring of such an event or presence of the vehicle.
- Notification to concerned entities.
- Alerting right-way drivers.
- Clearing the event.

Depending on the protocols used by the agencies in different regions of the state and the severity and scope of the events, these steps may significantly overlap and have been differentiated and described to generalize the WWD event response. The activities associated with managing a WWD event using the above-mentioned functional steps are provided below.

Detection of Wrong-Way Vehicle

Currently, an operator in a TMC may detect a potential WWD event or the presence of a wrong-way vehicle by one of the following detection methods:

- Receive a communication from 911 dispatch/law enforcement in TMC or directly from concerned motorists in the area.
- Visually observing a vehicle traveling in the wrong direction using a video surveillance system.
- Receiving an alarm issued by technology and systems designed specifically to detect potential wrong-way vehicles.

Currently, most wrong-way vehicles are detected via law enforcement agencies receiving alerts from motorists who use their cell phone to report the wrong-way driver through their 911/dispatching centers. Upon receiving a call, most ESP centers will immediately dispatch patrols to intercept and stop the wrong-way vehicle. As the event continues dispatchers will often receive additional calls about the event and they will relay information such as the location of the vehicle and physical description of the vehicle to patrol officers in the field.

In August 2010, the San Antonio Police Department (SAPD) began to use an emergency call signal (i.e., E-Tone) for its radio network when a wrong-way driver was reported to 911. In January 2011, SAPD implemented a code in their computer-aided dispatch (CAD) system that specifically identified all wrong-way driver events. Similarly, in March 2011, TxDOT TransGuide TMC operators began logging all WWD events, not just those that resulted in a crash. Data from these records between 2011 and 2013 show that the majority of WWD events are reported between midnight and 5:00 a.m. (68 percent) with a peak at 2:00 a.m. (the typical time for establishments that serve alcohol to close in Texas) (Figure 30). The average duration of a WWD event based on multiple calls to 911 was about 4 minutes, but 61 percent lasted less than or equal to 2 minutes. On average, the wrong-way driver traveled 2.4 miles and ranged from less than 1 mile to 13 miles. Overall, these data show that WWD events occur quickly, limiting the amount of time TMC personnel and ESPs have to receive and exchange information as well as respond to the event. ITS and CV technologies provide new opportunities to improve the efficiency and accuracy of the detection and notification.

Verification and Monitoring

After the ESPs have been notified that a potential wrong-way vehicle has been detected and the initial response implemented, the TME needs to verify that the event is real and provide updates to emergency responders as to the current location of the wrong-way vehicle. A TME will confirm that a WWD event is occurring and continue to monitor the event through one or more of the following ways:

- An operator in the TMC visually observes the wrong-way vehicle using the detection and surveillance equipment.
- A second alarm is issued by an upstream detection station.

- The event is confirmed by an ESP after receiving reports from officers in the field and/or multiple calls to the 911 center.

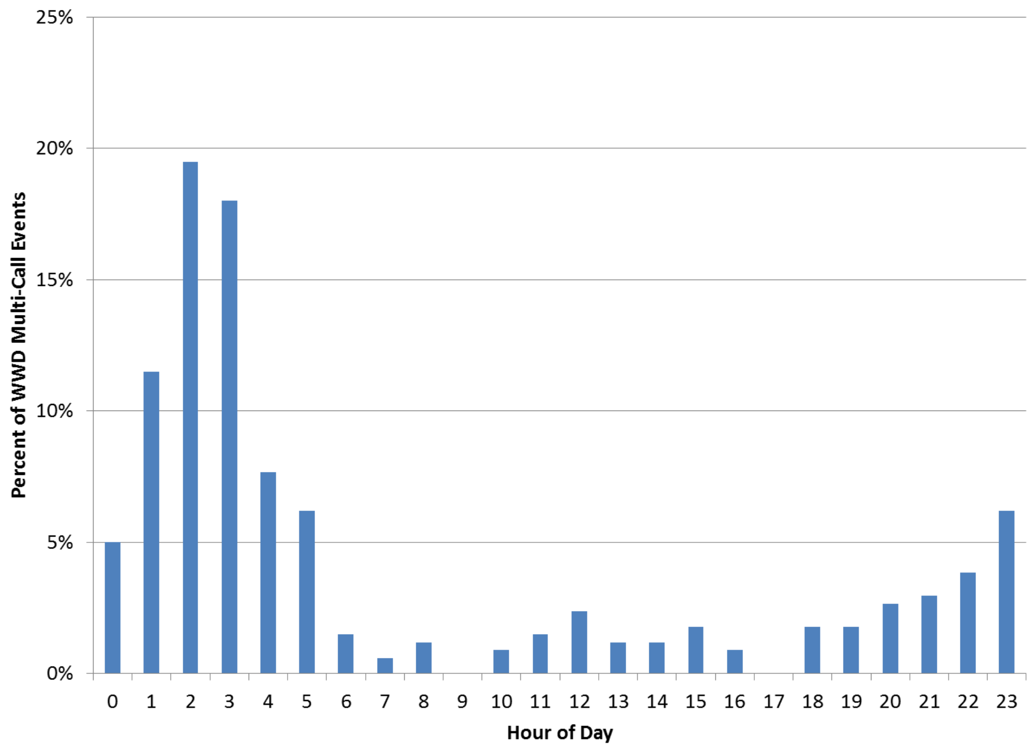


Figure 30. SAPD 911 WWD Multi-Call Events by Hour (2011–2013).

Notifications to Concerned Entities

If the TME is the first agency to detect a potential WWD event, the next step in the process is to notify other stakeholders, especially the ESPs, of a possible WWD event. In notifying the other stakeholders, the TME needs to provide sufficient information to allow these stakeholders to initiate a response. This includes providing information about the roadway on which the event was detected, the location where the potential event was detected, and any other information that might be useful to the ESP to intercept the wrong-way vehicle.

As mentioned previously, most wrong-way vehicles are currently detected by right-way drivers who use their cell phone to call 911. In urban areas, law enforcement agencies typically have an officer located at the TMC. When that officer receives information from the dispatch center, they share it with TME personnel.

Alerting Right-Way Drivers

Once a wrong-way vehicle has been detected, the TME will provide warnings to oncoming vehicles that a wrong-way vehicle may be in the vicinity. Because of the potential severity of a wrong-way vehicle colliding with another vehicle, a TME will generally issue warnings associated with WWD events before verifying the event. A TME uses existing traffic management devices, such as DMSs, to alert oncoming vehicles of the presence of a WWD event. Generally a TME has pre-programmed these devices in a response plan. An operator in a TMC is generally responsible for activating a response plan when a WWD event is either detected by sensors or reported by an ESP. Each response plan is included with the traffic management devices that are used to provide the response.

Clearing the Event

A WWD event ends when one of the following actions occurs:

- The wrong-way vehicle is stopped by an ESP.
- A collision occurs between the wrong-way vehicle and another vehicle or the infrastructure.
- The wrong-way driver corrects its path and continues in the appropriate direction.
- The wrong-way vehicle cannot be located.

Only an ESP can terminate a WWD event; therefore, the TME must continue to provide warning information until the event is declared over by an ESP. If the ESP reports that the wrong-way vehicle has been stopped or that a collision has occurred, the TME should discontinue providing wrong-way event alerts and manage the event as an incident (i.e., providing incident alert messages). If the ESP reports that the wrong-way vehicle cannot be located, is no longer on the freeway, or is otherwise declared over by the ESP, the TME will then cease providing wrong-way alerts messages and return DMSs and other traveler information systems to their normal operations.

Impacts of CVs on WWD Events

CV technologies are expected to provide another means of detecting WWD events. Two cases exist where a CV could be used to assist in the detection process. The first case is the situation in which the CV is the vehicle traveling in the wrong direction. In this situation, a TME could use the information contained in the BSM to detect and locate the CV traveling in the wrong direction. This would require the TME to have infrastructure in place to receive, process, and analyze the BSM data from the CV.

The other situation would be a CV traveling in the appropriate direction issuing an alert notifying other CVs that it has encountered a vehicle traveling in the wrong direction. An OEM or secondary equipment provider could develop an application that might use the collision avoidance systems or other technologies in the vehicle to detect and alert the driver of the potential WWD event. The first CVs to encounter the wrong-way vehicle could then broadcast an alert to other CVs to warn them of the hazard. The TME could also potentially receive the alerts through RSUs.

Not only would a TME need to receive information from CVs, but the TME also needs to be able to broadcast RSA messages to CVs. These messages would be received and processed by CVs traveling in the corridor to generate potential alert displays in the vehicle. OEMs and after-market equipment providers would be responsible for developing applications that would display the alert to drivers in their vehicles. The application in the vehicle would have to determine for itself if the alert was appropriate to be displayed based on its current position and the relative location of the WWD vehicle and to configure the alert display. The TME would be responsible for developing the content of the alert messages and for broadcasting (and deactivating) when appropriate.

User Needs

Based on the identified roles and responsibilities of the different stakeholders, the research team identified the following user needs associated with developing a CV WWD Detection and Management System for TxDOT. Table 7 shows the initial set of user needs that a WWD system should address. User needs deemed mandatory by the research team are shaded in this table.

Table 7. User Needs Associated with a CV WWD Application.

Number	Description of Need	Importance
1.	A TME needs to be able to **detect vehicl**es that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	**Mandatory**
1.1.	The TME needs to **detect a wrong-way vehicle** within a user defined level of certainty (e.g., 95 percent level).	**Mandatory**
1.2.	A TME needs to **determine the location** at which the wrong-way vehicle was detected entering the facility.	**Mandatory**
1.2.1.	The TME needs to be able to identify the **name of the route/roadway** on which the wrong-way vehicle is traveling.	**Mandatory**
1.2.2.	The TME needs to be able to identify the **name of the nearest cross-street** at which the wrong-way vehicle was detected.	**Mandatory**
1.2.3.	The TME needs to be able to identify the **mile marker reference** point of the location at which the wrong-way vehicle was detected.	Optional
1.2.4.	The TME needs to be able to identify the **latitude/longitude** of the location at which the wrong-way vehicle was detected.	Optional
1.3.	The TME needs to be able to **provide a description of the wrong-way vehicle.**	Optional
1.3.1.	The TME needs to be able to obtain the **make** of the wrong-way vehicle.	Optional
1.3.2.	The TME needs to be able to obtain the **model** of the wrong-way vehicle.	Optional
1.3.3.	The TME needs to be able to obtain the **color** of the wrong-way vehicle.	Optional
1.3.4.	The TME needs to be able to obtain the **license plate** of the wrong-way vehicle.	Optional
1.3.5.	The TME needs to be able to obtain the **vehicle identification number** of the wrong-way vehicle.	Optional
1.4.	The TME needs to be able to **update the current location** of the wrong-way vehicle as it travels upstream of the detection point at a user defined frequency.	**Mandatory**
1.4.1.	The TME needs to **update** the **name of the route/roadway** on which the wrong-way vehicle is traveling.	**Mandatory**
1.4.2.	The TME needs to **update** the **name of the last cross-street** at which the wrong-way vehicle was detected.	**Mandatory**
1.4.3.	The TME needs to **update** the **time of the latest update** of the location of the wrong-way vehicle.	**Mandatory**
1.4.4.	The TME needs to **update** the **mile marker reference point** of the location at which the wrong-way vehicle was last reported.	Optional
1.4.5.	The TME needs to **update** the **latitude/longitude** of the location at which the wrong-way vehicle was last detected.	Optional
1.5.	The TME needs to be able to **estimate the arrival time** of the wrong-way vehicle at access points upstream of the current position of the vehicle.	Optional

Number	Description of Need	Importance
1.6.	The TME needs to be able to **receive alerts** of potential wrong-way vehicles from other stakeholders.	**Mandatory**
1.6.1.	The TME needs to be able to **receive alerts** of potential WWD events **from ESPs**.	Optional
1.6.2.	The TME needs to be able to **receive alerts** of potential WWD events **from CVs**.	Optional
1.6.3.	The TME needs to be able to **detect** WWD events using **data from CVs.**	**Mandatory**
1.6.4.	The TME needs to be able to **receive data elements from BSMs** from CVs.	**Mandatory**
1.6.5.	The TME needs to be able to **process data elements from BSM**s to detect when a CV is traveling the wrong-way on a roadway	**Mandatory**
2.	The TME needs to be able to **issue notifications** throughout the duration of a WWD event.	**Mandatory**
2.1.	The TME needs to **notify other stakeholders** when a wrong-way vehicle is detected entering the freeway.	**Mandatory**
2.1.1.	The TME needs to **notify ESPs** when a wrong-way vehicle has been detected.	**Mandatory**
2.1.2.	The TME needs to **notify other TMEs** of when a wrong-way vehicle has been detected on a facility.	**Mandatory**
2.1.3.	The TME needs to **notify the Public Information Officer (PIO)** when a wrong-way vehicle has been detected on a facility.	**Mandatory**
2.2.	The TME needs to **issue an alert/notification** immediately upon detection of a potential WWD event.	**Mandatory**
2.2.1.	The TME needs to include information about the **location** of the wrong-way vehicle on the facility.	**Mandatory**
2.2.2.	The TME needs to include a **description** of the wrong-way vehicle on the facility.	Optional
2.2.3.	The TME needs to include the **estimate arrival time** of the wrong-way vehicle at points upstream of its current position.	Optional
2.3.	The TME needs to be able to **update the information** contained in a WWD alert/notification.	**Mandatory**
2.3.1.	The TME needs to be able to **update the initial alert/notification** when the event is verified.	**Mandatory**
2.3.2.	The TME needs to be able to **update an alert/notification** when the location of the wrong-way vehicle is updated.	**Mandatory**
2.4.	The TME needs to be able to assign a **time-to-live value** to each notification.	**Mandatory**
2.5.	The TME needs to be able to issue a notification when a wrong-way event has **concluded**.	**Mandatory**
2.6.	The **TME** needs to be able to **receive notification** of WWD events from other stakeholders (e.g., law enforcement).	**Mandatory**
2.7.	The **ESP** must be able to **provide notifications** of WWD events to the TME.	**Mandatory**

Number	Description of Need	Importance
2.7.1.	The ESP notification needs to identify **the name of the route/roadway** on which the wrong-way vehicle is traveling.	**Mandatory**
2.7.2.	The ESP needs to identify the **name of the nearest cross-street** at which the wrong-way vehicle was detected.	**Mandatory**
2.7.3.	The ESP needs to identify the **mile marker reference** point of the location at which the wrong-way vehicle was detected.	Optional
3.	The stakeholders need to be able to **verify** the location and direction of travel of a wrong-way vehicle.	**Mandatory**
3.1.	The TME needs to notify the ESP when a WWD event has been verified using their **video surveillance system**.	**Mandatory**
3.2.	The ESP needs to notify the TME when a WWD event has been verified through their **911 dispatchers and/or officers in the field**.	**Mandatory**
4.	The TME needs to **provide warning messages** to both CVs and non-CVs upstream of the wrong-way driver.	**Mandatory**
4.1.	The TME needs to **broadcast information** about the WWD event to CVs through properly formatted SAE J2735 RSA messages.	**Mandatory**
4.2.	The TME needs to broadcast information about the WWD event to **information service providers**.	
4.3.	The TME needs to **activate pre-planned response plans** based upon the location of the wrong-way vehicle.	Optional
4.3.1.	The TME may alert non-CVs by implementing pre-programmed message **on DMSs**.	Optional
4.3.2.	The TME may alert non-CVs by **activating special LED signs**.	Optional
4.3.3.	The TME may alert non-CVs by activating a special display on a **ramp control signa**l.	Optional
4.3.4.	The TME may activate **ramp control gates** in response to a WWD event.	Optional
4.4.	The TME needs to **update warning messages** as information about the WWD event is updated.	**Mandatory**
4.5.	The TME needs to **deactivate warning information** when the WWD event has concluded.	**Mandatory**
4.6.	A CV must be able to **receive** a **properly formatted RSA** issues by the TME.	Optional
4.7.	A CV needs to be able to process the RSA to **generate** an appropriate **warning alert** display to the driver.	Optional
5.	The TME needs to **maintain a record** of each action taken by the TME for each WWD event.	**Mandatory**
5.1.	The TME needs to record the **time at which actions associated** with each event occurred.	**Mandatory**
5.1.1.	The TME needs to record the **time when and by whom** the event was **detected**.	**Mandatory**
5.1.2.	The TME needs to record the **time when and by whom** the event was **verified**.	**Mandatory**

Number	Description of Need	Importance
5.1.3.	The TME needs to record the **time and how the event** was **cleared** (terminated).	**Mandatory**
5.2.	The TME needs to maintain a record of each **warning alert issued** associated with each WWD event	**Mandatory**

SUMMARY

The research team conducted a high-level assessment of potential CV applications to determine their potential applicability to address WWD events. The purpose of this assessment was to identify potential concepts used in these applications that could also be applied to a CV WWD application. Overall, the research team identified three CV applications that are highly relevant to a potential wrong-way event. In addition, the research team identified 11 CV applications that contained some concepts or elements that might be applicable to a WWD application. The research team also explored the types of information that can be exchanged by CVs.

The research team then conducted a needs assessment to provide the foundation for the concept of operations. In developing user needs, the research team identified three primary stakeholders to be considered in developing a wrong-way vehicle application: traffic management entities, emergency service providers (primarily law enforcement), and motorists. The research team reviewed current WWD event response protocols, the roles and responsibilities of the stakeholders during WWD events, and the potential impact of CVs on WWD events. Based this information, the research team identified the user needs associated with developing a CV WWD Detection and Management System for TxDOT.

CHAPTER 5: CONCEPT OF OPERATIONS

A concept of operations (ConOps) describes the goals and objectives of a system, as well as the high-level design criteria. The goals and objectives of the ConOps outlined herein are intended to be high-level and may not necessarily be quantifiable or testable. Specifically, the ConOps:

- Lays a foundation for the design, test, deployment, and implementation of WWD detection and subsequent verification, notification, alerting, and clearing using CV technology.
- Provides a resource for the development of engineering requirements and supports decision makers in their assessments, deployments, and evaluations of the WWD applications deployment under a variety of scenarios and settings.

The ConOps is an early and critical step in the systems engineering process, and the purpose is to provide a description of why a system is needed and how it would be used considering the viewpoints of the various stakeholders. The ConOps:

- Describes the environment and use of the system in a non-technical and easy-to-understand manner.
- Presents the information from multiple viewpoints.
- Bridges the gap between the problem and stakeholders' needs.

Overall, the ConOps describes the basic who, what, why, where, when, and how a WWD application is designed and deployed.

- Who – the stakeholders are, what their responsibilities are, and how they will use the system.
- What – the existing components or systems to be examine and /or integrated together.
- Why – the problems or issues the system will solve.
- Where – the geographic limits of the system.
- How – the resources needed to plan, design, deploy, and operate the system.

INTENDED AUDIENCE OF THE CONOPS

The ConOps helps stakeholders focus on the proposed system's capabilities and understand the effect of the proposed system upon other internal and external systems and practices. Stakeholders of the ConOps document include TxDOT, researchers, local and state governments, law enforcement agencies, private sector agencies, system engineers and architects, system implementers, equipment manufacturers, and application developers. The ConOps also helps system engineers and architects to understand the constraints, assumptions, requirements, and priorities set forth to design and deploy the WWD application.

REFERENCED DOCUMENTS

While preparing the ConOps, the research team referenced the following documents:

- Guide for the Preparation of Operational Concept Documents, ANSI/AIAA/G-043-1992, American Institute of Aeronautics and Astronauts, Washington, D.C., 1993.
- Systems Engineering for Intelligent Transportation Systems: An Introduction to Transportation Professionals, US Department of Transportation, Washington D.C., 2007.
- IEEE 802.11p http://standards.ieee.org/getieee802/download/802.11-2012.pdf and VAD spec http://www.its.dot.gov/meetings/pdf/T2-05_ASD_Device_Design_Specification_20120109.pdf. Accessed June 16, 2015.
- FCC report and order http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-03-324A1.pdf IEEE 1609 http://standards.ieee.org/develop/wg/1609_WG.html. Accessed June 26, 2015.
- Southeast Michigan 2014 Security Requirements http://www.its.dot.gov/testbed/PDF/SoutheastMi_Security_Requirements.pdf. Accessed June 21, 2015.
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- Systems Engineering Guidebook for Intelligent Transportation System (ITS) Version 3.0 http://www.fhwa.dot.gov/cadiv/segb/views/document/index.cfm. Accessed June 26, 2015.

- Systems Engineering for Intelligent Transportation Systems http://ops.fhwa.dot.gov/publications/seitsguide/index.htm. Accessed June 26, 2015.
- Connected Vehicle Reference Implementation Architecture http://www.iteris.com/cvria/index.html. Accessed June 26, 2015.

OPERATIONAL NEEDS

In current WWD application deployments, TMEs do not have the ability to alert individual right-way drivers based on their location. However, if the wrong-way and right-way vehicles are equipped with CV technology, there is an opportunity for the TME to use the wrong-way vehicle's position to communicate different messages to individual right-way drivers based on their location. TMEs and ESPs could also use the wrong-way vehicle position to reduce the time it takes to alert law enforcement in the area. Depending on the market penetration of CV technology in vehicles, there are also opportunities for the wrong-way vehicle to directly transmit its position to other right-way vehicles in the vicinity and allow them to avoid a collision.

Vehicle manufacturers and after-market equipment providers would be responsible for developing applications to display alerts to drivers. The in-vehicle application would determine if the alert was appropriate based on the relative location, speed, and heading of itself and the wrong-way vehicle. The TME may then be responsible for developing the content of the alert messages and for broadcasting (and deactivating) when appropriate. If the deployment of a WWD system is outside of a TME's coverage, vehicles themselves may generate alerts for the drivers. CV technology provides these opportunities by establishing communication and data exchange between TMEs, right-way vehicles, wrong-way vehicles, and law enforcement vehicles.

CV technology provides these opportunities by establishing communication and data exchange between TMEs, right-way vehicles, wrong-way vehicles, and law enforcement vehicles. In Chapter 4, the research team identified an initial set of user needs that a CV WWD Detection and Management system should address.

SYSTEM OVERVIEW

Proposed WWD System Scope and Applicable Physical Environment

The proposed system and its subsequent demonstration will showcase the applicability of CV technology to enhance the detection and mitigation of wrong-way driver events on Texas freeways. The demonstration system will use CV technology to demonstrate the feasibility of accurately detecting the location, heading, and speed of a wrong-way vehicle, and providing a variety of notification pathways to TMEs, ESPs (primarily law enforcement), and the traveling public.

These pathways will depend on the availability and proximity of other CV-equipped vehicles, DSRC roadside equipment, and the agencies themselves. From detection of the wrong-way vehicle to notification of TMC and law enforcement personnel and mitigation response, the CV WWD Detection and Management System will showcase the improved reliability, accuracy, responsiveness, and safety due to the introduction of CV technologies.

The system boundaries have been identified as high-speed, controlled-access, freeway-type facilities. These would include the main lanes of TxDOT freeways and major toll facilities, as well as their entrance and exit ramps. Rural and urban deployment scenarios offer unique technical challenges for CV technology deployment and application, and are both considered in this document. The system boundaries *do not include* frontage roads, cross-street approaches of frontage road intersections or the intersection itself, or urban roadways operated by municipalities.

System Goals and Objectives

The goals of the system are to efficiently detect and mitigate WWD events on Texas highways. The objectives that support these goals include:

- Identification of specific scenarios where CV technology can be used to detect a wrong-way vehicle and notify other drivers, a TMC, and/or law enforcement directly.
- Determination of the type, number, and placement of various components to support the selected scenarios.
- Identification of relevant CV communication strategies to facilitate timely and accurate WWD event management.

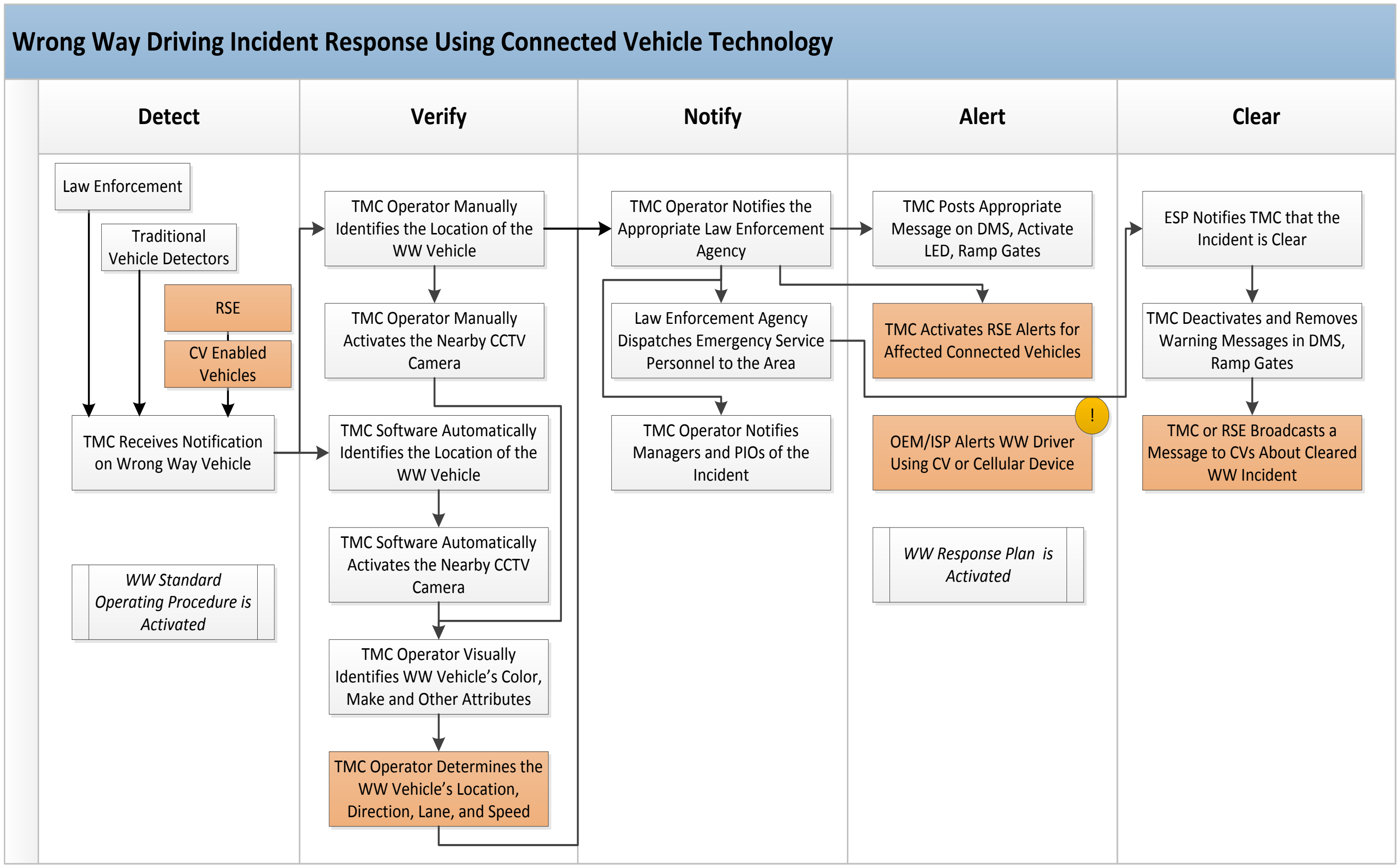
System Capabilities

The system should fulfill the needs of the stakeholders to more efficiently detect and respond to WWD events under different scenarios and operating environments. The CV-enabled system should have the ability to decrease the time required to alert emergency personnel and right-way drivers with or without roadside infrastructure. With regard to testing and demonstrating the system in a test bed environment, the system should have the ability to trace, validate, and verify various CV communication strategies for the purpose of detecting a wrong-way vehicle and alerting emergency personnel and right-way drivers. Using this information, researchers can then analyze limitations of the CV technology and its components, required density of CV-equipped vehicles for efficient operation, and conditions surrounding placement of RSE.

System Architecture

A typical WWD application includes five key steps—detection of a wrong-way vehicle, verification from additional sources, notifying and dispatching law enforcement, alerting right-way drivers, and clearing the event. The introduction of CV technology into the transportation system has the potential to radically change this, shortening the time between detection and alert. Figure 31 shows the key steps in responding to WWD events and how CV technology can enhance the overall response. Depending on the protocols adopted by various law enforcement agencies and TMEs, some steps may occur in a different order or overlap.

The steps shown in Figure 31 can be represented using physical components and communication pathways, particularly where CV technology components are involved. Figure 32 shows a CV WWD detection system in an urban, controlled-access freeway environment, where multiple exit ramps along a section of highway are monitored using infrastructure-based devices, and are connected to each other either directly or through a TMC. An infrastructure deployment like this would enable the rapid coordination among the various infrastructure components, TMC personnel, law enforcement, and other vehicles using both traditional and CV technologies. The various infrastructure components represented in this diagram include DSRC RSE, traditional wrong-way vehicle detection sensors, TMC, ESP dispatch, and DMS. This image represents a fully connected CV WWD detection demonstration system and illustrates the various physical, organizational, and operational components that would be involved.



RSE = Roadside Equipment
TMC = Traffic Management Center
CCTV = Closed Circuit Television
WW = Wrong Way
PIO = Public Information Officer of the TME

DMS = Dynamic Message Sign
LED = Light Emitting Diode
OEM = Original Equipment Manufacturer
CV = Connected Vehicle
ESP = Emergency Service Personnel
ISP = Information Service Provider

! Out of the Scope of this Project

Processes Where CV Technology Could Play a Key Role

Figure 31. Swim Lane Diagram Showing Key Steps in WWD Event Management Using CV Technology.

In Figure 32, the wrong-way driver entering the system on the right side of the graphic is detected independently using two methods: a traditional wrong-way vehicle sensor and the BSM from the wrong-way CV that includes the position and heading of the vehicle. The traditional sensor detects the vehicle moving in the wrong direction and alerts the TMC personnel, while the BSM broadcast from the WWD vehicle itself is received by the local RSE, which then uses data elements within the BSM and a map of expected directions of travel to determine that the vehicle is traveling the wrong direction. The RSE can immediately send out an RSA message, which will be received by the wrong-way vehicle, and any CV-equipped vehicles or other RSE within communication range. The RSE can also send a message to the TMC where it may be combined with other alerts. TMC personnel can then notify law enforcement, begin verification procedures using cameras or other infrastructure equipment, generate RSA messages for connected RSE, and place alerts on upstream DMSs.

Figure 33 illustrates how the various stakeholder components interact during each of the steps, and where CV technology might fit in. In this figure, detection of a wrong-way driver has four potential sources:

- CV-equipped wrong-way vehicle.
- CV-equipped right-way vehicles.
- Law enforcement.
- Infrastructure sensors, such as vehicle detectors or CV RSE.

Within each of these potential sources lay the possibility of CV technology contributing to the detection. Where CV technology is involved, the information about a wrong-way vehicle can be rapidly shared with RSE and other CV-equipped vehicles in range (which could include CV-equipped law enforcement vehicles). The introduction of CV technology means that properly equipped vehicles within range of a CV-equipped detection source will be alerted about the WWD (and be able to take countermeasures) before a TMC or traditional law enforcement are even notified of the event. This is one of the most transformative effects of integrating CV technology into wrong-way vehicle detection applications.

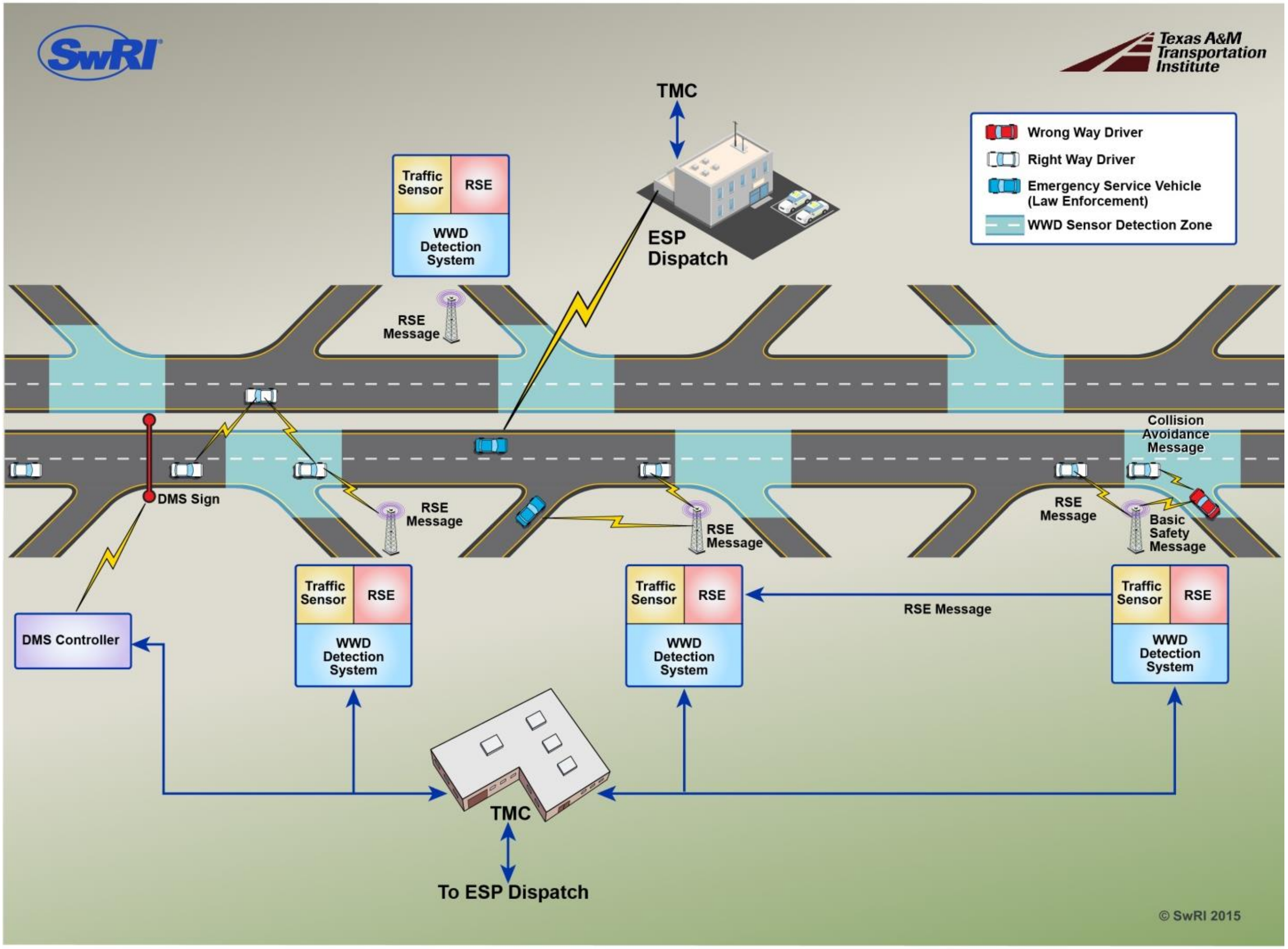


Figure 32. Urban Corridor with Multiple WWD Detection Zones and TMC and ESP Integration.

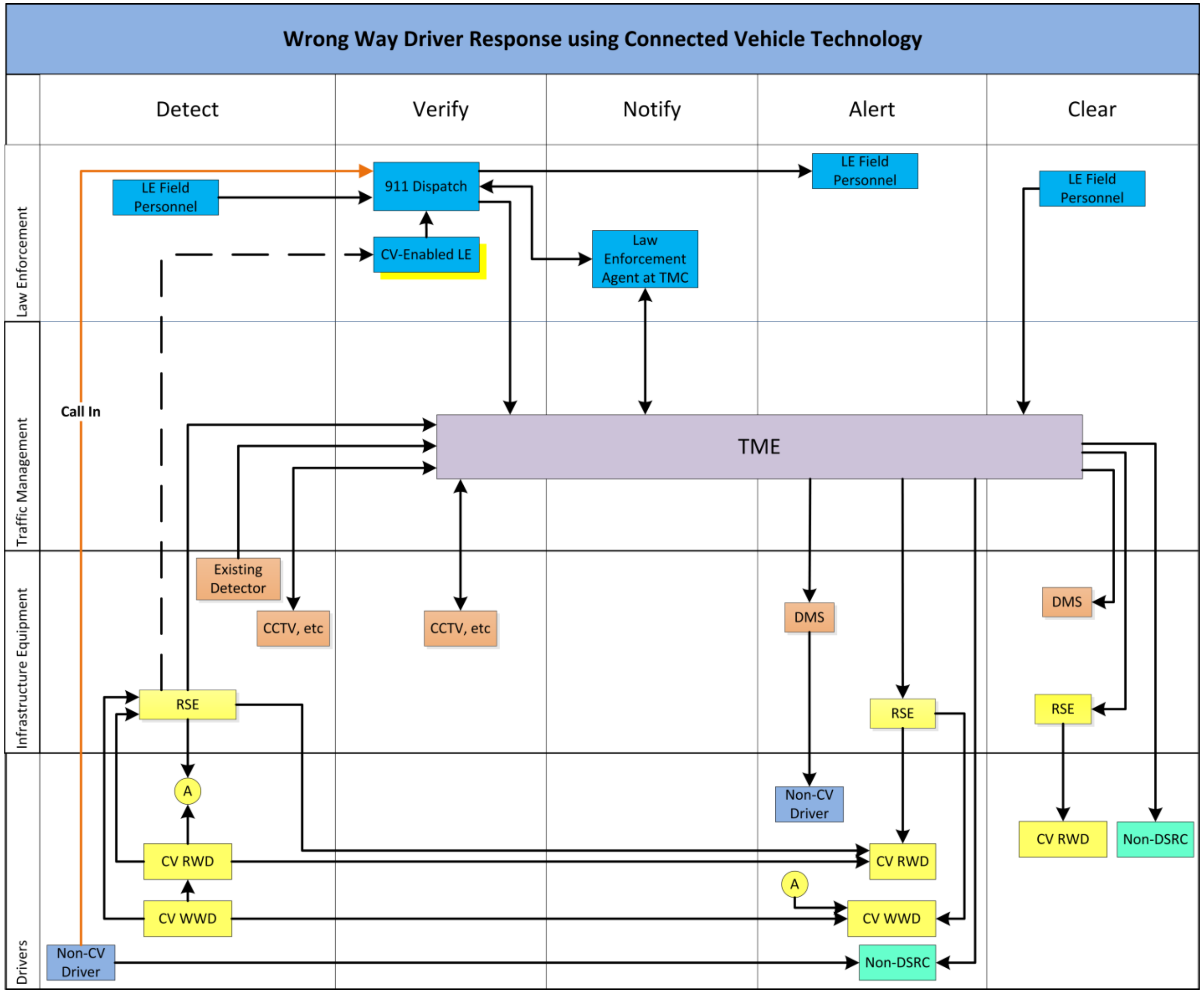


Figure 33. WWD Response Using CV-Equipped Vehicles and Infrastructure.

Various components of this system diagram would be active or inactive for different scenarios of deployment. For example, in areas outside of the TMC coverage, the alternative is to use standalone RSE or rely on V2V message propagation. These alternative scenarios are described in detail in the following later sections of this document.

Physical Components and Interfaces

The CVRIA was used to construct a set of system architecture viewpoints that describe the functions, physical and logical interfaces, enterprise relationships, and communication protocol dependencies necessary to deploy applications within a CV environment. The CVRIA supports policy considerations for certification, standards, core system implementation, and other elements of the connected vehicle environment. Across the CVRIA, language and components have been standardized so that disparate implementations across the nation can take place and ensure communication and data consistency. Three layers of information have been established to depict varying levels of detail:

- Layer 0 – is a high-level perspective of entities and interconnections.
- Layer 1 – shows a combined view with all of the project's objects, applications, and interconnections combined in one diagram.
- Layer 2 – shows detailed application-specific objects and interconnections.

A Layer 0 diagram is expanded to Layer 1 and Layer 2 diagrams by including application objects within each physical object and specifying functionality. Application objects define the functionality and interfaces that are required to support CV applications. Physical objects define major physical components necessary to deploy a CV environment whether that is a test bed or a real-world deployment. The following are some of the definitions for physical objects:

- A *driver* represents the person that operates a licensed vehicle. For this application, it means a wrong-way driver or right-way driver. It also includes operators of transit, commercial, and emergency vehicles, which may or may not be CV-equipped. The driver originates driver requests and receives driver information. Information and interactions that are unique to drivers of a specific vehicle type are covered by separate objects.
- *Vehicle OBEs* represents vehicles with On Board Equipment (OBE) with capabilities to communicate with one another and RSE. OBEs represent the on-board devices that

provide the vehicle-based processing, storage, and communication functions necessary to support CV operations.

- *ITS roadway equipment* represents the ITS equipment that provides information to (and is controlled by) the TMC. This physical object includes traffic detectors, DMSs, CCTV cameras, and video image processing systems.
- *Roadside equipment* represents the roadside devices that are used to send messages to, and receive messages from, nearby vehicles with OBEs using DSRC. Communications with adjacent ITS Roadway Equipment and back office centers that monitor and control the RSE are also supported.

The U.S. Department of Transportation in partnership with Iteris has developed a software tool to represent the relationships among the CVRIA components, called the Systems Engineering Tool for Intelligent Transportation (SET-IT). Figure 34 shows an example diagrammatic output of the SET-IT tool and shows a Physical Layer 0 architecture. It illustrates high-level communication links between various physical objects within a WWD application. In the diagram, communication links are shown as Peer-to-Peer. These links are shown in black and red colors. Red lines indicate trusted and confidential communication, while black lines indicate trusted, non-confidential communication. In a test environment such a distinction is not critical. However, it has been left in place to allow testing applications that require trusted or confidential communication. Local traveler information includes messages from nearby ITS equipment (e.g., DMS) or from a TMC to the RSE so that it can transmit messages to vehicle OBEs, such messages may include small area-wide alerts. Driver information may include travel advisories, vehicle signage data, fixed sign information, detour information, etc.

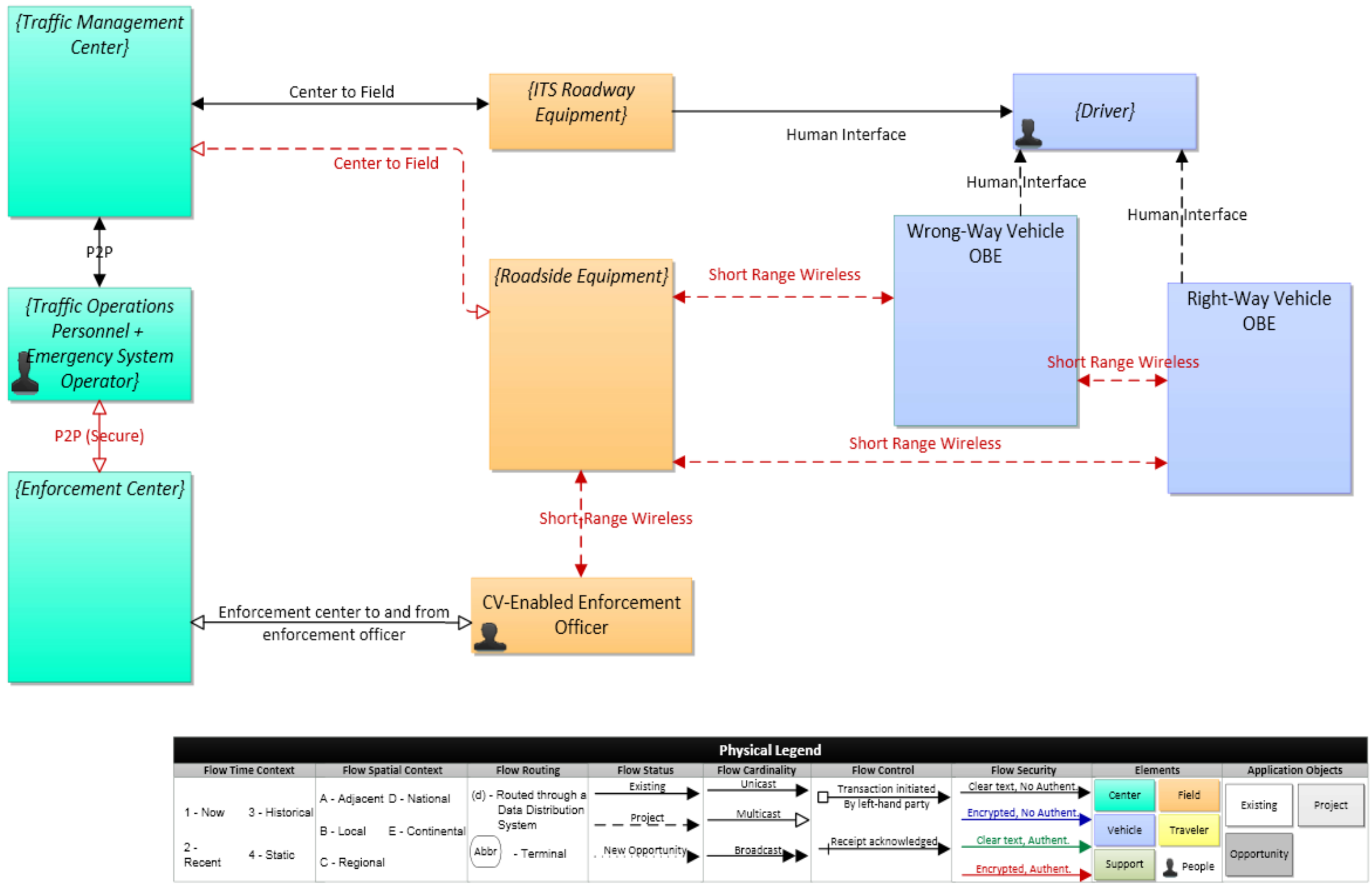


Figure 34. Layer 0 Architecture for a WWD Deployment Scenario that Includes Wrong-Way Vehicle with CV Capabilities.

Figure 35 provides the Layer 1 diagram, which is a combination of all of the WWD applications in one diagram. The communication links have been summarized in the case of multiple connections between the same objects. The Layer 1 diagram includes application objects that may apply to each of the objects. A brief description of the application objects are as follows:

- *RSE wrong-way detection* will compare a received vehicle's BSM with heading and location to a map of expected headings and regions. Vehicles that are traveling opposite to the expected direction of travel for a pre-determined amount of time will be detected as wrong-way vehicles. These data will be provided to the TMC and to the Wrong-Way Alert application in the RSE.
- *RSE wrong-way alert* will provide a directed warning to a detected WWD CV and will broadcast a notification alert to all CV vehicles regarding the wrong-way vehicle. Triggering this alert may occur automatically in the case of a remotely deployed RSE with a slow (or no) connection to a TMC or it may be triggered by a control message from a TMC.
- *Vehicle wrong-way application* will receive notifications or warnings from other CV equipment and provide updates to the driver regarding relevant information.
- *Roadway DMS* will receive control signals from the TMC and modify the contents of the DMS to alert drivers.
- *Enforcement center wrong-way application* will provide an information flow from deployed law enforcement officers who are communicating with the enforcement center, TME Personnel, and/or other ESP personnel.
- *TMC traffic surveillance* will handle communication to and from deployed ITS roadway equipment sensors, such as CCTV and loops.
- *TMC wrong-way driver warning* will be activated when TMC personnel verify a WWD alert and will send out alerts that should be presented to drivers either through ITS roadway equipment (e.g., DMS) or through RSE.

Figure 36 illustrates an example Layer 2 physical diagram for the specific scenario of a TMC and ESP connected to an RSE. The diagram illustrates specific communication flows between the physical objects.

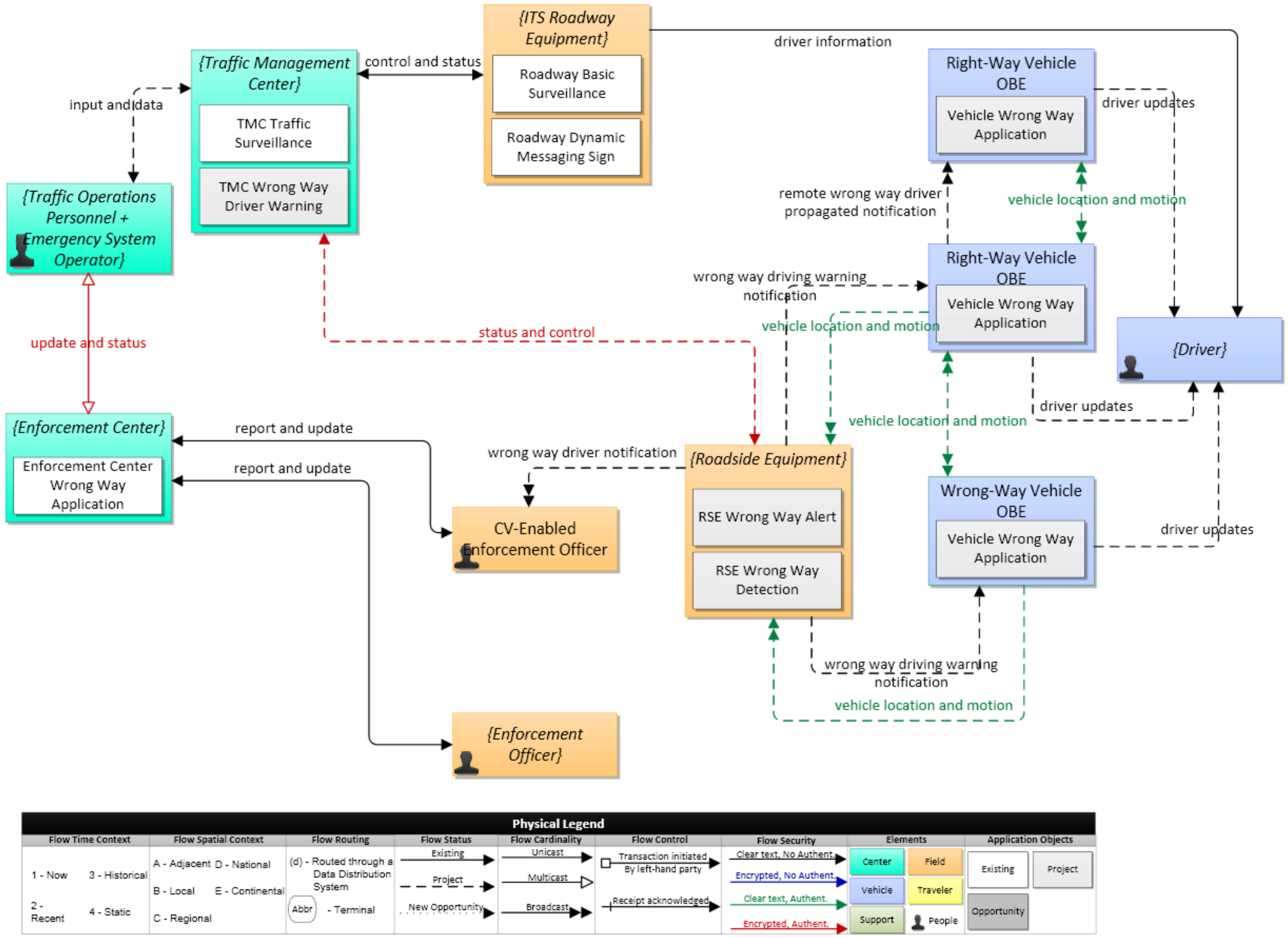


Figure 35. Layer 1 Physical Diagram Combining all Objects and Applications.

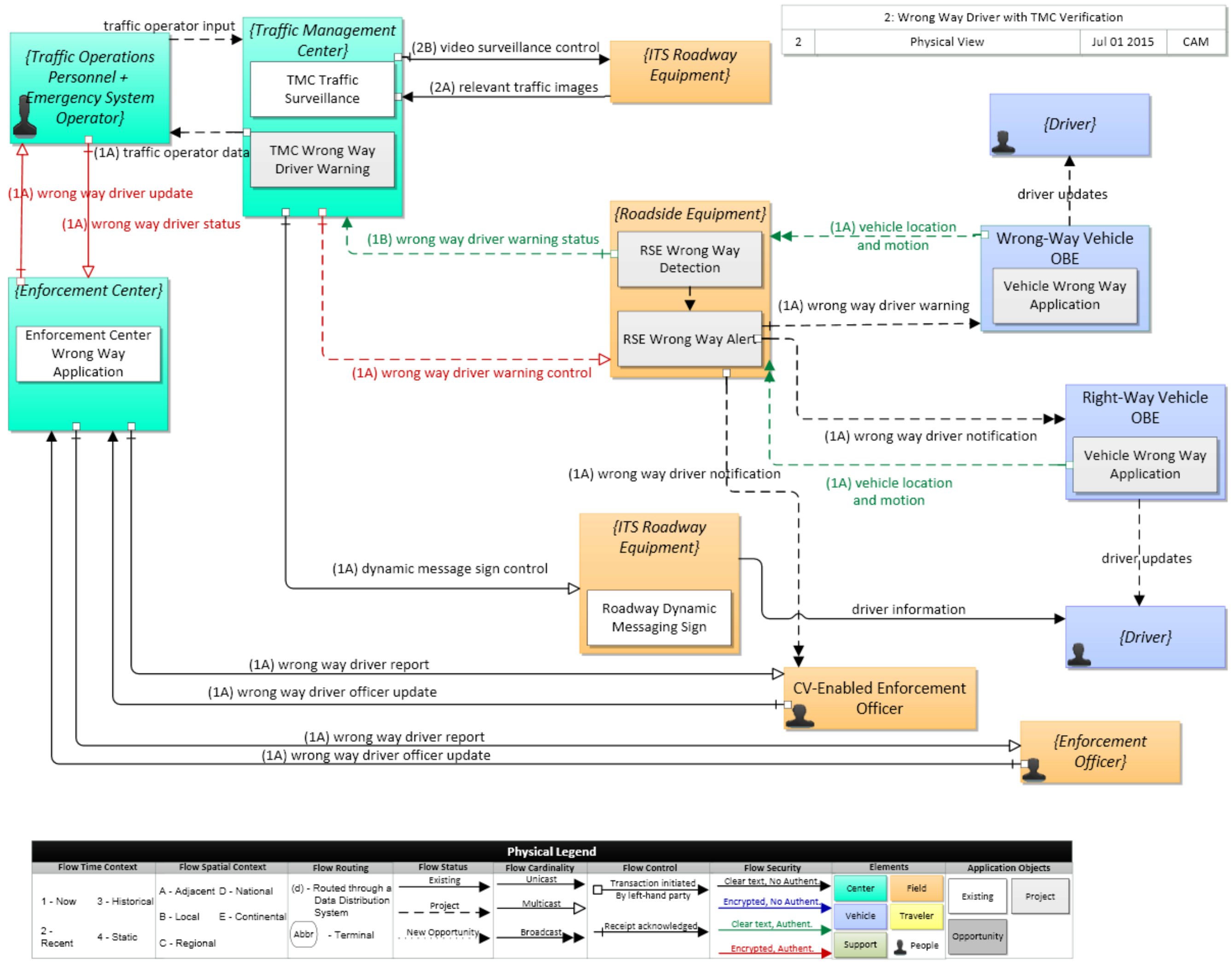


Figure 36. Layer 2 Architecture for a WWD Deployment Scenario that Includes a Wrong-Way Vehicle with CV Capabilities.

OPERATIONAL AND SUPPORT ENVIRONMENT

Operation and support of the CV WWD detection demonstration system contains a number of critical components, which are also relevant for an eventual deployed system.

- The traffic management entity and emergency service agencies that will be involved.
  - Which agencies are involved, and how do they participate?
- Coordination among agencies for any testing and data collection activities.
  - What data will be collected and how?
  - Are there data security or privacy concerns?
- The type and number of CV equipment must be identified.
  - How many vehicles will be equipped with CV equipment, and how will it be installed?
  - How many RSE units will be deployed, and where will they be located?
- Testing and demonstration procedures.
  - How are tests and demonstrations conducted?
  - What safety procedures are necessary?
- The technical resources needed for operation must be identified.
  - What are the staffing requirements for engineers, technicians, administration, and others?
- Data integration into traffic management software.
  - How will data be received and processed by Lonestar/other TMC software?

Each of these components must be considered as part of the overall system and will depend greatly on the location that is chosen for the model field deployment of a CV WWD Detection and Management system. The selected location will have a significant impact on the complexity of deployment, operation, and support of the system, as well as some impact on the types of use-case scenarios that can be tested. Initial testing of the CV WWD Detection and Management System could be conducted at a closed-access course, such as the Texas A&M University (TAMU) Riverside Campus.

The execution of a demonstration or test of the CV WWD system on an actual roadway will require personnel from research organizations, the participating TME (including TMC personnel), law enforcement, and demonstration drivers (CV and non-CV). A test or demonstration of the system will require the coordination of the TME and law enforcement to secure the section of roadway to be used to prevent unauthorized drivers from entering the test zone. All affected personnel will also be briefed as to the nature of the testing and provided with a clear understanding of the beginning and end of a test. Deployed CV hardware will need to be confirmed as functioning properly, and the TMC software will need to be ready to accept and store data from the testing.

During a test or demonstration in the field, the TME and law enforcement personnel will still need to be able to conduct normal operations, and procedures should be in place to interrupt testing if needed. Personnel should be trained on the nature of the demonstration system, its immediate and long-term goals, and the operating procedures that will be required. Their involvement and understanding of the system will be critical to its success. The operation of the system should include specific CV WWD detection and alert scenarios, with scripted and coordinated movements of vehicles. This will demonstrate the CV functionality and the TMC and law enforcement integration for each scenario type. However, the demonstration system should also be used to test unscripted scenarios, which will enable researchers to detect any gaps in the technology or application methods. These corner cases are often difficult to recognize using scripted methods, but may materialize through unforeseen combinations of circumstances.

After tests or demonstrations have been completed, the entire team that was involved should conduct a debrief discussion to identify successes or failures that the tests revealed, including errors by humans due to confusing, misleading, or missing information. The CV technology itself, and the integration of its data into the TMC software, should also be evaluated for performance against expectations.

Support of the demonstration system will require personnel from the organizations listed above and maintenance and technician staff to address hardware failures of field-deployed equipment. Additional personnel may also be required to maintain normal operation of the TME and law enforcement organizations during testing. Technical staff from research organizations and the participating TME will also be required to maintain software and hardware readiness of the CV technology and traffic management system software. They also will be responsible for changes and updates to hardware and software in support of the system tests and demonstrations.

Liaison personnel may be desired to perform public outreach and education, as testing and demonstrations of the system is likely to cause disruption to normal traffic flow along the selected test section of roadway. Staff members who can serve as a point of contact for an organization will be critical to ensuring the effective execution of tests and demonstrations of the CV WWD Detection and Management System, and may themselves wish to form a coordinating committee or similar group to assist in cross-organization communication and coordination.

OPERATIONAL SCENARIOS

The operational scenarios described below include both CV and traditional traffic management components for WWD detection, verification, notification, and alert. Each scenario examines how the introduction of CV technology into the traffic system can facilitate detection of the WWD vehicle and alert both approaching right-way drivers and law enforcement.

WWD Event Management within the TMC Coverage Area

Figure 37 shows a scenario that uses different aspects of the system to detect a wrong-way vehicle, notify TMC personnel and law enforcement, and alert CV-equipped vehicles. In this scenario, a traditional WWD detection sensor and an RSE work together to quickly alert approaching vehicles by sending out a RSA message without first requiring verification through a TMC. Other CVs in the area that are not in danger of encountering the wrong-way vehicle would receive the RSA via their on-board DSRC radio but would not necessarily notify the vehicle's driver. Law enforcement in this scenario would still be notified via TMC personnel; however, if the law enforcement vehicle is CV-equipped and within range of the RSE, it would receive the alert along with other CVs.

WWD Event Management Using V2V Technology Only

Figure 38 shows another scenario in which CVs could be alerted to a wrong-way vehicle even without deployed infrastructure. In this scenario, the deployed RSE is not located within communication range of the WWD event. Instead, the wrong-way vehicle is detected by either the wrong-way vehicle's OBE or multiple right-way vehicle OBEs. The OBEs would then send out the wrong-way vehicle alert and in the absence of RSE, the message is sent as a V2V message. In Figure 38, the blue van and yellow truck will not display alerts to their drivers (hence "No Message" shown). However, they will propagate the message to other vehicles in the right-way direction.

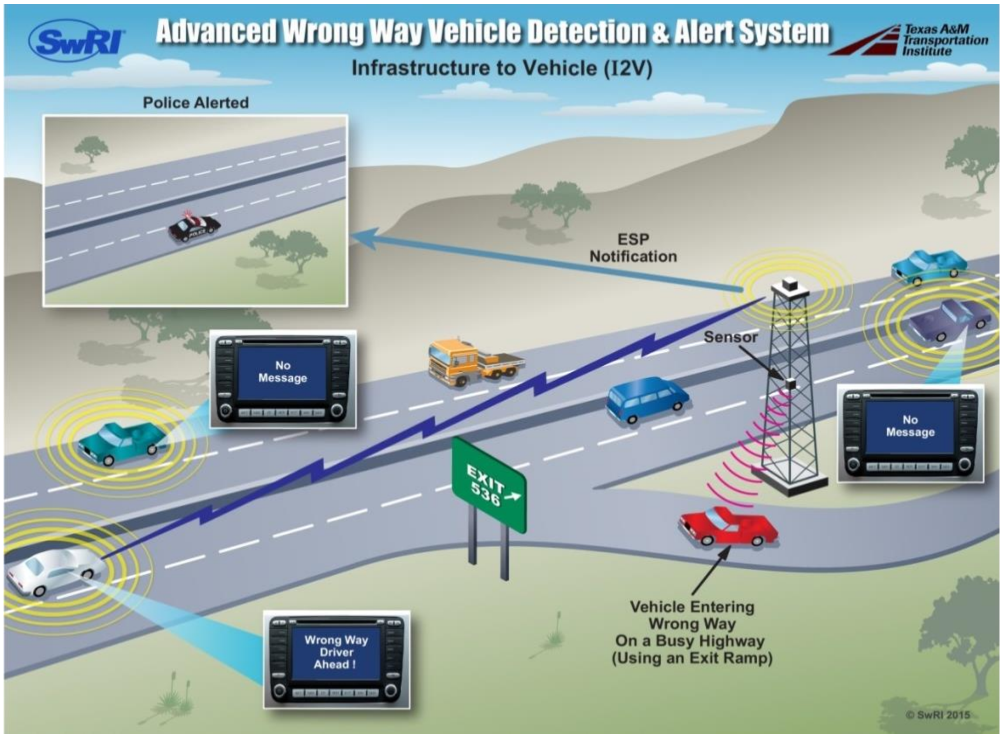


Figure 37. WWD Event Management within TMC Coverage Area Using V2I Communication.

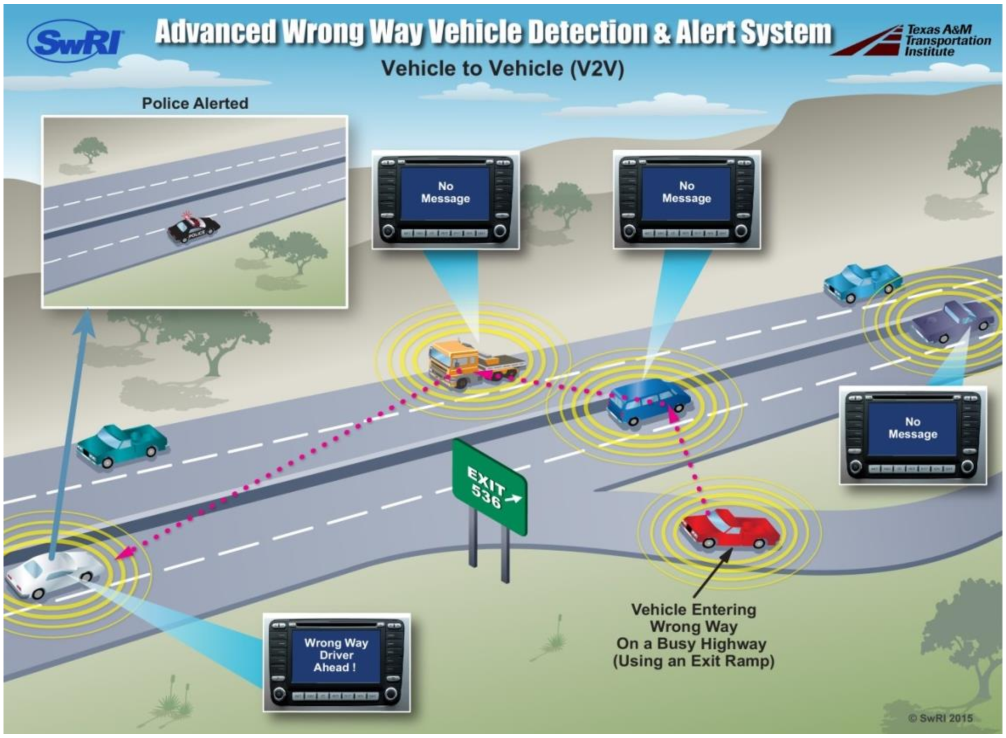


Figure 38. WWD Event Management Outside of TMC Coverage Area Using Propagation of Alert Message via V2V Communication.

In this scenario, the drivers that need the information about an approaching wrong-way vehicle may not get enough warning if the alert is only sent out as a V2V alert from the wrong-way vehicle. Instead, the other CV-equipped vehicles in the area can serve as message carriers to provide the alert to drivers who may soon be affected by the wrong-way vehicle. Although not all CVs in the area would be affected by the wrong-way vehicle (e.g., vehicles downstream of the wrong-way vehicle or vehicles traveling on the opposite side of the highway), these vehicles can participate in the distribution of the alert by sending a received alert back out as a repeated, or propagated, message. In this way, a wrong-way vehicle alert message can travel very rapidly among CV-equipped vehicles and other available CV technology in order to reach other CV-equipped vehicles that are still approaching the wrong-way vehicle and in danger of a crash. Once a propagated alert is received by an RSE that is connected to a TMC, the TMC is notified using the infrastructure connection and law enforcement is notified through TMC personnel. However, CV drivers who are in the most immediate danger of collision are notified more quickly and can take appropriate mitigation steps, sooner than they could have without CV technology. The propagation of the WWD alert could also continue until it was received by a CV-equipped law enforcement vehicle.

WWD Event at High Occupancy Vehicle/High Occupancy Toll Lanes

In a scenario in which a wrong-way vehicle enters a High Occupancy Vehicle (HOV)/High Occupancy Toll (HOT) lane, the CV-enabled detection and alert activities described above would be applicable, and traditional sensors placed within the lane could also provide notification to a TMC. Non-CVs approaching the wrong-way vehicle are warned by DMSs or other visual indicators not to enter the HOV/HOT lanes or to exit the lanes at the earliest opportunity, due to a wrong-way vehicle. CVs receive a wrong-way vehicle alert from local RSE or other CVs and should begin to exit the HOV/HOT lanes if the exit is in close proximity. In the case of reversible HOV lanes, where directional access is controlled by the movement of physical barriers, the HOV operators have another tool at their disposal. The nearest appropriate segment of HOV lane could be closed to right-way traffic, diverting them back into their standard lanes of traffic, while at the same time creating an exit from the HOV lanes for the wrong-way vehicle. This would force the wrong-way vehicle back into lanes of traffic that are traveling in its same direction.

In either case, TMC personnel are notified via infrastructure sensors or messages received by RSE, and law enforcement is notified of the event and location. Should the wrong-way vehicle be successfully diverted back into the right-way traffic without incident, law enforcement may continue to attempt to locate the driver.

Accounting for Contra-Flow Operation

In an evacuation, other emergency situation, or work zone, contra-flow of traffic may be enabled, whereby all or some available lanes of a highway are converted to a single direction of travel. In this scenario, the CV detection of wrong-way vehicles would pose a challenge, as both CVs and RSE would begin suddenly detecting hundreds or thousands of wrong-way vehicles. Ideally, prior to the activation of contra-flow, the TMC would update the wrong-way vehicle detection zones for all affected RSE. CV-equipped vehicles would also receive a message indicating an emergency situation where specific CV applications, like the wrong-way vehicle alert, are not applicable and should be temporarily deactivated. Alternatively, if the CVs are determining right-way and wrong-way drivers using a downloaded map of the roadway, which includes direction information on a per-lane basis, an alternate map could be sent to the CVs via local RSE.

Individual vehicles could also disable their wrong-way vehicle alerts in the case where they receive multiple wrong-way vehicle alerts within a short period of time or for a small geographic region. However, this capability would need to have security protocols in place to avoid a situation where a wrong-way vehicle alert is broadcast rapidly using different vehicle identifications and locations. A de-activation of wrong-way vehicle events could also be propagated similar to activation of the wrong-way vehicle alert, and this dynamic cancelation could be applicable to RSE as well. Situations such as emergency evacuations are an example where the messaging standards for wrong-way vehicle alerts need to be coordinated with the relevant standards bodies.

RSE Does Not Detect a WWD

An RSE may not detect a wrong-way vehicle for several reasons, including but not limited to, the two specific scenarios described below.

WWD Detection Region Defined Incorrectly in RSE

The RSE wrong-way vehicle application contains a region that is user-definable, which it uses to compare the direction of travel as reported by vehicles' BSM. If this region is incorrectly defined, vehicles will not be detected as right- or wrong-way drivers. In this case, the wrong-way vehicle would be detected using either traditional sensors or through approaching CVs, which do not need to use a region for wrong-way vehicle detection but can compare their own heading to that of approaching vehicles. The detection and alert mechanisms are then propagated among vehicles and RSE, including the RSE that missed the detection. After the wrong-way vehicle event is cleared, TMC personnel would examine the detection and alert mechanisms from the event and discover that the wrong-way vehicle was not first detected by an RSE. Although this may indicate that the driver entered the highway through a non-traditional route, perhaps crossing a grassy median, it may indicate an RSE with an ill-defined wrong-way vehicle detection region, which could be easily checked by TMC personnel, and if needed, corrected.

RSE Stops Communicating with the TMC or CVs

If an RSE stops communicating with the TMC for some reason, this would be detectable by TMC personnel prior to a wrong-way vehicle event and should be remedied immediately. The communication status for each RSE is available using software at the TMC, and an unreachable RSE will require a service call or infrastructure repair. However, even if an RSE is unable to communicate with the TMC, it may still be communicating with other CVs in the area. Therefore, the CV wrong-way vehicle detection and alert mechanisms already discussed would be applicable, although notification to the TMC would be delayed. Through message propagation, however, the wrong-way vehicle alert could quickly reach another RSE, which could then relay the message to TMC personnel. If the RSE is not communicating with the TMC and other vehicles, then detection of the wrong-way vehicle will be delayed until other detection mechanisms are engaged.

CHAPTER 6: FUNCTIONAL REQUIREMENTS

This chapter documents the development of a set of functional requirements for both a small-scale CV WWD Detection and Management System test bed as well as for a larger-scale field deployment. Based on the anticipated scale of the requirements—the desire to have broad access by a variety of stakeholders to the requirements and a desire to use common tools—Microsoft © Excel was chosen as the requirements management tool.

ORGANIZATION OF REQUIREMENTS

Each requirement was identified by a unique identifier that indicated its level in the hierarchy, as well as the phase of the event to which it applied (i.e., detection, verification, notification, alert, clear, and safety). A common set of requirements was developed for both the test bed and the field deployment. The inputs to the requirements consisted primarily of the information documented in the ConOps, which included the identified user needs, the scenarios describing the use of the system, and the description of the system architecture, including the event responses, components, and component interactions. Bi-directional traceability between the requirements and the identified needs has been documented and is maintained to ensure that the identified needs are satisfied by the requirements and to ensure that the documented requirements are traceable to identified needs.

There are two levels of requirements that fit into the six phases of a WWD event. The highest-level requirements serve as a translation step between the system needs and the architecturally dependent system-level requirements. They generally do not make assumptions about the architecture selected for the test bed or for the field deployment. The second level of documented requirements is high-level system requirements, which are based not only on the needs identified in the ConOps but also from the scenarios and system architecture described in the ConOps. Table 8 illustrates the organization of the requirements.

Table 8. Functional Requirements Organization.

Category	Number of Top Level	Number of Second Level
Detection	8	84
Verification	3	10
Notification	6	15
Alert	6	19
Clear	5	12
Safety	2	0

This table illustrates the focus of a CV WWD Detection and Management System on the detection stage of a WWD event. Although the identified needs are generally applied to both the test bed and the field deployment scenarios, different priorities and performance metrics are associated with the requirements for each scenario. A number of methods can be used to specify the priority of requirements and the performance metrics associated with those requirements. Breaking the set into "requirements" and "desires" is one way to specify priorities. Listing thresholds versus objectives for performance requirements is another way to indicate the importance of different levels of performance for various requirements. The research team chose to use a set of low, medium, and high priorities to identify the relative importance of the requirements. The research team also chose to use separate performance requirements for the test bed and the field deployment. Therefore, a separate set of priorities and performance metrics are documented for each of the requirements for the test bed and for the field deployment. Separating the requirement priorities and performance metrics allows for the construction of a test bed that focuses on the areas still needing research, while specifying an ultimate system that will satisfy the expressed needs. Providing threshold and objective criteria for the performance metrics of the requirements was not considered beneficial at this point in the systems engineering process, but could be considered later. The performance criteria provided should be considered as thresholds. The full set of requirements is maintained in an Excel file, and includes the following columns:

- **Number** – A unique requirement number.
- **Requirement Category** – System phases (detect, verify, etc.). This column is only populated for rows with single-digit identifiers.
- **Architecture Agnostic Requirements** – Populated for the highest-level requirements (those with two-digit identifiers).

- **High-level Requirements** – Populated for high-level system requirements (those with three-digit identifiers).
- **Rationale** – Populated for all rows with two- and three-digit identifiers. It contains the rationale for the requirement.
- **Test Bed Priority** – Populated for all rows with two- and three-digit identifiers. It contains the priority for implementation of the requirement in the test bed environment, and has a value of low, medium, or high.
- **Test Bed Performance** – Populated for all rows with two- and three-digit identifiers. It contains the performance specification for the requirement in the test bed environment. The performance specifications indicate the threshold performance needed for the requirement.
- **System Priority –** Populated for all rows with two- and three-digit identifiers. It contains the priority for implementation of the requirement in the field deployment environment, and has a value of low, medium, or high.
- **System Performance** – Populated for all rows with two- and three-digit identifiers. It contains the performance specification for the requirement in the field deployment environment. The performance specifications indicate the threshold performance needed for the requirement.
- **Traceability Number** – A set of two columns that provide traceability between the requirements and the needs specified in the ConOps document, and the "High-level Requirements" and the "Architecture Agnostic Requirements." For rows with two-digit identifiers (i.e., Architecture Agnostic Requirements) there is only traceability to one or more needs identified in the ConOps. For three-digit rows, there should always be a reference tracing to the "Architecture Agnostic Requirement" under which the requirement is grouped. In some cases, there is also a specific need (or needs) that the requirement addresses.
- **Comment** – Pertinent comments about the requirement.
- **Traceability Statement** – A set of two (2) columns analogous to the "Traceability Number" columns containing the test of the need or requirement to which the requirement is traced. If the requirement traces to multiple needs, the cell contains only a notation that there are multiple needs.

In addition to capturing the requirements, performance metrics, and traceability within the spreadsheet, the project team also captured the user needs, as documented in the ConOps, to facilitate traceability between the needs and requirements.

REQUIREMENTS, PERFORMANCE, AND TRACEABILITY

Extracted portions of the functional requirements, system performance, and traceability are located in the appendix.

CHAPTER 7: EMERGENCY SERVICE PROVIDER INTEGRATION

As discussed in Chapter 4 and shown in Figure 39, current applications/systems for WWD event response are generally stand-alone and require moderate to high levels of human interaction for decision-making. Integration of emergency vehicles, especially law enforcement, into a CV WWD Detection and Management System provides new opportunities to improve response time and thus safety of the road network. In order to gain a better understanding of current emergency service provider procedures, needs, and perceptions of the integration of CV technology, the research team reviewed literature and conducted structured telephone interviews with several first responders. The research team also developed preliminary connectivity concepts for emergency service providers.

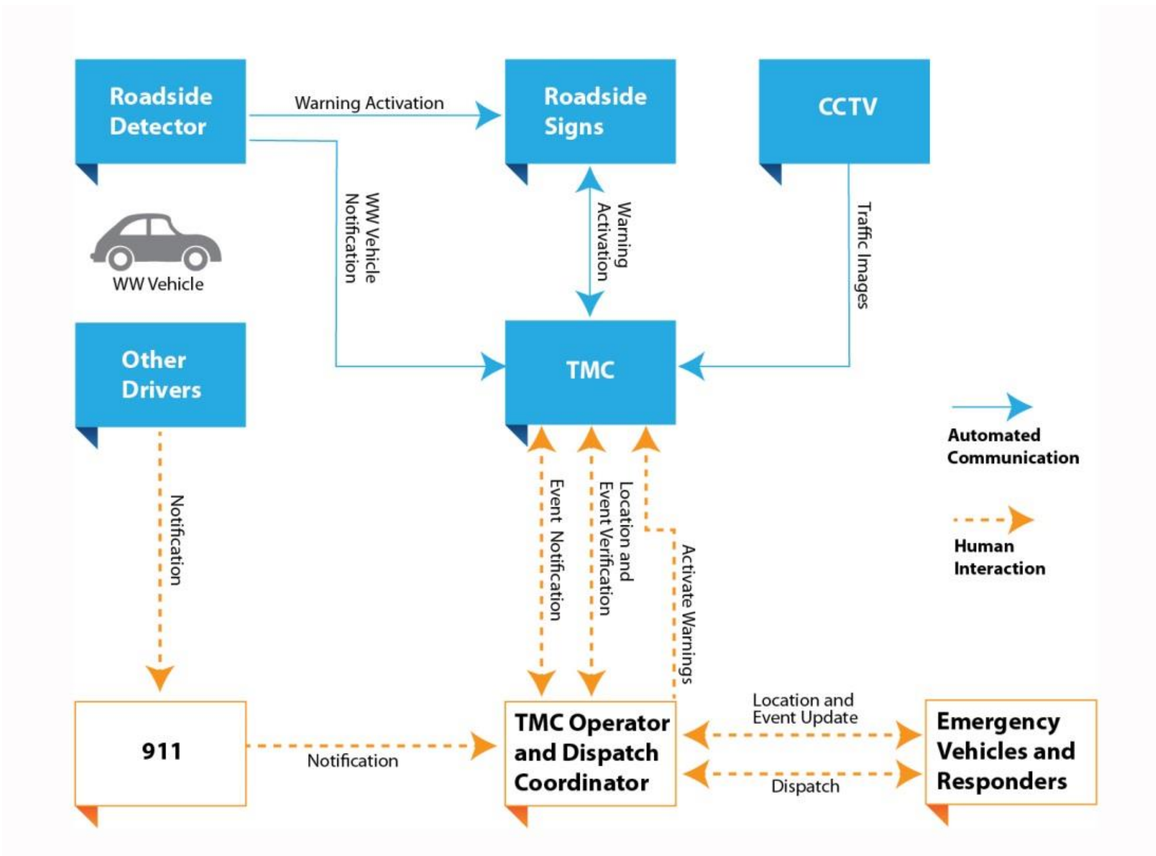


Figure 39. Current Integration of Emergency Vehicles in WWD Event Response.

EMERGENCY SERVICE PROVIDER RESPONSE TO WWD EVENTS

Literature Review

In a 2012 report, the National Transportation Safety Board (NTSB) described some law enforcement intervention practices (*1*). Law enforcement may be informed of WWD incidents by command centers, which can also notify other drivers through DMSs. On controlled-access highways (i.e. freeways), law enforcement officers have different options, which often involve high risk, to intercept the wrong-way vehicle:

- Drive in the opposite direction with the flow of traffic and attempt to gain the driver's attention with emergency lights, sirens, and spotlights.
- Deploy tire deflation techniques or entangler stopping systems to the wrong-way vehicle.
- Conduct a traffic break to reduce the speed of the wrong-way vehicle.
- Create a roadblock with a patrol car that can be either stationary or moving.
- Perform a pursuit intervention technique where the front corner of a patrol vehicle makes enough contact with the rear corner of a wrong-way vehicle that it starts to rotate and eventually stalls so that other officers can intervene before the vehicle continues the wrong-way.
- Pin the wrong-way vehicle against a barrier (continuous median barrier).

The methods described above often involve high risk. Therefore, the NTSB recommended that the International Association of Chiefs of Police and National Sheriffs Association collaborate to create a best practices document for all law enforcement officers to follow.

The National Sheriffs' Association released a *Wrong-Way Driving Model Policy* the following year with the goal of establishing set guidelines for responding to wrong-way drivers (*30*). To pick the most appropriate response method, officers should consider the "condition of driver, environmental and road conditions, vehicular and pedestrian traffic, the safety performance of the wrong-way driver, and whether other people are in the emergency vehicle (*30*)." Preparation is a key component. The emergency vehicle with the most markings and emergency lights should be used and equipped with warning equipment that corresponds to the chosen response method. Motorcycles may be used if there is not another marked vehicle available. Officers should have completed initial and periodic updates in training. Traffic laws should not be violated during the response measure. When responding to a wrong-way driver event, the officer should convey the location, direction, and speed of the wrong-way driver, as well as description of vehicle, to communications personnel. The officer is responsible for updating this information to communications personnel while in response to the WWD event. Communications personnel should notify available supervisors of the incident and relay necessary information to other officers and jurisdictions. The role of the supervisor is to ensure that the proper steps are followed upon receipt of the updated wrong-way vehicle information. Non-force methods should be used by trained officers to stop the wrong-way vehicle and subsequent safety procedures should be followed after stopping the vehicle.

If the wrong-way driver crosses into another state, the law officers should comply with laws of both states. The actions of the officers in the bordering state are governed by the officers' agency, inter-jurisdictional agreements, and laws of the state. Once the wrong-way vehicle is stopped, the wrong-way driver must complete a Standard Field Sobriety Test. The supervisor should request a Drug Recognition Expert if he/she suspects that drugs or alcohol was involved. After the incident, responding officers shall file a report that is checked by the supervisor. The department shall periodically review reports.

Structured Telephone Interviews

The research team identified five key areas in which to seek information about user needs for CV systems:

- Dispatch Center 911 call handling.
- Dispatch Center communications with patrol officers.
- Chain of Command in decision making.
- Inter-agency coordination.
- Integration of CV into existing systems and procedures.

Using these five themes, the research team developed a series of open-ended questions to explore the details of current dispatching and response operations. The questions were arranged such that a broad question was asked initially in each section, and the respondent given the opportunity to explain processes. A series of follow-up questions were asked only if the initial response did not address that specific detail. Once a draft interview script was completed and vetted by the research team members, a practice interview was conducted with a TTI personnel member who is a former police officer. This practice resulted in some re-ordering of questions and provided a sense of the amount of time needed to complete the interview. The goal was to spend no more than 15 minutes speaking to the officers out of respect for their time.

This activity was considered human subjects research by the Texas A&M University Office of Human Subject Protection. For this reason, all participant recruiting materials and interview questions were reviewed and approved by the Texas A&M Institutional Review Board (IRB) before conducting the interviews. This review included assurances of confidentiality of responses and reporting in a way that does not identify the respondent.

The research team identified interview participants from the project's expert panel, referrals by regional TMC personnel, and other personal contacts. An invitation to participate was sent via email and a time for the phone interview was scheduled. The researchers sent invitations to a cross-section of people representing urban and rural areas, different governmental agencies, and different functions in the organization. City police departments, county sheriff's offices, Department of Public Safety troopers, motorist assistance programs, and toll road authorities were invited. The response rate was lower than desired. Only four people participated in the interviews representing three major urban centers and one rural area in Texas, as well as state, city, county, and toll road law enforcement agencies. The sections below summarize the responses received. The consistency of responses across the four people does demonstrate that the response protocols are similar across agencies and regions.

Dispatch Center 911 Call Handling

When a 911 call is received, the operator asks for the location of the WWD event and a description of the vehicle. Depending on the reported location of the vehicle, the call is transferred to the appropriate service area, which may be to a secondary 911 center managed by a toll authority, county, or individual municipality. The dispatcher may ask the caller for additional information such as make, model, color, license plate, number of occupants, speed, lane of travel, and time of observation.

For some tolling authorities, their dispatch center may contact local municipal police for assistance, particularly if their nearest patrol officer is far away from the reported location of the wrong-way vehicle. Highway motorist assistance patrol vehicles may also be dispatched to the area to assist in locating the wrong-way vehicle and to travel with emergency lights on to alert motorists of a potential problem.

When available, the dispatch center will contact the local TMC to request assistance with locating and verifying the wrong-way vehicle. The TMC operator will use traffic surveillance cameras to locate the wrong-way vehicle based on the last reported location. Often a series of 911 calls is received each reporting a different location along the path. This information also assists in locating the wrong-way vehicle.

For those agencies with automatic detection systems utilizing loop detectors or radar at on-ramps, when a WWD alert is received, a light or tone in the TMC is activated to immediately draw attention to the detection. One agency's automated system also immediately puts the relevant camera feed on to the TMC video wall and activates DMSs.

The agencies reported that the 911 operators and dispatch personnel are good at getting the wrong-way vehicle description information. They will query drivers for landmarks and cross-streets if callers are unsure of their current locations. When asked what additional information they would like to obtain from the initial report, the most common item desired was license plate information. The vehicle description information (preferably with license plate) is important because it helps officers locate the vehicle if it self-corrects and exits the highway. Previous studies have found that many wrong-way drivers are intoxicated; therefore, law enforcement would still like to pursue them even if they self-correct or exit the highway. Having a detailed vehicle description is necessary in the rare event that two wrong-way drivers are actually active at the same time so that pursuit of the second one continues after the first one is resolved.

The overall duration of events was estimated at 10 to 15 minutes from notification to resolution (or interception) of the wrong-way vehicle. This would include any time needed to locate the vehicle if it had self-corrected and left the highway. It typically is only a few minutes before law enforcement personnel are in pursuit or on an intercept course. An event is declared to be over when a crash occurs or a traffic stop is executed. For those cases where a report is made and the vehicle cannot be located, the search continues until the TMC camera operators and law enforcement supervisors communicating with officers in the field verify that there is no wrong-way driver along the path indicated by the initial call. If the initial location was near an interchange, searches along intersecting highways will be initiated. They would also verify that no additional 911 calls have been received.

Dispatch Center Communications with Patrol Officers

For the law enforcement agencies interviewed, a WWD event would be treated as a "priority call," which triggers a special audio tone on police radios that precedes the general broadcast concerning the report. Officials use the radio rather than a law enforcement vehicle's mobile data terminal because the radio call can be heard by all officers immediately whether or not they are in their vehicle, the priority alert commands attention, and the radio is faster than entering the information into the data terminal system. The radio may also reach detectives or off-duty officers who could assist in locating the reported wrong-way vehicle. In addition to the responding general patrol officers, a traffic officer will also be assigned to respond if the agency has a special traffic division.

Some agencies use computer aided dispatch systems, and thus have location information about patrol vehicles. Agencies that use automatic vehicle location (AVL) for their emergency vehicle fleets would also have the ability to dispatch a vehicle that is closest to the event location or incident scene. However, the agencies interviewed reported that when officers hear the radio call, they self-identify as being near the reported location and that this method is quicker than consulting GPS locations of nearby vehicles. When coordinating a downstream response, the GPS system may be used more in order to locate good access points for intercepting the wrong-way driver.

All the interviewees stressed that a WWD report, once verified by cameras or an officer, is an "all hands on deck" situation and treated with the highest priority. There is great urgency in stopping the driver and the greatest challenge is finding their exact location.

Chain of Command in Decision Making

All of the interviewees reported that the responding officer has great autonomy in deciding how to proceed. This is based on their eyes on the situation and their knowledge of the road system. Supervisors will be monitoring the radio calls in order to verify that the best response is being made. The supervisor may be able to check the GPS map, get a better "bird's eye" view of the route, and suggest possible intercept points. One agency reported that their system allowed them to direct TMC camera feed directly onto the officer's mobile data terminal so the officer can see the general make and model of the wrong-way vehicle.

Inter-agency Coordination

With advances in radio system inter-operability and CAD systems, communication across law enforcement agencies is much better than in the past. Dispatch centers of different agencies routinely call each other with requests for assistance. Neighboring jurisdictions are typically alerted that a wrong-way vehicle has been detected so that nearby officers can render assistance and also to alert them in case the vehicle attempts to exit the highway onto surface streets or intersecting facilities.

When a pursuit crosses jurisdictional lines (for instance when a roadway crosses county lines), the officer initiating the pursuit stays engaged. The neighboring jurisdiction, having been notified by the dispatch centers talking to each other, may position its officers downstream to aid in an interception.

The toll agencies and law enforcement entities in rural areas do not report directly to TxDOT that there is a WWD event. However, in urban areas, law enforcement agencies typically have an officer located at the TMC. When that officer receives information from the dispatch center, they share it with other TMC personnel and work together to locate and verify the WWD event.

Integration of Connected Vehicles into Existing Systems and Procedures

The main benefit of CV systems identified by the interviewees was automatic detection and location information. If the vehicle itself could identify that it is going the wrong way that information may become available to dispatch via roadside equipment. This would be viewed as reliable information, similar to an automatic detection system. CV technology was also viewed as being able to assist in knowing that a vehicle U-turned or otherwise self-corrected and was no longer an immediate threat.

Once detected, the respondents thought the emergency response procedures would be the same with the added benefit of possible updates on location by subsequent messages from the CV. Three of the four respondents felt the detection message should still go to central dispatch first rather than directly to a nearby law enforcement vehicle so that dispatch decisions can be made there. One respondent desired a system that would in fact require a fair amount of intelligence and processing. In his view, the wrong-way vehicle could send a message directly to the nearest police vehicle. He noted that valuable response time is lost in relaying information through dispatch and verifying with TMC cameras.

Conclusions

It became clear to the research team that the officials interviewed were under the impression that CV systems were going to be able to provide a "moving blip" of an individual car that could be traced along a path and easily located. Some of the interviewees also believed that the CV signal would include vehicle registration data so that an exact vehicle description would be available. The U.S. Department of Transportation's vision for the CV systems includes safeguards for privacy that explicitly guard against such vehicle tracking. One conclusion of this research is that further education is needed with the law enforcement community about the privacy settings inherent in CV messages.

The user needs identified in this research highlight the importance of knowing the location of the wrong-way vehicle. Any system should focus on providing specific and updated location information throughout the event.

Each of the agencies interviewed expressed interest in participating in any demonstration projects planned by TxDOT. Procedures are in place to review any in-vehicle technology placed in law enforcement vehicles which would have to be followed, but they were all supportive of our efforts.

PRELIMINARY CONNECTIVITY FOR EMERGENCY SERVICE PROVIDERS

In Chapter 5, the research team presented a ConOps in which the role of law enforcement and other emergency service providers was discussed within the paradigm of CV technology. One of the primary benefits of deploying CV technology to law enforcement vehicles is the shortened delay time between detection of a wrong-way driver, and alerting law enforcement personnel. The functional requirements presented in Chapter 6 showed that once a wrong-way vehicle is detected by the TxDOT CV WWD Detection and Management System, TMC operators will notify other stakeholders, including law enforcement central dispatch. In addition, the project team envisions that the system will have the capability to directly alert nearby law enforcement vehicles equipped with CV technology. Although V2V notification depends on a significant market penetration of CV technology, which may not occur for a decade or more, law enforcement could immediately benefit from implementing a V2I system using DSRC technology.

In this deployment, DSRC devices would be permanently mounted to roadside infrastructure at or near exit ramps that have been designated as WWD detection zones. In order to detect wrong-way vehicles that are not CV-equipped, traditional detection devices such as microwave, magnetometer, laser, and radar devices would be installed, and their data streams would be interfaced with the DSRC RSE, perhaps using a separate computing platform. Many existing WWD detection technologies, however, are prone to unacceptably high false-positive detection rates. To minimize the effects of these false-positives, the RSE or separate computing platform would filter the incoming data and only generate a WWD alert message once a detection threshold has been reached. This threshold may be determined using a combination of attributes such as the number of reported detections from the traditional sensor(s) over a designated timespan. This filtering mechanism would need to be calibrated based on the performance of the sensor with which it is interfaced but would provide for a more robust overall system response for the WWD detection.

The law enforcement vehicles themselves would then need a DSRC onboard device to communicate with the RSE(s) within the test zone. The research team has successfully installed such devices in vehicles using self-contained hardware and non-permanent mounting techniques. The SwRI-developed portable onboard device (POD) only requires a 12 volt power supply, and the placement of the DSRC/GPS antenna on the roof of the test vehicle using a magnetic mounting surface. The POD itself consists of a small power management device, a power over Ethernet (PoE) device, a DSRC radio, and an Android tablet for displaying CV messages and enabling a user to interact with the system. All of this equipment can be contained in a small Pelican case (Figure 40).

The transit case is closed during operation and can be secured in a vehicle wherever is convenient. CV applications run on the DSRC radio, which communicates with the Android tablet via Wi-Fi and can be mounted to the vehicle’s windshield using the included tablet mount. An audio interface to the driver is possible if that is preferred over a tablet. A schematic for the system is shown in Figure 41.

Figure 40. Example of POD.

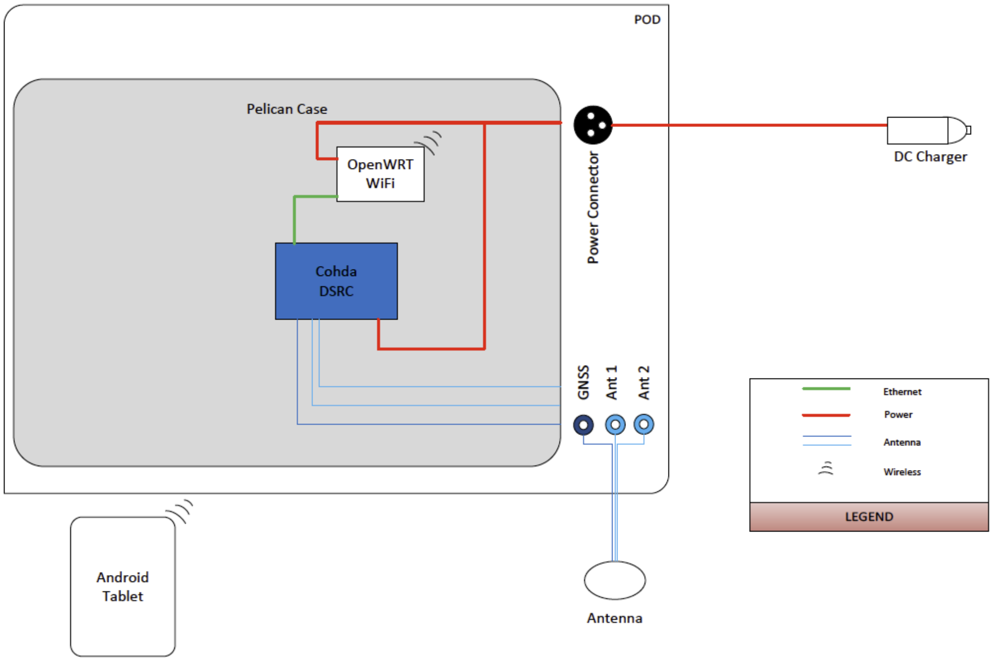


Figure 41. POD Schematic.

Law enforcement vehicles could be equipped with CV technology immediately by using a POD, which could be installed within the vehicle according to law enforcement personnel requirements. The installation of a POD would be a near-term solution for equipping law enforcement vehicles with CV technology and would be expected to be replaced by functionally-equivalent consumer products in the future. One area of research that could be conducted using the POD system is secure communication for law enforcement and other emergency vehicle DSRC devices. The CV program as currently outlined does not address the need for some devices to behave differently than others. For example, the current standards governing this technology dictate that a BSM is transmitted by vehicles at 10 hz. This message contains, among other data, information on the vehicle's current GPS position, heading, speed, and its path history for the previous 300 meters. This requirement, however, may not be acceptable to law enforcement and may require that DSRC devices installed in law enforcement vehicles exhibit modified behaviors.

Similarly, law enforcement may benefit from receiving a WWD alert message from an RSE that differs from the WWD alert message that is broadcast to all CVs within the RSE's communication range. It may be desirable to target a message from an RSE to only law enforcement vehicles within communication range or even to a specific law enforcement vehicle. This may require not only a special message format but also encryption or other layers of security. These concepts could be explored using the CV WWD Detection and Management System test bed, and the findings could be used to inform the applicable standards bodies, application developers, and hardware vendors.

CHAPTER 8: HIGH-LEVEL SYSTEM DESIGN

This chapter provides a high-level system design concept for the proposed CV WWD Detection and Management application. A high-level design is the transitional step between what the system does and how the system will be implemented to meet the system requirements (i.e., architecture and interfaces). This high-level system design establishes the relationships between hardware and software components and the interfaces necessary to execute the application. It also provides the framework for development of each individual components and subsystems needed to deploy a CV WWD application.

OVERVIEW

Figure 42 provides the high-level system design for the TxDOT CV WWD Detection and Management System. The concept system consists of five primary functional modules, which are shown in green in the diagram:

- The Wrong-Way Detection Module.
- The Wrong-Way Notification Module.
- The Wrong-Way Verification Module.
- The Wrong-Way Alert Module.
- The Wrong-Way Data Warehouse.

The system is also expected to interface several existing functional elements of the TxDOT LoneStar ATMS. These elements are shown in orange in Figure 42 and include the following:

- The TxDOT LoneStar DMS Modules.
- The TxDOT LoneStar Operator Interface.
- The TxDOT LoneStar Wrong-Way Warning Sign Module.
- The TxDOT LoneStar Law Enforcement Interface.

The following sections provide a high-level functional description of each of the primary modules.

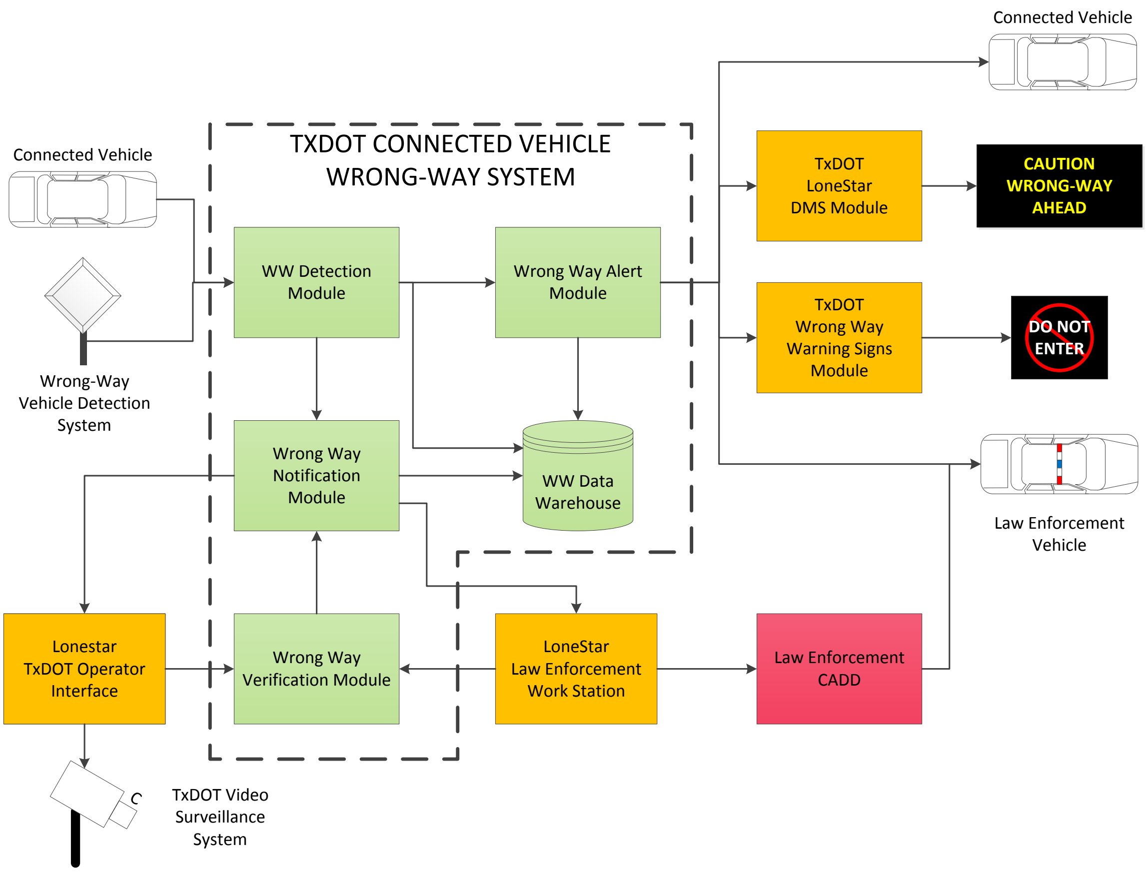


Figure 42. High-Level System Design.

Wrong-Way Detection Module

This module would be responsible for receiving data and processing it to determine if a vehicle is traveling in the wrong way on a freeway. The module may be designed to receive data from two primary sources: connected vehicles and infrastructure sensors.

CV Detection Subsystem

The Wrong-Way Detection Module could be configured to receive BSMs from CVs traveling past RSE stations adjacent to the roadway. The BSM contains information about the current speed and direction of travel of the CV. This information is updated every 1/10 of a second.

Upon receiving a BSM from a CV, the Wrong-Way Detection Module could compare the speed and direction of travel of each CV to thresholds established for each RSE. If the Wrong-Way Detection Module determines that a CV is traveling in the wrong direction, it could issue a message to the Wrong-Way Notification Module for further processing. The detection message sent to the Wrong-Way Notification Module could include the following data elements:

- The identification and mile marker location of the RSE where the wrong-way vehicle was detected.
- The speed and direction of travel of the wrong-way vehicle.
- The time that the wrong-way vehicle was detected.
- A flag indicating the wrong-way vehicle was detected by the CV Detection Subsystem.
- Any optional data elements contained in the BSM data which could potentially be used to re-identify the vehicle at another upstream detection point.

Infrastructure Sensor Detection Subsystem

The Wrong-Way Detection Module could also have the ability to detect wrong-way vehicles using infrastructure sensors, which could be installed at strategic locations on the freeway. The Infrastructure Sensor Detection Subsystem should have the capability of receiving inputs from the following types of infrastructure sensors: radar, in-ground loops, and/or magnetometer-based detection systems. It is expected that each of these types of detection systems will have their own logic for identifying vehicles that are traveling in the wrong-detection and will simply issue an alarm or flag indicating that a vehicle is traveling in the wrong direction. Furthermore, it is expected that one or more infrastructure sensors will be installed at a detection station and that each detector station will be associated with a particular location on the freeway (e.g., mile marker). The Infrastructure Wrong-Way Detection Subsystem could be responsible for monitoring the alert status of each of the infrastructure wrong-way detector. If the Infrastructure Wrong-Way Detection submodule detects a change in alert status of any of the sensors associated with a detector station, it could issue a detection message to the Wrong-Way Notification Module. This module might contain the following information:

- The identification and mile marker location associated with the sensor station where the wrong-way vehicle was detected.
- The speed and direction of travel of the wrong-way vehicle (if available from the sensor).
- The time that the wrong-way vehicle was detected.
- A flag indicating the wrong-way vehicle was detected by the Infrastructure Sensor Detection Subsystem.

Wrong-Way Notification Module

The Wrong-Way Notification Module would be responsible for sending notification messages to both the TxDOT LoneStar ATMS, as well as to other entities that are capable of receiving center-to-center alert messages from the TxDOT LoneStar ATMS. To do this, the Wrong-Way Notification Module should have the capability to receive all the alert status messages issued by the Wrong-Way Detection Module and formulate properly formatted messages that can be processed by the TxDOT LoneStar ATMS.

As it is possible that the same wrong-way vehicle can be detected by both the CV Detection Subsystem and the Infrastructure Sensor Detection Subsystem, the Wrong-Way Notification Module must be able to synthesize the data from multiple detection messages to determine if it is a new, unique event, or multiple reports of the same event. The Wrong-Way Notification Module should also perform data quality checks on the messages to determine if detection alerts are false alarms.

After processing the data and performing quality checks on the data, the Wrong-Way Notification Module could assign an identification number associated with the suspected WWD event. The notification message could include the following type of information:

- Identification number of the suspected WWD event.
- Status of the WWD event.
- Current time stamp of the notification.
- Roadway and location (mile marker or cross street name).
- Speed and direction of travel of the wrong-way vehicle.
- Estimated arrival times at upstream mile markers or cross streets.

Wrong-Way Verification Module

The purpose of the Wrong-Way Verification Module is to allow TxDOT TMC operators and law enforcement personnel to verify that a wrong-way event is actually in progress. WWD events can be verified in a number of ways. The first way is through the TxDOT TMC Operator. After receiving notification of a possible WWD event, the TxDOT TMC Operator can use their video surveillance system to locate the vehicle. If the vehicle is observed traveling the wrong way, the operator can enter a message into the system indicating that the event has been confirmed.

Another way that a WWD event can be verified is if multiple 911 calls are received by the law enforcement dispatch center. After receiving multiple WWD notifications, the law enforcement center can issue a notification back to the CV WWD system that the event has been verified.

A final way that that a WWD event can be verified is through multiple detections being reported to different WWD detection systems. For example, if the Wrong-Way Detection Module detects that a wrong-way vehicle has been detected in both the Connected Vehicle and the Infrastructure Sensor Detection Subsystems, then the WWD event can be considered to be confirmed.

Wrong-Way Alert Module

The primary function of the Wrong-Way Alert Module is to active the response plan developed by TxDOT for managing WWD events in the implementation corridor. As a result, it could be responsible for performing the following functions:

- Producing and distributing properly formatted J2735 Roadside Safety Alert (RSA) messages for providing warning message to CVs.
- Producing and distributing warning alert messages for broadcasting over TxDOT Dynamic Message Signs.
- Activating appropriate WWD dynamic LED signs in accordance to the TxDOT response plan for the corridor.

The Wrong-Way Alert Module should generate warning messages immediately after the wrong-way vehicle is detected. It should also automatically generate a response plan based on the location of the current position of the wrong-way vehicle. The response plan may involve the generation of messages and activating devices for multiple RSE stations and dynamic message signs, depending on the location of the WWD event and the number and type of devices upstream of the wrong-way vehicle. As the position of the wrong-way vehicle is updated, the Wrong-Way Alert Module should automatically update the response plan.

Wrong-Way Data Warehouse

The last module of the CV WWD System is the data warehouse. The primary function of the data warehouse is to record and retain any relevant records associated with each WWD event detected and managed by the system. For each event the warehouse should retain the following information:

- The identification number of the wrong-way events.
- The roadway, mile marker location, and manner in which the WWD event was detected.
- The roadway, mile marker location and manner in which the WWD event ended (or terminated).
- All criteria time elements associated with the event, including time at which the event was detected, the time at which each entity (or stakeholder) was notified, the time (and by whom and how) the event was verified, and the time (and manner) in which the event was terminated.

The data warehouse should also contain a complete record of the traffic management responses associated with each event. This could include the following:

- The time, locations, and content of message(s) displayed on DMS activated during the event.
- The time and location of any infrastructure sign elements activated in as part of the response.
- The time, locations, and content of the RSA messages broadcasted from each RSE station during the event.

The data contained in the warehouse could be used to generate performance metrics to evaluate the system, and could be retained for an extended period of time as specified by TxDOT.

CHAPTER 9: WRONG-WAY DRIVER WARNING MESSAGES

The research team conducted one-on-one surveys to assess motorist understanding of wrong-way driver warning messages that were designed to be displayed on DMSs. The research team also investigated the use of RSA messages to provide warning to CVs about approaching wrong-way drivers.

WRONG-WAY DRIVER WARNING MESSAGES FOR DMS

For a recent TxDOT research project TTI researchers conducted focus groups to obtain motorists' opinions regarding the design of wrong-way driver warning messages to be displayed on DMSs(*6*). Based on the accepted message design principles, the focus group findings, and a review of currently used wrong-way driver warning messages, researchers developed the single-phase message shown in Figure 43. Recognizing that some TxDOT districts still have DMSs with only 15 characters per line, TTI researchers also recommended the alternative single-phase message shown in Figure 44. As part of Task 6 of this project, the research team conducted one-on-one surveys to assess motorist understanding of these two messages. This part of the technical memorandum documents the study design and results from these surveys.

WARNING
WRONG WAY DRIVER
REPORTED

Figure 43. Recommended Message (*6*).

WARNING
WRONG WAY VEH
REPORTED

Figure 44. Alternative 15-Character Messages (*6*).

This activity was considered human subjects research by the Texas A&M University Office of Human Subject Protection. For this reason, all participant recruiting materials and questions were reviewed and approved by the Texas A&M IRB before conducting the surveys.

Experimental Design

Researchers conducted the motorist surveys at Texas Department of Public Safety offices in four Texas cities: Bryan, Houston, Austin, and Forth Worth. Participants were required to be at least 18 years old and have a valid driver license. Researchers administered 30 surveys per message in each city, yielding 60 surveys in each city and 240 total surveys.

Researchers conducted a pilot in Bryan, Texas, to ensure that the instructions and format of the study instrument were clear to participants and that the desired information was obtained. The pilot study revealed that even though researchers told participants they were driving in the correct direction, participants thought they were driving the wrong-way and the message was warning them about that. Researchers felt this was a result of the messages being shown in isolation instead of in an actual roadway environment (Figure 45).

a) Form A.

b) Form B.

Figure 45. Initial Message Displays.

At the remaining three locations, researchers showed the warning messages on an actual DMS located over a multi-lane, bi-directional freeway (Figure 46). Participant feedback at these locations indicated a better understanding of the scenario. Therefore, the data collected in Bryan was not included in the results reported. The sample size in the final dataset for each message was 90 (180 overall).

a) Form A. **b) Form B.**

Figure 46. Final Message Displays.

Researchers based the survey demographics on the age and gender of the Texas driving population and the educational attainment from the U.S. Census Bureau (*31*, *32*). Table 9 summarizes the demographic distribution obtained for the survey, as well as the Texas-based demographics. While the gender and educational attainment are reversed in rates, it is believed that the results obtained in the study represent Texas drivers reasonable well.

Table 9. Participant versus Texas Demographics.

Sample	Gender		Age Group			Education	
	Male	Female	18-24	25-64	65+	High School Diploma or Less	Some College or More
Survey (n= 180)	53%	47%	13%	70%	17%	53%	47%
Texas (*31*,*32*)	49%	51%	13%	70%	17%	46%	54%

Each participant only viewed one message. They were told to imagine that they were driving the correct direction on a freeway. After reading the message out loud to the researcher, each participant answered the following questions:

- What information is this sign telling you?
- What is the problem?
- Where is the problem located?
- Do you think you could encounter a wrong-way driver on this freeway? Why?
- What driving action would you take after reading this sign, if any?

- Have you ever seen a warning message like this on an electronic sign? If yes, where? If yes, did you understand the sign and what action did you take?
- Do you have any suggestions for this type of warning message?

Data Analysis

Researchers entered all the data collected into spreadsheets, categorized participant answers to all questions, and computed percentages to assess motorist comprehension of the messages evaluated. A message was considered acceptable for use when 85 percent of the total survey participants correctly interpreted the meaning of the message (*33*). When the comprehension level was less than 85 percent, researchers used a confidence interval test with a 5 percent significance level (alpha=0.05) to determine if the comprehension percentage was statistically different from the 85 percent criterion. If 0.85 fell within the boundaries of the confidence interval, then the level of comprehension for the tested message was not statistically different from 85 percent.

Results

Motorist Understanding of the Abbreviation for Vehicle

Previous studies have shown that VEH can be used as an abbreviation for vehicle with a prompt word (i.e., STALLED VEH and EMER [emergency] VEH) (*34*, *35*, *36*). The research team used the first portion of the survey where the participant read the message out loud to determine if the participants understood the abbreviation for vehicle (i.e., VEH) when used with WRONG WAY. Among the 90 participants that viewed Form B, 77 percent read VEH as vehicle. The confidence interval for these data was 0.85 to 0.68, which includes 0.85. This means the comprehension level of VEH was not statistically different from the 85 percent criterion.

Of the 23 percent of participants that did not say vehicle, 81 percent initially felt that VEH was an acronym. The majority thought “V” was vehicle but could not figure out what the “E” and “H” stood for. Also at first, 19 percent of participants were not sure what VEH meant. After further consideration and discussion, 95 percent of those that did not initially say vehicle understood that VEH was the abbreviation for vehicle.

Motorist Understanding of the Overall Message

A review of the results from the remaining questions revealed that both messages yielded similar responses. Thus, the research team combined all data for further analysis. Table 10 indicates that the majority of participants (98 percent) understood that the problem was a wrong-way driver on the freeway downstream of their location. These findings confirm that the location of the problem (i.e., ahead) is implied by the messages. The other 2 percent thought the sign was telling them they were going the wrong way.

Table 10. Percentage of Responses Regarding Problem.

Location	What is the problem?		Where is the problem located?	
	Wrong-Way Driver	Other	Ahead on Freeway	Other
Austin (n=60)	97	3	100	0
Fort Worth (n=60)	97	3	98	2
Houston (n=60)	100	0	95	5
Total (n=180)	98	2	98	2

Table 11 contains the responses to the question, "What driving action would you take after reading this sign?" Eighty percent of the participants state that they would use caution, watch for the wrong-way vehicle, and/or slow down. These answers confirm that non-specific driving actions are implied in the messages. Therefore, wrong-way driver warning messages do not need to contain extra text such as USE EXTREME CAUTION. Interestingly, many participants said they would take a specific driving action: 48 percent would pull over to the shoulder, 26 percent would exit the freeway, and 16 percent would continue down the roadway in the right lane. Even though calls to 911 are currently the primary method used to detect a wrong-way driver, only 9 percent of participants commented that they would call 911.

Table 11. Percentage of Responses Regarding Proper Action.

Location	Use Caution, Watch for Vehicle, and/or Slow Down	Pull Over to Shoulder	Exit Freeway	Move to Right Lane	Call 911	Other
Austin (n=60)	88	42	22	27	7	3
Fort Worth (n=60)	87	53	30	8	13	2
Houston (n=60)	63	48	27	12	7	0
Total (n=180)[a]	80	48	26	16	9	2

[a] Total responses is more than 100 percent since participants could provide multiple responses.

Familiarity with Wrong-Way Driver Warning Messages

Only three participants indicated that they had seen a wrong-way driver warning message before this survey. One person saw a wrong-way driver warning message in the Netherlands. He remembered that the message was GHOST DRIVERS AHEAD, but he did not remember what action he took. One other individual had seen a wrong-way driver warning message on I-30 in Fort Worth. He did not remember what the message said, but he did remember slowing down. The third person had seen a wrong-way driver warning message in Chicago. He also did not remember the message but indicated that he moved to the shoulder until the wrong-way vehicle passed him.

Participant Suggestions

Several participants made suggestions regarding the wrong-way driver warning messages. The most frequent comment dealt with the desire for more information about the situation (e.g., time, location, action). However, the majority of them understood that the situation would be constantly changing, making it challenging to monitor and update in a timely manner. The second most frequent comment addressed the need for the sign to catch the attention of motorists and to distinguish the wrong-way driver warning message from other DMS messages. These comments support a recommendation from the previous project to activate beacons on the DMS when a wrong-way driver warning message is displayed (*6*). The entire single-phase message should be flashed only if the DMS does not have beacons. One line of these messages should never be flashed.

WRONG-WAY DRIVER WARNING MESSAGES FOR CONNECTED VEHICLES

RSA Messages

RSAs are alert messages that provide warning information of nearby hazards to travelers. RSAs are sent to connected vehicles from infrastructure (e.g., roadside equipment). RSA messages are intended to provide simple alerts (such as “bridge icing ahead,” “train coming,” or “ambulance operating in the area”) to travelers either in their vehicle or on a portable device through the DSRC radio. These messages are intended to deal specifically with mobile hazards such as WWD events, construction zones, or roadside events that may be transient in nature.

RSA messages are not to support V2V cooperative communications, mayday, or other safety applications.

Not just any information can be sent in an RSA message. Instead, the construction of the RSA messages (and the information provided through the message) is governed by Society of Automotive Engineers Standard J2735 Dedicated Short-Range Communication (*37*). This standard provides a rigid structure for the way messages are formed and the content of information contained in the messages. RSA messages are built by combining integer codes associated with International Traveler Information Systems (ITIS) phrases. These codes are intended to standardize phrases and terminology used to describe incidents and other types of hazards that a driver may encounter. The list of codes is contained in SAE standard J2540.2 (*38*). The message elements were developed to be consistent with the data elements contained in the Institute of Transportation Engineers (ITE) Traffic Management Data Dictionary (TMDD). Using a standardized code list allows any device (assuming it is constructed to standards) to receive and interpret the content of an RSA message in a consistent manner. However, using a standardized code list restricts the type of information that can be conveyed to the device to only those specific phrases contained in the code list. RSA messages are not intended to support the transmission of free-form text information to connected vehicles.

The RSA message is only a mechanism to convey alert information to the vehicle and does not represent the final form in which the information is displayed and presented to the driver. A device inside the vehicle (either a portable device or the vehicle's "infotainment" center) is responsible for "un-packaging" the information contained in the message and generating a "display" of the content of the message. Each device is aware of its own position and heading and can use the content of the RSA message to develop a message that is specific to that individual device. For the purposes of this project, the research team has assumed onboard equipment manufacturers or after-market providers will develop properly formatted displays (which account for all the human-factor issues associated with developing those displays) to convey the information in RSA message.

Content and Format of RSA Message

The standard governing the content and format of the RSA message is contained in the SAE J2735 DSRC standard. While there are a number of individual data elements that are needed to construct an RSA message, the basic content of an RSA message, at its highest level, is shown in Table 12. Those elements that are shown as "Mandatory" in the table represent those portions of the message that MUST be present in order to have a properly formatted message. Optional elements represent those portions of the message that can be used to provide additional information pertinent to the message but do not necessarily have to be present to represent a properly formatted message. A discussion of each portion of the message is provided below.

Table 12. Elements of the SAE J2735 Roadside Alert Message.

Name	Description	Requirement
msgID	This portion of the message is used to define which type of DSRC message is being sent. A value of "11" is sent to indicate that the message is an RSA message.	Mandatory
msgCnt	This portion of the message is used to provide the sequence number within a stream of messages with the same message identification number. This can be used to send updates to previously sent messages.	Mandatory
typeEvent	An ITIS Phrase code used to identify the type of event to which all subsequent information contained in the message applies.	Mandatory
description	A sequence of up to 8 ITIS codes that are used to describe the event, give advice, or provide any other type of warning information about the event.	Optional
Priority	This portion of the message is used to convey the urgency of the message relative to other similar RSA messages received by the device.	Optional
Heading	The direction of travel, expressed in sixteen 22.5-degree slices of a unit circle starting from North and moving Eastward, for which the message is applicable.	Optional
Extent	The spatial distance over which the message applies and should be presented to the driver.	Optional
Position	A compact summary of the position, heading, rate of speed, etc. of the event in question, including stationary and wide area events.	Optional
furtherInfoID	A code used to link the message to other information about the event (e.g., an incident).	Optional
msgCRC	This portion of the message is used to convey the end of the message and is used for error checking.	Mandatory

The following describes how the elements of an RSA message could be used to convey information about a WWD event:

- The "typeEvent" message element would be used to identify that the content of the message pertains to a WWD event. The ITIS standards contain two codes that could potentially be used to convey information about a WWD event. This includes code 1793 "vehicle-traveling-wrong-way" and code 12310 "wrong-way."

- For the "description" message elements, the SAE J2735 standards allow up to 8 additional codes that can be used to provide more detailed information about the WWD event. This could potentially include information (location, lane, time, or distance) about the last known position of the wrong-way vehicle or the action required by the recipient (exit the freeway, move to the left-shoulder, stop, proceed with caution, etc.) in response to the WWD event.
- The "priority" element would be used to convey the relative urgency of the message (compared to other RSA messages currently active in the vehicle) using an integer ranging from zero to seven where zero represents a routine event. This message element is similar to the "priority" element used to provide hierarchy to dynamic message sign elements. Because of the critical nature of a wrong-way event, the "priority" assigned to a wrong-way RSA should be relatively high.
- The "heading" element of the message would be used to convey the direction of travel for which the message is intended. For example, if the normal direction of travel was northbound and the wrong-way direction of travel was southbound, the "heading" message element would be used to convey that the message was intended for northbound vehicles only by selecting the corresponding heading slices. Southbound vehicles who received the RSA would use this message element to determine that this particular message did not pertain to them but could potentially propagate the message to other vehicles in the northbound direction.
- The "extent" message element could be used to convey the distance downstream for which the message would remain active on the display. It could also be used to determine the message content displayed to right-way vehicle drivers. For example, right-way vehicles closer to the wrong-way driver may receive a different message then right-way vehicles further away.
- The "position" element could potentially be used to convey information about the direction of travel of the wrong-way vehicle (if known). The display on the vehicle could potentially be used to compute the relative distance and expected closure time (or distance) until the vehicle intercepted the wrong-way vehicle. This might be a very

valuable element to convey to emergency vehicles that might be tasked to intercept the wrong-way vehicle.

Potential RSA Messages for Right-Way Connected Vehicles

In developing potential RSA messages for right-way connected vehicles (i.e., vehicles traveling the correct direction about to encounter a wrong-way vehicle), the research team utilized the same general concepts for generating messages to be displayed on DMSs. Research has shown that in order to build a proper DMS message, the following questions need to be answered:

- What happened?
- Where?
- What and how many lanes affected?
- What is the effect on traffic?
- Who is the audience for the action statement?
- What action should motorist take?

Table 13 shows how the answers to these questions can be used to generate a proper content of an incident message for use on a dynamic message sign. The research team used the same concept to identify the type of information that should be conveyed to the drivers traveling in the correct direction that might encounter a vehicle approaching in the wrong direction. The team identified potential ITIS phrases that could be used to generate messages for a WWD event. Table 14 shows ITIS phrases that were identified. These elements could be combined to form various potential RSA messages. For example, these codes could be combined to generate an RSA message that contains the following information:

- Vehicle-traveling-wrong-way / Drive with extreme caution.
- Vehicle-traveling-wrong-way / Expected in [n] feet.
- Vehicle-traveling-wrong-way / Expected in [n] second[s].
- Vehicle-traveling-wrong-way / In left [right, center] lane.
- Vehicle-traveling-wrong-way / Exit [n] / Use next exit.
- Vehicle-traveling-wrong-way / Exit freeway.
- Vehicle-traveling-wrong-way / Use left [right, center] lane.

Table 13. Application of Questions to Generate DMS Incident-Related Message.

Question	Answer
What happened?	Accident
Where?	At Exit 45
What and how many lanes affected?	Left lane closed
What is the effect on traffic?	Major Delay
Who is the audience for the action statement?	Galveston Traffic
What action should motorist take?	Use Loop 610

Table 14. ITIS Phrases that can be used to Generate RSA Messages .

Message Element	Information Content	ITIS Phrase Code
What Happened?	Vehicle-traveling-wrong-way Wrong-way	1793 12310
Where?	Expected in [n] feet Expected in [n] mile[s] Expected in [n] second[s] Exit [n]	7705, 7683, [12545-12644], 8710 7705, 7683, [12545-12644], 8711[8712] 7705, 7683, [12545-12644], 8711[8712] 11794, [12545-12644]
Lanes Affected?	In Left Lane In Right Lane In Center Lane On Left-shoulder On Right-Shoulder	7683, 8195 7683, 8196 7683, 8197 7688, 8209 7688, 8208
Action to be taken?	Drive with extreme caution Stay in lane Stop on left shoulder Stop on right shoulder Use center lane Use right lane Use left lane Use next exit Exit freeway Travel in center lane Travel in left lane Travel in right lane Proceed to next exit	7170 7450 12294, 7688, 8209 12294, 7688, 8208 7716, 8197 7427 7428 7716, 13582, 11794 11794, 11778 8961, 7683, 8197 8961, 7683, 8195 8961, 7683, 8196 7714,13582,11794

SUMMARY AND RECOMMENDATIONS

Warning Messages for DMS

The motorist survey findings support the use of the two wrong-way driver warning messages shown in Figure 43 and Figure 44. However, there was some evidence that the abbreviation for vehicle (VEH) when used with WRONG WAY may be initially misunderstood.

Therefore, the alternative message in Figure 44 should only be used for DMSs with 15 characters per line. Anytime one of these messages is displayed on a DMS, the beacons located on the DMS should be activated. If the DMS does not have beacons, the entire message may be flashed. One line of these messages should never be flashed.

The motorist survey findings verified that the location of the problem (i.e., ahead) is implied by the recommended messages. The findings also confirmed that non-specific driving actions, such as use caution, watch for the wrong-way driver, and slow down, are inferred from the two recommended messages. Therefore, wrong-way driver warning messages do not need to contain extra text, such as USE EXTREME CAUTION.

Warning Messages for CVs

Although these data elements are available for use to generate wrong-way messages that can be broadcast via RSAs, a need exists to conduct human factors studies to determine motorist needs, comprehension, and interpretations of these data elements in a WWD context. For example, there is the potential to transmit different RSAs to right-way vehicles in the immediate vicinity of the wrong-way vehicle and those further away. However, it is unknown what information both of these audiences would want and/or need to take action to avoid the wrong-way vehicle.

It is also important to understand how motorists will respond to the information contained in potential RSAs. For example, it is unclear whether providing a time-based warning to the wrong-way vehicle (e.g., Expected in [n] seconds) will be interpreted similarly to distance-based warnings (e.g., Expected in [n] feet). Likewise, concerns exist as to how motorists will behave when presented with different types of action information, such as “Exit freeway” or “Stop on right shoulder.” These and other human factors issues should be examined in additional phases of this project to determine the most appropriate manner in which to provide WWD alerts in a CV environment.

CHAPTER 10: SUMMARY AND RECOMMENDATIONS FOR FUTURE RESEARCH

The goal of this project was to develop a concept of operations, functional requirements, and high-level system design for a CV WWD Detection and Management System. This system was designed to detect wrong-way vehicles, notify TxDOT and law enforcement personnel, and alert affected travelers. For this project, the system boundaries were identified as high-speed, controlled-access, freeway-type facilities. These included the main lanes of TxDOT freeways and major toll facilities, as well as their entrance and exit ramps. System boundaries *do not include* frontage roads, cross-street approaches of frontage road intersections or the intersection itself, or urban roadways operated by municipalities. The system was also not designed for multi-lane, divided highways without access control.

SUMMARY

To accomplish the project goal, the research team reviewed the state of the practice regarding ITS and CV technologies currently applied as WWD countermeasures and the WWD crash trends in Texas from 2010 to 2014. The research team also identified the user needs associated with the implementation of a CV WWD Detection and Management System and preliminary ways to connect with law enforcement. Based on these tasks, the research team developed a concept of operations, functional requirements, and a high-level system design for a CV WWD Detection and Management System.

One-on-one surveys confirmed motorist understanding of two wrong-way driver warning messages designed to be displayed on DMSs. Researchers also explored the use of RSA messages to provide warning to CVs about approaching wrong-way drivers. Based on the findings from all of these tasks, researchers developed recommendations regarding the next steps toward the implementation of a CV WWD Detection and Management System.

RECOMMENDATIONS

Prior to installing and evaluating a model field deployment of a CV WWD Detection and Management System at a site in Texas, the research team recommends the development of a proof-of-concept test bed at the TAMU Riverside Campus in Bryan, Texas. The purpose of the test bed is to provide an offline location for the research team and TxDOT to test and fine-tune the system components and operations prior to installing them on the open roadway.

To the extent possible, the test bed would replicate an actual field deployment, using the same technologies running the same processes as an actual field deployment. Figure 47 depicts the preliminary concept of the test bed configuration at the TAMU Riverside Campus. It shows three hypothetical ramps spaced approximately 1,500 feet apart and a wrong-way driver CV detection station installed upstream of each ramp. Each wrong-way driver CV detection station would consist of a DSRC radio and a processor unit. The DSRC radios would be powered by a POE injector. A wireless Ethernet network would be installed to connect the wrong-way driver CV detection stations in order to replicate TxDOT TMC field architecture.

Four TTI test vehicles would be equipped with SwRI-developed PODs. The POD system will allow the test vehicle to operate as a CV, providing BSMs, as well as receiving WWD alerts from other CVs and from the test infrastructure. The POD system also includes an Android tablet to display wrong-way driver warnings to vehicle operators, simulating an in-vehicle user interface.

In addition to installing the CV-based WWD system, the research team plans to install typical infrastructure-based systems that might integrate with the CV-based system. This includes installing a portable DMS upstream of the first ramp and an LED WWD sign and traditional detection device at the last ramp. These devices will be used to test the activation of TxDOT infrastructure devices using the CV-based system.

A need also exists to conduct additional human factors studies to determine motorist needs, comprehension, and interpretations of RSA data elements in a WWD context. These studies should also investigate the timing and frequency of messages relative to the location of the WWD detection. In addition, it is important to understand how motorists will respond to the information contained in potential RSAs. These and other human factors issues should be examined in additional phases of this project to determine the most appropriate manner in which to provide WWD alerts in a CV environment.

The lessons learned from the deployment in the test bed environment would be used by the research team to determine the design considerations for a model field deployment of the CV WWD Detection and Management System, which could be implemented in additional phases of this project. Using these design considerations, the research team would identify one location in

Texas to implement the system, conduct a feasibility study for that deployment, and identify any outstanding threats that could negatively impact a real-world application (e.g., integration of the system with the TxDOT Lonestar ATMS).

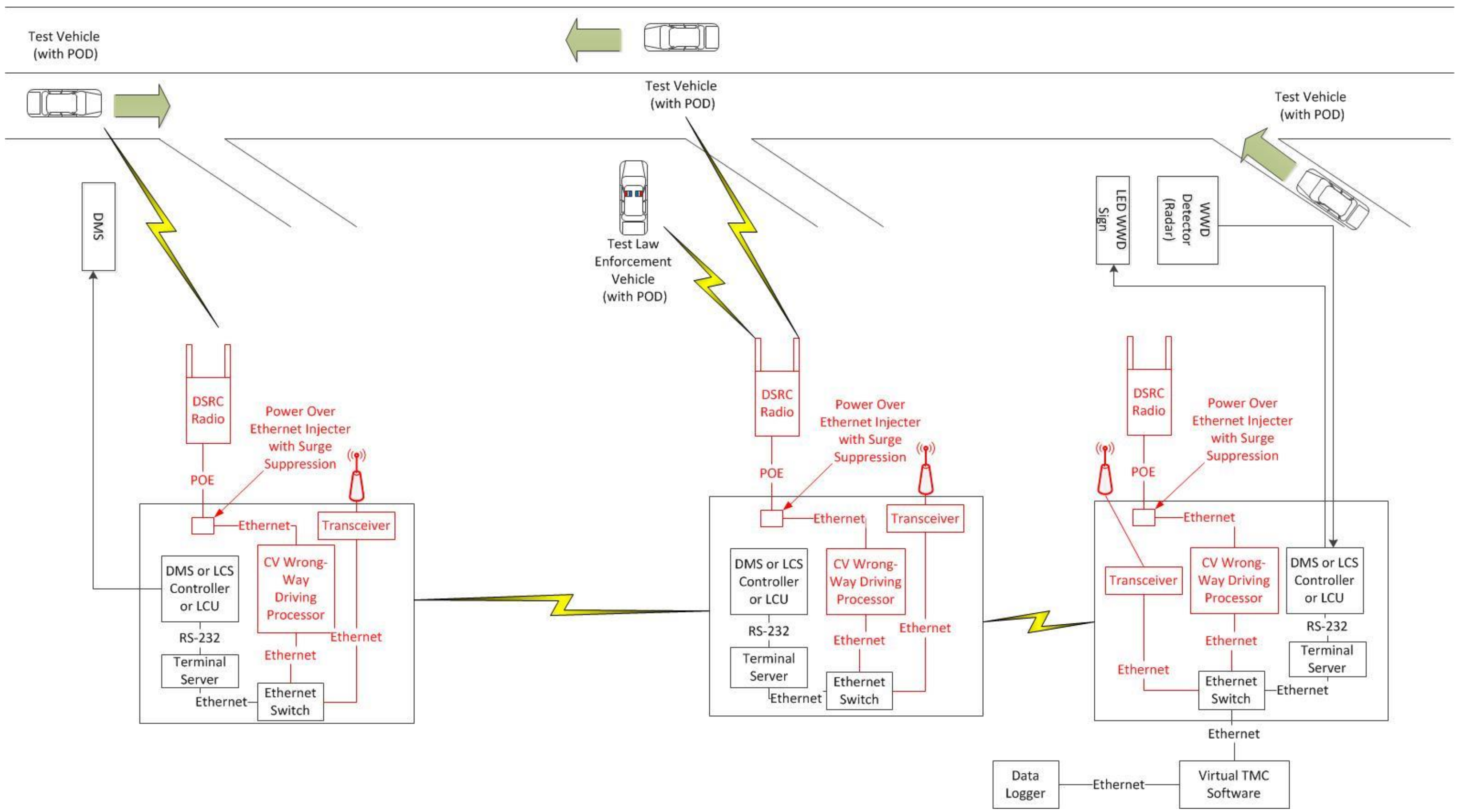


Figure 47. TAMU Riverside Campus Test Bed Schematic.

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APPENDIX:
FUNCTIONAL REQUIREMENTS

Table A1. Functional Requirements for a CV WWD Detection and Management System.

System Requirement	Description	Rationale	User Need Traceability
1. DETECTION			
1.1	The WWD System/Test Bed shall be capable of detecting a vehicle potentially traveling in the wrong direction in the area of WWD protection using **dedicated detection devices**.	If the system is not successful in detecting vehicles entering the area of WWD protection, the vehicles will present a significant danger to right way drivers.	1 1.1
1.1.1	Wrong-way vehicle detectors mounted near main lanes and at exits shall be capable of detecting vehicles entering the area of WWD protection in the wrong direction.	The current system architecture is expected to include detectors mounted near main lanes and at the exits.	1
1.1.2	Wrong-way vehicle detectors shall be capable of transmitting messages to RSE indicating that a vehicle potentially traveling in the wrong direction has been detected entering the area of WWD protection.	Timely response to the WWD event requires rapid automated transmission through the RSE to the TMC.	1
1.1.3	Wrong-way vehicle detectors shall be capable of transmitting messages including the identity of the detector to the RSE.	There is a need to be able to have the identity of the detector of the WWD event so that the response can be directed correctly.	1.2
1.1.4	Wrong-way vehicle detectors shall be capable of transmitting messages including the time of detection to the RSE.	Knowing when the WWD event was detected is critical to ensure that the response can be directed correctly.	1.4.3
1.1.5	Wrong-way vehicle detectors shall be capable of transmitting messages including the location of detection to the RSE.	There is a need to be able to have the location of the WWD event so that the response can be directed correctly.	1.2
1.1.6	RSE shall be capable of receiving messages from wrong-way vehicle detectors related to vehicles potentially traveling in the wrong direction.	The initial architecture for the WWD detection system will include transmission of the detection through the RSE.	1

System Requirement	Description	Rationale	User Need Traceability
1.1.7	RSE shall be capable of transmitting a TBD message to local CVs alerting them to the detection of a potential WWD event, including the time, location and heading of the detected vehicle.	Immediate notification of nearby CVs is necessary to minimize potential catastrophic events.	2.2
1.1.8	CV on-board equipment must be capable of receiving a TBD message that a potential wrong-way vehicle has been detected, including time, location, and heading information.	Immediate notification of nearby CVs is necessary to minimize potential catastrophic events.	1
1.1.9	CV on-board equipment must be capable of displaying alerts to the driver based on TBD messages indicating that a potential wrong-way vehicle has been detected, if appropriate.	The systems within other vehicles must be capable of responding to the alert messages.	1
1.1.10	CV on-board equipment must be capable of re-broadcasting the TBD messages indicating that a potential wrong-way vehicle has been detected, if appropriate.	The systems within other vehicles must be capable of responding to the alert messages.	1
1.1.11	RSE shall be capable of transmitting a message to the TMC indicting the location of the vehicle potentially traveling in the wrong direction.	Detected events need to be transmitted to the TMC system.	1.2
1.1.12	RSE shall be capable of transmitting messages to the TMC including the time of detection to the roadside equipment.	Knowing when the WWD event was detected is critical to ensure that the response can be directed correctly.	1.4.3
1.1.13	TMC system shall be capable of receiving messages from RSE indicating that a potential wrong-way vehicle has been detected, including the time and location of detection to the roadside equipment.	The TMC must be able to receive the alerts to display them to the operators.	1.2
1.1.14	The TMC system shall provide the capability to display to an operator received information that indicates that a potential wrong-way vehicle detector has detected that a vehicle is traveling in the wrong direction in the area of WWD protection.	The information that the vehicle has detected that it is traveling in the wrong direction must be displayed to an operator to facilitate verification of the WWD event.	1

System Requirement	Description	Rationale	User Need Traceability
1.1.15	The TMC system shall provide the capability to display to an operator the received vehicle location information, including route/roadway and nearest cross street, for a vehicle that has been detected potentially traveling in the wrong direction in the area of WWD protection.	The information about the location of the vehicle that has been detected traveling in the wrong direction must be displayed to an operator to facilitate verification of the WWD event.	1.2 1.2.1 1.2.2
1.1.16	The TMC system shall provide the capability to display to an operator received vehicle location information, including mile marker and latitude/longitude, for a vehicle that has been detected potentially traveling in the wrong direction in the area of WWD protection.	Additional information about the location of the vehicle that has been detected traveling in the wrong direction may be displayed to an operator to facilitate verification of the WWD event.	1.2.3 1.2.4
1.1.17	The TMC system shall provide the capability to display to an operator received detection time information for a vehicle that has been detected potentially traveling in the wrong direction in the area of WWD protection.	Operators need to know the time of detection to appropriately respond to the wrong-way event.	1.4.3
1.2	The WWD System/Test Bed shall be capable of detecting a CV potentially traveling in the wrong direction in the area of WWD protection using **Roadside Equipment**.	Continuing status of wrong-way events and detection of wrong-way events not caught at or being initiated at the exits requires detection of vehicles already in the roadway.	1 1.1 1.4 1.6.5
1.2.1	CVs shall be capable of transmitting Basic Safety Messages (BSMs) including their current location and heading.	One of the primary foci of this research is an evaluation of the use of CV capabilities to enhance the detection of WWD events.	1.2
1.2.2	RSE shall be capable of receiving BSMs from nearby CVs.	To detect WWD events by CVs, RSEs must be able to receive BSMs from CVs.	1.6.3 1.6.4
1.2.3	The map update system shall have the capability to provide RSE information about the configuration of roadways in the area of WWD protection.	RSEs need up-to-date local map information to compare to Connected Vehicles' location and heading to determine if the vehicle is traveling in the wrong direction.	1.2

System Requirement	Description	Rationale	User Need Traceability
1.2.4	RSE shall be capable of using a Connect Vehicle's location and heading, combined with local map information to determine if the vehicle is potentially traveling in the wrong direction.	Given both map information and vehicle location and heading information, the RSE must be capable of detecting a WWD event.	1.6.5
1.2.5	RSE shall be capable of transmitting a TBD message to local CVs alerting them to the detection of a potential WWD event, including the time, location and heading of the detected vehicle.	Immediate notification of nearby CVs is necessary to minimize potential catastrophic events.	2.2
1.2.6	CV on-board equipment must be capable of receiving a TBD message that a potential wrong-way vehicle has been detected, including time, location, and heading information.	Immediate notification of nearby CVs is necessary to minimize potential catastrophic events.	1
1.2.7	CV on-board equipment must be capable of displaying alerts to the driver based on TBD messages indicating that a potential wrong-way vehicle has been detected, if appropriate.	The systems within other vehicles must be capable of responding to the alert messages.	1
1.2.8	CV on-board equipment must be capable of re-broadcasting the TBD messages indicating that a potential wrong-way vehicle has been detected, if appropriate.	The systems within other vehicles must be capable of responding to the alert messages.	1
1.2.9	RSE shall be capable of transmitting a message to the TMC indicting the location of the vehicle potentially traveling in the wrong direction.	Detected events need to be transmitted to the TMC system.	1
1.2.10	RSE shall be capable of transmitting messages to the TMC including the time of detection to the roadside equipment.	Knowing when the WWD event was detected is critical to ensure that the response can be directed correctly.	1.4.3
1.2.11	TMC system shall be capable of receiving messages from RSE indicating that a potential wrong-way vehicle has been detected, including the location and time of detection to the roadside equipment.	The TMC must be able to receive the alerts to display them to the operators.	1.2

System Requirement	Description	Rationale	User Need Traceability
1.2.12	The TMC system shall provide the capability to display to an operator received information that indicates that Road Side Equipment has detected that a vehicle is potentially traveling in the wrong direction in the area of WWD protection.	The information that the vehicle has detected that it is traveling in the wrong direction must be displayed to an operator to facilitate verification of the WWD event.	1
1.2.13	The TMC system shall provide the capability to display to an operator the received vehicle location information, including route/roadway and nearest cross street, for a vehicle that has been detected potentially traveling in the wrong direction in the area of WWD protection.	The information about the location of the vehicle that has detected traveling in the wrong direction must be displayed to an operator to facilitate verification of the WWD event.	1.2 1.2.1 1.2.2
1.2.14	The TMC system shall provide the capability to display to an operator received vehicle location information, including mile marker and latitude/longitude, for a vehicle that has been detected potentially traveling in the wrong direction in the area of WWD protection.	Additional information about the location of the vehicle that has been detected traveling in the wrong direction may be displayed to an operator to facilitate verification of the WWD event.	1.2.3 1.2.4
1.2.15	The TMC system shall provide the capability to display to an operator received detection time information for a vehicle that has been detected potentially traveling in the wrong direction in the area of WWD protection.	Operators need to know the time of detection to appropriately respond to the wrong-way event.	1.4.3
1.3	The WWD System/Test Bed shall be capable of having a **CV detect that it is traveling in the wrong direction** in the area of WWD protection.	Given sufficient up-to-date map and location information, the vehicle itself may be the device that can most rapidly and reliably recognize that it is traveling in the wrong direction.	1 1.1
1.3.1	The map update system shall have the capability to provide CVs information about the configuration of roadways in the area of WWD protection.	To determine whether it is going in the correct or wrong direction, a CV must have up-to-date information about the local roadway configuration.	1.2

System Requirement	Description	Rationale	User Need Traceability
1.3.2	CV on-board equipment shall have the capability to detect the location of the vehicle.	The vehicle's on-board equipment can only detect that it is going in the wrong direction if it knows where it is with sufficient precision.	1.2
1.3.3	CV on-board equipment shall have the capability to determine from the map information and its location that it is a potential wrong-way vehicle.	The vehicle's on-board equipment must be capable of detecting that it is a potential wrong-way vehicle.	1
1.3.4	CV on-board equipment must be capable of transmitting a TBD message indicating that it is traveling in the wrong direction, including time, location, and heading.	The vehicle must get the information to RSEs and other vehicles for it to be useful.	1, 1.2
1.3.5	CV on-board equipment must be capable of receiving a TBD message that a potential wrong-way vehicle has been detected, including time, location, and heading information.	Immediate notification of nearby CVs is necessary to minimize potential catastrophic events.	1
1.3.6	CV on-board equipment must be capable of displaying alerts to the driver based on TBD messages indicating that a potential wrong-way vehicle has been detected, if appropriate.	The systems within other vehicles must be capable of responding to the alert messages.	1
1.3.7	CV on-board equipment must be capable of re-broadcasting the TBD messages indicating that a potential wrong-way vehicle has been detected, if appropriate.	The systems within other vehicles must be capable of responding to the alert messages.	1
1.3.8	RSE shall be capable of accepting a TBD message from a vehicle that has detected that it is traveling in the wrong direction in the area of WWD protection.	For a vehicle to alert the system that it is traveling in the wrong direction, the system must be capable of receiving messages from the vehicle.	1
1.3.9	RSE shall be capable of transmitting information, including location of detection, received in TBD messages from CVs to the TMC system.	There is a need to be able to have the location of the WWD event so that the response can be directed correctly.	1

System Requirement	Description	Rationale	User Need Traceability
1.3.10	RSE shall be capable of transmitting information, including time of detection, received in TBD messages from CVs to the TMC system.	There is a need to be able to have the time of detection of the WWD event so that the response can be directed correctly.	1.2
1.3.11	TMC system shall be capable of receiving messages from RSE indicating that a potential wrong-way vehicle has been detected, including the location and time of detection to the roadside equipment.	The TMC must be able to receive the alerts to display them to the operators.	1.2
1.3.12	The TMC system shall provide the capability to display to an operator received information that indicates that a vehicle has detected that it is traveling in the wrong direction in the area of WWD protection.	The information that the vehicle has detected that it is traveling in the wrong direction must be displayed to an operator to facilitate verification of the WWD event.	1
1.3.13	The TMC system shall provide the capability to display to an operator the received vehicle location information, including route/roadway and nearest cross street, for a vehicle that has detected that it is traveling in the wrong direction in the area of WWD protection.	The information about the location of the vehicle that has been detected traveling in the wrong direction must be displayed to an operator to facilitate verification of the WWD event.	1.2 1.2.1 1.2.2
1.3.14	The TMC system shall provide the capability to display to an operator received vehicle location information, including mile marker and latitude/longitude that indicates that a vehicle has detected that it is traveling in the wrong direction in the area of WWD protection.	Additional information about the location of the vehicle that has been detected traveling in the wrong direction may be displayed to an operator to facilitate verification of the WWD event.	1.2.3 1.2.4
1.3.15	The TMC system shall provide the capability to display to an operator received detection time information for a vehicle that has been detected traveling in the wrong direction in the area of WWD protection.	Operators need to know the time of detection to appropriately respond to the wrong-way event.	1.4.3

System Requirement	Description	Rationale	User Need Traceability
1.4	The WWD System/Test Bed shall be capable of accepting a message from **a CV that has detected that another vehicle is traveling in the wrong direction** in the area of WWD protection.	To permit the traffic operations personnel to respond to the WWD event, the information must be received and transmitted to the TMC.	1 1.6.2 1.6.3
1.4.1	The map update system shall have the capability to provide CVs information about the configuration of roadways in the area of WWD protection.	To determine whether it is going in the correct or wrong direction, a CV must have up-to-date information about the local roadway configuration.	1.2
1.4.2	A CV's on-board equipment shall be capable of receiving BSMs from other CVs.	To determine if another CV is a potential WW vehicle, the CV must receive their BSMs.	1
1.4.3	CV on-board equipment shall have the capability to determine from the map information and the information in a received BSM that it has detected a potential wrong-way vehicle.	The vehicle's on-board equipment must be capable of detecting that it is a potential wrong-way vehicle.	1
1.4.4	CV on-board equipment must be capable of transmitting a TBD message indicating that it has detected a vehicle potentially traveling in the wrong direction, including time, location and heading.	The vehicle must get the information to RSEs and other vehicles for it to be useful.	1 1.2
1.4.5	CV on-board equipment must be capable of receiving a TBD message that a potential wrong-way vehicle has been detected, including time, location, and heading information.	Immediate notification of nearby CVs is necessary to minimize potential catastrophic events.	1
1.4.6	CV on-board equipment must be capable of displaying alerts to the driver based on TBD messages indicating that a potential wrong-way vehicle has been detected, if appropriate.	The systems within other vehicles must be capable of responding to the alert messages.	1
1.4.7	CV on-board equipment must be capable of re-broadcasting the TBD messages indicating that a potential wrong-way vehicle has been detected, if appropriate.	The systems within other vehicles must be capable of responding to the alert messages.	1

System Requirement	Description	Rationale	User Need Traceability
1.4.8	RSE shall provide the capability to receive TBD messages from CVs indicating that a potential wrong-way vehicle has been detected.	For a vehicle to alert the system that it has detected another vehicle traveling in the wrong direction, the system must be capable of receiving messages from the vehicle.	1
1.4.9	RSE shall provide the capability to transmit information received in messages from CVs including the location of the detected vehicle to the TMC system.	There is a need to be able to have the location of the WWD event so that the response can be directed correctly.	1
1.4.10	RSE shall provide the capability to transmit information received in messages from CVs including the time of detection of a vehicle potentially traveling in the wrong direction to the TMC system.	The information that the vehicle has detected another vehicle that is potentially traveling in the wrong direction must be available to the TMC system to facilitate verification of the WWD event.	1.4.3
1.4.11	The TMC system shall provide the capability to receive messages from roadside equipment that indicate the time and location of the detection of a vehicle that is potentially traveling in the wrong direction in the area of WWD protection.	The information that the vehicle has detected another vehicle that is potentially traveling in the wrong direction must be available to the TMC system to facilitate verification of the WWD event.	1.2
1.4.12	The TMC system shall provide the capability to display to an operator information received from roadside equipment that indicates that a vehicle has detected another vehicle that is potentially traveling in the wrong direction in the area of WWD protection.	The information that the vehicle has detected another vehicle that is potentially traveling in the wrong direction must be displayed to an operator to facilitate verification of the WWD event.	1
1.4.13	The TMC system shall provide the capability to display to an operator received information that indicates the location, including route/roadway and nearest cross-street, of a vehicle that is potentially traveling in the wrong direction in the area of WWD protection.	The location information for a vehicle that is traveling in the wrong direction must be displayed to an operator to facilitate verification of the WWD event.	1.2.1 1.2.2

System Requirement	Description	Rationale	User Need Traceability
1.4.14	The TMC system shall provide the capability to display to an operator received information that indicates the location, including mile marker and latitude/longitude, of a vehicle that is potentially traveling in the wrong direction in the area of WWD protection.	Additional location information for a vehicle that is traveling in the wrong direction may be displayed to an operator to facilitate verification of the WWD event.	1.2.3 1.2.4
1.4.15	The TMC system shall provide the capability to display to an operator received information that indicates the time at which a vehicle that was detected potentially traveling in the wrong direction in the area of WWD protection.	Operators need to know the time of detection to appropriately respond to the wrong-way event.	1.4.3
1.5	The WWD System/Test Bed shall be capable of accepting **input from 911 calls** reporting a vehicle potentially traveling in the wrong direction in the area of WWD protection.	While there are few CVs, many WWD events will be detected by other motorist and reported via 911 calls.	1.6 1.6.1 2.7
1.5.1	The Emergency Response Center system shall provide the capability for an operator to receive a 911 call from the general public.	The general public will report WWD events using the 911 system.	2.7
1.5.2	The Emergency Response Center system shall provide the capability for potential wrong-way driver events received from 911 calls to be entered.	Wrong-way driver events will need to be entered into the traffic management system so that the operators can address them and track them.	2.7
1.5.3	The Emergency Response Center system shall provide the capability for potential wrong-way driver events received from 911 calls to be transmitted electronically to the traffic management control system.	Electronic transmission of detected WWD events between systems should speed response and minimize introduction of communications errors.	2.7
1.5.4	The TMC system shall provide the capability to receive electronically transmitted potential wrong-way driver events.	Electronic transmission of detected WWD events between systems should speed response and minimize introduction of communications errors.	2.7

System Requirement	Description	Rationale	User Need Traceability
1.5.5	The TMC system shall provide the capability to display to an operator information received from the Emergency Service Center that indicates that a vehicle has been detected potentially traveling in the wrong direction in the area of WWD protection.	The information that the vehicle has detected another vehicle that is potentially traveling in the wrong direction must be displayed to an operator to facilitate verification of the WWD event.	1
1.5.6	The TMC system shall provide the capability to display to an operator received information that indicates the location, including route/roadway and nearest cross-street, of a vehicle that is potentially traveling in the wrong direction in the area of WWD protection.	The location information for a vehicle that is traveling in the wrong direction must be displayed to an operator to facilitate verification of the WWD event.	1.2.1, 1.2.2
1.5.7	The TMC system shall provide the capability to display to an operator received information that indicates the location, including mile marker and latitude/Longitude, of a vehicle that is potentially traveling in the wrong direction in the area of WWD protection.	Additional location information for a vehicle that is traveling in the wrong direction may be displayed to an operator to facilitate verification of the WWD event.	1.2.3 1.2.4
1.5.8	The TMC system shall provide the capability to display to an operator received information that indicates the time at which a vehicle that was detected potentially traveling in the wrong direction in the area of WWD protection.	Operators need to know the time of detection to appropriately respond to the wrong-way event.	1.4.3
1.6	The WWD System/Test Bed shall be capable of accepting **input from TME operators** that they have detected a vehicle potentially traveling in the wrong direction in the area of WWD protection.	If operators notice a wrong-way driver event in progress, they need to be able to enter it into the system.	1
1.6.1	The Traffic Management Control system shall provide the capability for operators to view images from controllable cameras covering the area of WWD protection.	One way of verifying the WWD event is to use cameras covering the area of WWD protection to visually verify that the event is occurring.	1

System Requirement	Description	Rationale	User Need Traceability
1.6.2	The Traffic Management Control system shall provide the capability for operators to enter potential wrong-way driver events.	Once an operator notices a WWD event, the operator needs to be able to enter the WWD event into the system.	1
1.7	The WWD System/Test Bed shall be capable of accepting **input from emergency service personnel** that they have detected a vehicle potentially traveling in the wrong direction in the area of WWD protection.	Wrong-way drivers may be spotted first by police or other emergency service personnel.	2.7
1.7.1	The Emergency Response Center system shall be provide the capability for emergency service personnel to communicate to emergency service dispatch operators that they have detected a vehicle potentially traveling in the wrong direction in the area of WWD protection.	To coordinate responses to a WWD event, emergency service personnel should report the existence of the wrong-way driver to the emergency dispatch operator.	2.7
1.7.2	The Emergency Response Center system shall be provided the capability for emergency service dispatch operators to transmit the information from emergency service personnel that a vehicle has been detected potentially traveling in the wrong direction in the area of WWD protection to the TMC operators via telephone.	Telephone is the default mechanism for transmitting information from the emergency dispatch operators to the TMC operators.	2.7
1.7.3	The Emergency Response Center system shall be provided the capability for emergency service dispatch operators to electronically transmit the information from emergency service personnel that a vehicle has been detected potentially traveling in the wrong direction in the area of WWD protection to the traffic management system.	Communications of the existence of a WWD event may be sped up by transmitting the information electronically.	2.7

System Requirement	Description	Rationale	User Need Traceability
1.7.4	The Emergency Response Center system shall be provided the capability for emergency service dispatch operators to transmit route/roadway and nearest cross-street information from emergency service personnel for a vehicle detected potentially traveling in the wrong direction in the area of WWD protection to the TMC system.	Communications of specific location information is needed to facilitate addressing the wrong-way event.	2.7.1 2.7.2
1.7.5	The Emergency Response Center system shall be provided the capability for emergency service dispatch operators to transmit mile marker information from emergency service personnel for a vehicle detected potentially traveling in the wrong direction in the area of WWD protection to the TMC system.	Communications of specific location information is needed to facilitate addressing the wrong-way event.	2.7.3
1.7.6	The Emergency Response Center system shall be provided the capability for emergency service dispatch operators to transmit time of detection from emergency service personnel for a vehicle detected potentially traveling in the wrong direction in the area of WWD protection to the TMC system.	Knowing when the potential wrong-way driver was detected is necessary for predicting upstream times and for verification and response.	1.5
1.7.7	The TMC system shall provide the capability to receive electronically transmitted potential wrong-way driver events.	Electronic transmission of detected WWD events between systems should speed response and minimize introduction of communications errors.	2.7
1.7.8	The TMC system shall provide the capability to display to an operator information received from the Emergency Response Center that indicates that a vehicle has been detected potentially traveling in the wrong direction in the area of WWD protection.	The information that the vehicle has detected another vehicle that is potentially traveling in the wrong direction must be displayed to an operator to facilitate verification of the WWD event.	1

System Requirement	Description	Rationale	User Need Traceability
1.7.9	The TMC system shall provide the capability to display to an operator received information that indicates the location, including route/roadway and nearest cross-street, of a vehicle that is potentially traveling in the wrong direction in the area of WWD protection.	The location information for a vehicle that is traveling in the wrong direction must be displayed to an operator to facilitate verification of the WWD event.	1.2.1 1.2.2
1.7.10	The TMC system shall provide the capability to display to an operator received information that indicates the location, including mile marker and latitude/longitude, of a vehicle that is potentially traveling in the wrong direction in the area of WWD protection.	Additional location information for a vehicle that is traveling in the wrong direction may be displayed to an operator to facilitate verification of the WWD event.	1.2.3 1.2.4
1.7.11	The TMC system shall provide the capability to display to an operator received information that indicates the time at which a vehicle that was detected potentially traveling in the wrong direction in the area of WWD protection.	Operators need to know the time of detection to appropriately respond to the wrong-way event.	1.4.3
1.7.12	The TMC system shall provide operators the capability to enter information received via telephone that indicates that a vehicle that was detected potentially traveling in the wrong direction in the area of WWD protection.	For systems using phone notification, the TMC operators must be able to enter the information from the Emergency Dispatch Center.	2.7
1.8	The WWD Test Bed shall maintain a record of the detection of a vehicle potentially traveling in the wrong direction in the area of WWD protection.	To be able to review and improve reactions to WWD events, each action must be recorded.	5
1.8.1	The TMC system shall maintain a record of the source of the detection of a vehicle potentially traveling in the wrong direction in the area of WWD protection.	To be able to review and improve reactions to WWD events, each action must be recorded.	5.1.1

System Requirement	Description	Rationale	User Need Traceability
1.8.2	The TMC system shall maintain a record of the time of the detection of a vehicle potentially traveling in the wrong direction in the area of WWD protection.	To be able to review and improve reactions to WWD events, each action must be recorded.	5.1.1
2. VERIFICATION			
2.1	The WWD Test Bed shall provide the capability to allow operators to verify the detection of a vehicle traveling in the wrong direction in the area of WWD protection.	To minimize the impact of false positives, operators must be able to verify WWD events.	3
2.1.1	The TMC system shall provide the capability for operators to view images from controllable cameras covering the area of WWD protection.	To directly verify WWD events, operators must be able to control cameras and view images from those cameras.	
2.1.2	The TMC system shall provide the capability for operators to enter verification that a WWD event is occurring.	To initiate necessary actions for verified WWD events, operators must be able to enter verifications into the traffic management system.	
2.2	The WWD System/Test Bed shall provide the capability for TMC operators to enter additional information for WWD events.	To optimize actions to deal with WWD events, operators need to be able to enter additional information about the events into the TMC system.	1.3 1.4
2.2.1	The TMC system shall provide the capability for operators to enter updated location information, including route/roadway and cross-street, for WWD events.	Operators need to enter location data dynamically into the TMC system so that appropriate scenarios can be initiated and so that appropriate staff can be notified of the current location of the wrong-way driver.	1.4
2.2.2	The TMC system shall provide the capability for operators to enter vehicle make and model information for WWD events.	Vehicle model information may be useful in finding and clearing the incident.	1.3.1 1.3.2
2.2.3	The TMC system shall provide the capability for operators to enter vehicle color information for WWD events.	Vehicle color information may be useful in finding and clearing the incident.	1.3.3

System Requirement	Description	Rationale	User Need Traceability
2.2.4	The TMC system shall provide the capability for operators to enter vehicle license plate information for WWD events.	Vehicle license plate information may be useful in finding and clearing the incident.	1.3.4
2.2.5	The TMC system shall associate a time with information updates for wrong- way driving events.	Operators need to know the time of an update to appropriately respond to the wrong-way event.	1.4.3
2.2.6	The TMC system shall provide the capability for operators to enter updated location information, including Mile Marker and Latitude/Longitude, for WWD events.	Operators need to enter location data dynamically into the traffic management system so that appropriate scenarios can be initiated and so that appropriate staff can be notified of the current location of the wrong-way driver.	1.4.4 1.4.5
2.2.7	The TMC system shall calculate estimated arrival times at upstream points for the wrong-way vehicle.	Operators need to be able to help emergency personnel rapidly get to the wrong-way driver.	1.5
2.3	The WWD Test Bed shall maintain a record of the verification of a vehicle traveling in the wrong direction in the area of WWD protection.	To be able to review and improve reactions to WWD events, each action must be recorded.	5
2.3.1	The TMC system shall maintain a record of the source of the verification of a vehicle traveling in the wrong direction in the area of WWD protection.	To be able to review and improve reactions to WWD events, each action must be recorded.	5.1.2
2.3.2	The TMC system shall maintain a record of the time of the verification of a vehicle traveling in the wrong direction in the area of WWD protection.	To be able to review and improve reactions to WWD events, each action must be recorded.	5.1.2
3. NOTIFICATION			
3.1	The WWD Test Bed shall provide the capability to allow TMC operators to notify other stakeholders of the detection of a vehicle traveling in the wrong direction in the area of WWD protection.	If the WWD event is first detected by the traffic management system then the TMC operators must be able to notify the Emergency Dispatch Center operators of the incident.	2 2.1 2.1.1 2.2 3.1

System Requirement	Description	Rationale	User Need Traceability
3.1.1	The TMC system shall provide the capability for operators to notify Emergency Service Center operators of the detection of a vehicle traveling in the wrong direction in the area of WWD protection via telephone.	The default mechanism for notifying the emergency dispatch operators of a WWD event is via the telephone.	
3.1.2	The TMC system shall provide the capability for operators to electronically notify Emergency Service Center operators of the detection of a vehicle traveling in the wrong direction in the area of WWD protection..	Electronic notification of emergency dispatch personnel that a WWD event is occurring may speed response to the event.	
3.1.3	The TMC system shall provide the capability for operators to notify other TMCs of the detection of a vehicle traveling in the wrong direction in the area of WWD protection via telephone.	In the case of WWD events near boundaries of control or passing from one area of control to another, operators at the other TMC needs to be notified so that they can coordinate to address the event.	2.1.2
3.1.4	The TMC system shall provide the capability for operators to notify the appropriate Traffic Management Entity Public Information Officer of the detection of a vehicle traveling in the wrong direction in the area of WWD protection via telephone.	Public information officers need to be informed of WWD events so that the public can be appropriately informed.	2.1.3
3.1.5	The TMC system shall provide the capability for operators to include location information in the notifications of the detection of a vehicle traveling in the wrong direction in the area of WWD protection.	To address the wrong-way event appropriately, other stakeholders need to know the location of the vehicle.	2.2.1
3.1.6	The TMC system shall provide the capability for operators to include vehicle description information in the notifications of the detection of a vehicle traveling in the wrong direction in the area of WWD protection.	Vehicle descriptions will be useful for other stakeholders as they address the WWD event.	2.2.2

System Requirement	Description	Rationale	User Need Traceability
3.1.7	The TMC system shall provide the capability for operators to include estimated arrival times for points upstream in the notifications of the detection of a vehicle traveling in the wrong direction in the area of WWD protection.	Upstream arrival times will be useful for stakeholders as they address the WWD event.	2.2.3
3.1.8	The TMC system shall provide the capability to update other stakeholders when the status of a vehicle traveling in the wrong direction in the area of WWD protection is updated.	Stakeholders need to have the most up-to-date information to be able to respond to the WWD event appropriately.	2.3.2 4.4
3.2	The WWD Test Bed shall provide the capability to allow Emergency Service Center operators to notify TMC operators of the detection of a vehicle traveling in the wrong direction in the area of WWD protection.	If the WWD event is first detected by the Emergency Service Center Operators then the Emergency Service Center operators must be able to notify the TMC operators of the incident.	2.7
3.2.1	The Emergency Service Center system shall provide the capability to allow operators to notify TMC operators of the detection of a vehicle traveling in the wrong direction in the area of WWD protection via telephone.	Notification by telephone is the default method and should be available.	
3.2.2	The Emergency Service Center system shall provide the capability to allow operators to electronically notify TMC operators of the detection of a vehicle traveling in the wrong direction in the area of WWD protection.	Electronic notification should speed the process of initiating scenarios associated with a WWD event.	
3.3	The WWD Test Bed shall provide the capability to allow TMC operators to notify Emergency Service Center operators of the verification of a vehicle traveling in the wrong direction in the area of WWD protection.	If TMC operators verify the existence of a WWD event they must be able to notify Emergency Service Center operators of the verification.	2.3.1

System Requirement	Description	Rationale	User Need Traceability
3.3.1	The TMC system shall provide the capability to allow operators to notify Emergency Service Center operators of the verification of a vehicle traveling in the wrong direction in the area of WWD protection via telephone.	Notification via telephone is the default mechanism used by TMC operators to notify Emergency Service Center operators.	
3.3.2	The TMC system shall provide the capability to allow operators to electronically notify Emergency Service Center operators of the verification of a vehicle traveling in the wrong direction in the area of WWD protection.	Electronic notification of verification should speed the verification and facilitate response to the distracted driving event.	
3.4	The WWD System/Test Bed shall provide the capability to allow Emergency Service Center operators to notify TMC operators of the verification of a vehicle traveling in the wrong direction in the area of WWD protection.	If the WWD event is verified by the Emergency Service Center operators then they need to be able to notify the TMC operators that a verified WWD event is occurring.	3.2
3.4.1	The Emergency Service Center System shall provide the capability to allow operators to notify TMC operators of the verification of a vehicle traveling in the wrong direction in the area of WWD protection via telephone.	Notification via telephone is the default mechanism used by Emergency Service Center operators to notify TMC operators.	
3.4.2	The Emergency Service Center System shall provide the capability to allow operators to electronically notify TMC operators of the verification of a vehicle traveling in the wrong direction in the area of WWD protection.	Electronic notification of verification should speed the verification and facilitate response to the distracted driving event.	
3.5	The WWD System/Test Bed shall provide the capability for emergency dispatch operators to notify emergency service personnel of verified WWD events.	Emergency service personnel are responsible for directly addressing WWD events and must be notified of the verification of the event.	

System Requirement	Description	Rationale	User Need Traceability
3.6	The WWD Test Bed shall maintain a record of the notifications of a vehicle traveling in the wrong direction in the area of WWD protection.	To be able to review and improve reactions to WWD events, each action must be recorded.	5
3.6.1	The TMC system shall maintain a record of the source of Notifications of a vehicle traveling in the wrong direction in the area of WWD protection.	To be able to review and improve reactions to WWD events, each action must be recorded.	5.1
3.6.2	The TMC system shall maintain a record of the Time of Notifications of a vehicle traveling in the wrong direction in the area of WWD protection.	To be able to review and improve reactions to WWD events, each action must be recorded.	5.1
4. ALERT			
4.1	The WWD System/Test Bed shall provide the capability to allow TMC operators to provide an alert to drivers of oncoming non-CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.	Oncoming drivers must be warned of a wrong-way driver.	4
4.1.1	The TMC system shall provide the capability to allow operators to display an alert on dynamic message signs to drivers of oncoming vehicles that a potential WWD event is occurring.	Even if the WWD event has not been notified, nearby drivers need to be warned.	4.3.1
4.1.2	The TMC system shall provide the capability to allow operators to display an alert on dynamic message signs to drivers of oncoming vehicles that a verified WWD event is occurring.	Drivers should be given the information that the WWD event has been verified.	4.3.1
4.1.3	The TMC system shall provide the capability to allow operators to initiate pre-planned responses based on the location of the wrong-way vehicle to alert drivers of oncoming vehicles that a verified WWD event is occurring.	Use of pre-planned responses is necessary to minimize the time required to get the alerts to the drivers.	4.3 4.3.1.

System Requirement	Description	Rationale	User Need Traceability
4.1.4	The TMC system shall provide the capability to display an alert by activating special LED signs for drivers of oncoming vehicles that a verified WWD event is occurring.	Where available special LED signs may be useful in alerting non-CV drivers.	4.3.3
4.1.5	The TMC system shall provide the capability to display an alert by activating special display on a ramp control signal for drivers of oncoming vehicles that a verified WWD event is occurring.	Where available, special displays on ramp control signals may be useful in alerting non-CV drivers.	4.3.4
4.1.6	The TMC system shall provide the capability to activate ramp control gates in response to a verified WWD event.	Where available ramp control gates may be useful in controlling WWD events.	4.3.5
4.2	The WWD System/Test Bed shall provide the capability to alert drivers of on-coming CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.	Oncoming drivers must be warned of a wrong-way driver.	4
4.2.1	The TMC system shall provide the capability to allow operators to transmit an alert to roadside equipment that a potential WWD event is occurring.	Even if the WWD event has not been verified nearby drivers need to be warned.	4.7
4.2.2	The TMC system shall provide the capability to allow operators to transmit an alert to roadside equipment that a verified WWD event is occurring.	Drivers should be given the information that the WWD event has been verified.	4.7
4.2.3	Roadside equipment shall provide the capability to transmit messages to oncoming CVs that a verified WWD event is occurring using properly formatted SAE J2735 RSA messages.	For CVs to interpret the messages, they need to be formatted in accordance with the appropriate standard.	4.1
4.2.4	Onboard equipment in oncoming vehicles shall provide the capability to receive properly formatted SAE J2735 RSA messages that a verified WWD event is occurring.	For CVs to provide the information to their drivers, they must be able to interpret the messages formatted in accordance with the appropriate standard.	4.6

System Requirement	Description	Rationale	User Need Traceability
4.2.5	Onboard equipment in oncoming vehicles shall provide the capability to generate appropriate warnings for drivers when it receives properly formatted SAE J2735 RSA messages that a verified WWD event is occurring.	To warn the drivers, the vehicles must be able to generate warnings based on the RSA messages.	4.7
4.3	The WWD System/Test Bed shall provide the capability to alert drivers of emergency service CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.	Emergency service vehicle drivers must be warned of a wrong-way driver.	2.6
4.3.1	The TMC system shall provide the capability to allow operators to transmit an alert to be displayed inside the vehicle to drivers of nearby connected emergency service vehicles that a potential WWD event is occurring.	Even if the WWD event has not been verified nearby emergency service vehicle drivers need to be warned.	
4.3.2	The TMC system shall provide the capability to allow operators to transmit an alert to be displayed inside the vehicle to drivers of nearby connected emergency service vehicles that a verified WWD event is occurring.	Emergency service vehicle drivers should be given the information that the WWD event has been verified.	
4.3.3	Roadside equipment shall provide the capability to transmit messages to oncoming CVs that a verified WWD event is occurring using properly formatted SAE J2735 RSA messages.	For CVs to interpret the messages, they need to be formatted in accordance with the appropriate standard.	4.1
4.3.4	Onboard equipment in oncoming vehicles shall provide the capability to receive properly formatted SAE J2735 RSA messages that a verified WWD event is occurring.	For CVs to provide the information to their drivers, they must be able to interpret the messages formatted in accordance with the appropriate standard.	4.6

System Requirement	Description	Rationale	User Need Traceability
4.3.5	Onboard equipment in oncoming vehicles shall provide the capability to generate appropriate warnings for drivers when it receives properly formatted SAE J2735 RSA messages that a verified WWD event is occurring.	To warn the drivers, the vehicles must be able to generate warnings based on the RSA messages.	4.7
4.4	The WWD System/Test Bed shall provide the capability to alert drivers of emergency service non-CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.	Drivers of emergency service vehicles that are not CVs must be alerted ongoing WWD events.	2.1.1
4.4.1	The Emergency Service Center system shall provide the capability to allow operators to alert drivers of nearby non-connected emergency service vehicles that a potential WWD event is occurring.	Even if the WWD event has not been verified nearby emergency service vehicle drivers need to be warned.	
4.4.2	The Emergency Service Center system shall provide the capability to allow operators to alert drivers of nearby non-connected emergency service vehicles that a verified WWD event is occurring.	Emergency service vehicle drivers should be given the information that the WWD event has been verified.	
4.5	The WWD System/Test Bed shall provide the capability to alert information service providers that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.	To better alert the general public, information service providers need to be alerted of WWD events.	4.2
4.6	The WWD Test Bed shall maintain a record of the verification of a vehicle traveling in the wrong direction in the area of WWD protection.	To be able to review and improve reactions to WWD events, each action must be recorded.	5
4.6.1	The TMC system shall maintain a record of the source of the verification of a vehicle traveling in the wrong direction in the area of WWD protection.	To be able to review and improve reactions to WWD events, each action must be recorded.	5.2
4.6.2	The TMC system shall maintain a record of the time of the verification of a vehicle traveling in the wrong direction in the area of WWD protection.	To be able to review and improve reactions to WWD events, each action must be recorded.	5.2

System Requirement	Description	Rationale	User Need Traceability
5. CLEAR			
5.1	The WWD System/Test Bed shall provide emergency service personnel the capability to indicate to the emergency dispatch operator that the status of a WWD event has been changed.	Emergency service personnel are responsible for determining that a WWD event's status has changed. Emergency service personnel interact directly with emergency dispatch operators.	5.1 2.3
5.1.1	The Emergency Service Center system shall provide emergency service personnel the capability to inform operators that a WWD event has been transformed into a traffic incident.	When a WWD event results in a traffic incident, different scenarios need to be invoked.	
5.1.2	The Emergency Service Center system shall provide emergency service personnel the capability to indicate to operators that a WWD event has been successfully terminated.	It is important to quickly remove signs indicating that a WWD event is in progress if the event has terminated; otherwise, the general public will begin to ignore the warnings.	
5.1.3	The Emergency Service Center system shall provide emergency service personnel the capability to indicate to operators that a WWD event has been terminated due to the inability to find the wrong-way vehicle.	It is important to quickly remove signs indicating that a WWD event is in progress if the event has terminated; otherwise, the general public will begin to ignore the warnings.	
5.2	The WWD System/Test Bed shall provide the capability for Emergency Service Center operators to alert the TMC operators that the status of a WWD event has been changed.	TMC operators are responsible for modifications of alerts to the general public.	2.7
5.2.1	The Emergency Service Center system shall provide the capability for operators to alert the TMC operators that the status of a WWD event has been changed via telephone.	The default method used by Emergency Survive Center operators to notify TMC operators to changes in WWD event statuses is via telephone.	
5.2.2	The Emergency Service Center system shall provide the capability for operators to electronically alert the TMC operators that the status of a WWD event has been changed.	Alerting TMC operators electronically may speed updates to driver communications devices.	

System Requirement	Description	Rationale	User Need Traceability
5.3	The WWD System/Test Bed shall provide TMC operators the capability to modify the alerts to the general public when WWD event status changes.	TMC operators are responsible for managing the capabilities of the wrong-way driver system/test bed to alert general public drivers.	2.3
5.3.1	The TMC system shall provide operators the capability to discontinue alerting general drivers when the status of a WWD event is changed to indicate a successful termination of the event.	Alerts must be removed when a WWD event is terminated so that users will not get used to ignoring them.	2.5 4.5
5.3.2	The TMC system shall provide operators the capability to discontinue alerting general drivers when the status of a WWD event is changed to indicate the wrong-way vehicle cannot be found.	Alerts must be removed when a WWD event is terminated so that users will not get used to ignoring them.	
5.3.3	The TMC system shall provide operators the capability to initiate a traffic incident scenario when the status of a WWD event is changed to indicate that it has resulted in a traffic incident.	When a traffic incident occurs, it must become the focus of the alert system.	
5.4	The WWD System/Test Bed shall cease alerting oncoming CVs of the WWD event when it has been cleared.	Alerts to oncoming vehicles must cease when the threat caused by the WWD event ends.	2.4
5.4.1	The TMC system shall cause roadside equipment to cease alerting oncoming CVs of the WWD event when its status has been changed to not active.	CVs must receive affirmative indications that the WWD event has concluded.	
5.4.2	The TMC system shall cause CVs receiving messages from roadside equipment to cease alerting oncoming CVs of the WWD event when its status has been changed to not active.	Vehicles receiving messages that the WWD event has concluded must discontinue propagating the alert messages.	
5.4.3	The roadside equipment shall cease alerting oncoming CVs of the WWD event when a message that the WWD event has been cleared has been received from the TMC.	Vehicles receiving no changes to WWD event alert status must cease propagating WWD event alert messages after a specified period.	

System Requirement	Description	Rationale	User Need Traceability
5.5	The WWD Test Bed shall maintain a record of the status changes (including termination of the wrong-way event) of a vehicle traveling in the wrong direction in the area of WWD protection.	To be able to review and improve reactions to WWD events, each action must be recorded.	5
5.5.1	The TMC system shall maintain a record of the source of the status changes (including termination of the wrong-way event) of a vehicle traveling in the wrong direction in the area of WWD protection.	To be able to review and improve reactions to WWD events, each action must be recorded.	5.1.3
5.5.2	The TMC system shall maintain a record of the time of status changes (including termination of the wrong-way event) of a vehicle traveling in the wrong direction in the area of WWD protection.	To be able to review and improve reactions to WWD events, each action must be recorded.	5.1.3
6. SAFETY REQUIREMENTS			
6.1	The WWD System/Test Bed shall provide the capability to ensure that only test vehicles are within the test bed for active tests.	Only vehicles being used in the test should be in an area of WWD protection while it is being operated as a test bed.	
6.2	The WWD System/Test Bed shall provide the capability to ensure that all Wrong-way vehicles have been removed or turned around before the test bed reverts to other uses.	No wrong-way vehicles should in the test bed when it reverts to other usages.	

Table A2. System Performance Requirements for a CV WWD Detection and Management System.

System Requirement	Test Bed Priority	Test Bed Performance	System Priority	System Performance
1. DETECTION				
1.1	High	> 80% true positives, < 1 false positive per detector per month	High	> 95% true positives, < 1 false positive per detector per year
1.1.1	High	> 80% true positives, < 1 false positive per detector per month	High	> 95% true positives, < 1 false positive per detector per year
1.1.2	High	In < 1 second from detection	High	In < 1 second from detection
1.1.3	High	In < 1 second from detection	High	In < 1 second from detection
1.1.4	High	to within < 1 second	High	to within < 1 second
1.1.5	High	In < 1 second from detection	High	In < 1 second from detection
1.1.6	High	In < 1 second from detection	High	In < 1 second from detection
1.1.7	High	In < 1 second from detection	High	In < 1 second from detection
1.1.8	Medium	< 1 second after detection	High	< 1 second after detection
1.1.9	Medium	< 1 second after detection	High	< 1 second after receiving the message
1.1.10	Medium	< 1 second after detection	High	< 1 second after receiving the message
1.1.11	High	≥1 Message per second < 5 Seconds delay per message	High	≥ 1 Message per second < 5 Seconds delay per message
1.1.12	High	≥ 1 Message per second < 5 Seconds delay per message	High	≥ 1 Message per second < 5 Seconds delay per message
1.1.13	High	In < 1 second from message reception	High	In < 1 second from message reception
1.1.14	Medium	In < 1 second from message reception	High	In < 1 second from message reception
1.1.15	Medium	In < 1 second from message reception	High	In < 1 second from message reception
1.1.16	Low	in < 5 seconds	Medium	In < 1 second
1.1.17	High	to within < 1 second	High	to within < 1 second
1.2	High	> 80% true positives, < 1 false positive per detector per month	High	> 95% true positives, < 1 false positive per detector per year
1.2.1	High	As specified by SAE J2945/1	High	As specified by SAE J2945/1
1.2.2	High	In < 1 second from detection	High	In < 1 second from detection
1.2.3	High	Roadway information may be static	High	> 1 second before initial transition time included in the message

System Requirement	Test Bed Priority	Test Bed Performance	System Priority	System Performance
1.2.4	High	> 80% true positives, < 1 false positive per detector per month	High	> 95% true positives, < 1 false positive per detector per year
1.2.5	High	In < 1 second from detection	High	In < 1 second from detection
1.2.6	Medium	< 1 second after detection	High	< 1 second after detection
1.2.7	Medium	< 1 second after receiving the message	High	< 1 second after receiving the message
1.2.8	Medium	< 1 seconds after receiving the message	High	< 1 second after receiving the message
1.2.9	High	≥ 1 Message per second < 5 Seconds delay per message	High	≥ 1 Message per second < 5 Seconds delay per message
1.2.10	High	≥ 1 Message per second < 5 Seconds delay per message	High	≥ 1 Message per second < 5 Seconds delay per message
1.2.11	High	In < 1 second from message transmission	High	In < 1 second from message transmission
1.2.12	High	in < 1 second	High	In < 1 second
1.2.13	High	in < 1 second	High	In < 1 second
1.2.14	Low	in < 1 second	Medium	In < 1 second
1.2.15	High	to within < 1 second	High	to within < 1 second
1.3	Medium	< 20 seconds for a vehicle to detect that it is traveling in the wrong direction	High	< 10 seconds for a vehicle to detect that it is traveling in the wrong direction
1.3.1	Medium	Roadway information may be static	High	Roadway information must be dynamically provided to vehicles before the vehicle enters a roadway segment.
1.3.2	Medium	GPS accuracies may be sufficient.	High	GPS accuracies may be sufficient.
1.3.3	Medium	> 80% true positives, < 1 false positive per detector per month	High	> 95% true positives, < 1 false positive per detector per year
1.3.4	Medium	< 1 seconds after detection	High	< 1 second after detection
1.3.5	Medium	< 1 seconds after detection	High	< 1 second after detection
1.3.6	Medium	< 1 seconds after receiving the message	High	< 1 second after receiving the message
1.3.7	Medium	< 1 seconds after receiving the message	High	< 1 second after receiving the message
1.3.8	Medium	≥ 1 message per second	High	≥10 message per second from up to 150 vehicles
1.3.9	Medium	≥ 1 Message per second < 5 Seconds delay per message	High	≥ 1 Messages per second < 5 Seconds delay per message

System Requirement	Test Bed Priority	Test Bed Performance	System Priority	System Performance
1.3.10	Medium	≥ 1 Message per second < 5 Seconds delay per message	High	≥ 1 Message per second < 5 Seconds delay per message
1.3.11	High	In < 1 second from message transmission	High	In < 1 second from message transmission
1.3.12	Medium	in < 1 second	High	In < 1 second
1.3.13	Medium	in < 1 second	High	In < 1 second
1.3.14	Low	in < 1 second	Medium	In < 1 second
1.3.15	Low	to within < 1 second	Medium	to within < 1 second
1.4	Low	For wrong-way vehicles within the Test Bed	High	For vehicles in direct line of sight within .497 miles of CV RSE
1.4.1	Low	Roadway information may be static	High	Roadway information must be dynamically provided to vehicles before the vehicle enters a roadway segment.
1.4.2	Low	As per SAE J2945/1	High	As per SAE J2945/1
1.4.3	Low	> 80% true positives, < 1 false positive per detector per month	High	> 95% true positives, < 1 false positive per detector per year
1.4.4	Low	< 1 second after detection	High	< 1 second after detection
1.4.5	Low	< 1 second after detection	High	< 1 second after detection
1.4.6	Low	< 1 second after receiving the message	High	< 1 second after receiving the message
1.4.7	Low	< 1 second after receiving the message	High	< 1 second after receiving the message
1.4.8	Low	≥ 1 message per second	High	≥ 10 message per second from up to 150 vehicles
1.4.9	Low	≥ 1 Message per second < 5 Seconds delay per message	High	In < 1 second
1.4.10	Low	in < 1 second	High	In < 1 second
1.4.11	Low	in < 1 second	High	In < 1 second
1.4.12	Low	in < 1 second	High	In < 1 second
1.4.13	Low	in < 1 second	High	In < 1 second
1.4.14	Low	in < 1 second	Medium	In < 1 second
1.4.15	Low	in < 1 second	Medium	In < 1 second
1.5	High	< 30 seconds after vehicle reported > 1 call simultaneously	High	< 20 seconds after vehicle reported > 3 call simultaneously

System Requirement	Test Bed Priority	Test Bed Performance	System Priority	System Performance
1.5.1	High	> 1 call at a time < 20 seconds after the call is placed	High	> 3 calls at a time < 15 seconds after the call is placed.
1.5.2	High	< 20 seconds after notification	High	< 20 seconds after notification
1.5.3	Low	< 1 second after entry into the dispatch system	Medium	< 1 second after entry into the dispatch system
1.5.4	Low	< 1 second after entry into the dispatch system	Medium	< 1 second after entry into the dispatch system
1.5.5	Low	in < 1 second	High	In < 1 second
1.5.6	Low	in < 1 second	High	In < 1 second
1.5.7	Low	in < 1 second	Medium	In < 1 second
1.5.8	Low	in < 1 second	Medium	In < 1 second
1.6	High	< 30 seconds from user detection to scenario activation	High	< 15 seconds from user detection to scenario activation
1.6.1	High	> 50% of the test bed area covered	High	> 90% of the area of WWD protection covered
1.6.2	High	< 30 seconds to enter event	High	< 15 seconds to enter event
1.7	Medium	< 30 seconds after detection	High	< 20 seconds after detection
1.7.1	Medium	< 30 seconds after detection	High	< 20 seconds after detection
1.7.2	Medium	< 20 seconds after receiving the report	High	< 20 seconds after receiving the report
1.7.3	Low	< 20 seconds after receiving the report	Medium	< 20 seconds after receiving the report
1.7.4	Medium	< 20 seconds after receiving the report	High	< 20 seconds after receiving the report
1.7.5	Low	< 20 seconds after receiving the report	Medium	< 20 seconds after receiving the report
1.7.6	Low	< 20 seconds after receiving the report	Medium	< 20 seconds after receiving the report
1.7.7	Low	< 1 second after entry into the dispatch system	Medium	< 1 second after entry into the dispatch system
1.7.8	Low	in < 1 second	High	In < 1 second
1.7.9	Low	in < 1 second	High	In < 1 second
1.7.10	Low	in < 1 second	Medium	In < 1 second
1.7.11	Low	in < 1 second	Medium	In < 1 second
1.7.12	Medium	Within < 1 minute of receipt of the phone call	High	Within < 1 minute of receipt of the phone call

System Requirement	Test Bed Priority	Test Bed Performance	System Priority	System Performance
1.8	High	Within < 1 second of the action	High	Within < 1 second of the action
1.8.1	High	Within < 1 second of the action	High	Within < 1 second of the action
1.8.2	High	Within < 1 second of the action	High	Within < 1 second of the action
2. VERIFICATION				
2.1	High	< 5 minutes from alert > 80% of the time	High	< 2 minute from alert > 95 % of the time
2.1.1	High	> 50% of the test bed area covered	High	> 90% of the area of WWD protection covered
2.1.2	High	< 1 minute after verification	High	< 30 seconds after verification
2.2	High	< 60 seconds to open screen and enter information	High	< 30 seconds to open screen and enter information
2.2.1	Medium	< 60 seconds to open screen and enter information	High	< 30 seconds to open screen and enter information
2.2.2	Low	< 60 seconds to open screen and enter information	Medium	< 30 seconds to open screen and enter information
2.2.3	Low	< 60 seconds to open screen and enter information	Medium	< 30 seconds to open screen and enter information
2.2.4	Low	< 60 seconds to open screen and enter information	Medium	< 30 seconds to open screen and enter information
2.2.5	Medium	< 5 second accuracy	High	< 1 second accuracy
2.2.6	Low	< 60 seconds to open screen and enter information	Medium	< 30 seconds to open screen and enter information
2.2.7	High	< 30 seconds after location determined/entered.	High	< 10 seconds after location determined/entered.
2.3	High	Within < 1 second of the action	High	Within < 1 second of the action
2.3.1	High	Within < 1 second of the action	High	Within < 1 second of the action
2.3.2	High	Within < 1 second of the action	High	Within < 1 second of the action
3. NOTIFICATION				
3.1	Medium	< 60 seconds after detection	High	< 30 seconds after detection
3.1.1	Medium	< 60 seconds after detection	High	< 30 seconds after detection
3.1.2	Low	< 15 seconds after detection	Medium	< 10 seconds after detection

System Requirement	Test Bed Priority	Test Bed Performance	System Priority	System Performance
3.1.3	N/A		High	< 1 minute after a determination that the event is likely to cross a boundary within 5 minutes
3.1.4	Low	< 5 minutes after detection	High	< 1 minute after detection
3.1.5	Medium	< 60 seconds after detection	High	< 30 seconds after detection
3.1.6	Low	< 60 seconds after detection	Medium	< 30 seconds after detection
3.1.7	Low	< 60 seconds after detection	Medium	< 30 seconds after detection
3.1.8	High	< 60 seconds after detection	High	< 30 seconds after detection
3.2	High	< 30 seconds from detection	High	< 20 seconds from detection
3.2.1	High	< 30 seconds from detection	High	< 20 seconds from detection
3.2.2	Low	< 15 seconds from detection	Medium	< 5 seconds from detection
3.3	High	< 30 seconds after verification	High	< 20 seconds after verification
3.3.1	High	< 30 seconds after verification	High	< 20 seconds after verification
3.3.2	Low	< 20 seconds after verification	Medium	< 15 seconds after verification
3.4	High	< 30 seconds after verification	High	< 20 seconds after verification
3.4.1	High	< 30 seconds after verification	High	< 20 seconds after verification
3.4.2	Low	< 20 seconds after verification	Medium	< 15 seconds after verification
3.5	High	< 30 seconds after verification	High	< 30 seconds after verification
3.6	High	Within < 1 second of the action	High	Within < 1 second of the action
3.6.1	High	Within < 1 second of the action	High	Within < 1 second of the action
3.6.2	High	Within < 1 second of the action	High	Within < 1 second of the action
4. ALERT				
4.1	High	< 20 seconds after detection throughout the test bed	High	< 20 seconds after detection
4.1.1	High	< 20 seconds after detection throughout the test bed	High	< 20 seconds after detection
4.1.2	High	< 20 seconds after verification throughout the test bed	High	< 20 seconds after verification
4.1.3	High	< 20 seconds after verification	High	< 20 seconds after verification
4.1.4	Low	< 20 seconds after verification	Medium	< 20 seconds after verification
4.1.5	Low	< 20 seconds after verification	Medium	< 20 seconds after verification

System Requirement	Test Bed Priority	Test Bed Performance	System Priority	System Performance
4.1.6	Low	< 20 seconds after verification	Medium	< 20 seconds after verification
4.2	High	< 10 seconds after detection throughout the test bed	High	< 20 seconds after status change
4.2.1	High	< 10 seconds after detection throughout the test bed	High	< 10 seconds after detection
4.2.2	High	< 10 seconds after verification throughout the test bed	High	< 10 seconds after verification
4.2.3	High	< 10 seconds after verification throughout the test bed	High	< 10 seconds after verification
4.2.4	High	< 10 seconds after verification throughout the test bed < 1 second after receiving the message	High	< 10 seconds after verification
4.2.5	High	< 10 seconds after verification throughout the test bed < 1 second after receiving the message	High	< 10 seconds after verification < 1 second after receiving the message
4.3	High	< 10 seconds after status change throughout the test bed	High	< 10 seconds after status change
4.3.1	High	< 10 seconds after detection throughout the test bed	High	< 10 seconds after detection
4.3.2	High	< 10 seconds after verification throughout the test bed	High	< 10 seconds after verification
4.3.3	High	< 10 seconds after verification throughout the test bed	High	< 10 seconds after verification
4.3.4	High	< 10 seconds after verification throughout the test bed	High	< 10 seconds after verification
4.3.5	High	< 10 seconds after verification throughout the test bed < 1 second after receiving the message	High	< 10 seconds after verification < 1 second after receiving the message
4.4	High	< 10 seconds after status change throughout the test bed	High	< 10 seconds after status change

System Requirement	Test Bed Priority	Test Bed Performance	System Priority	System Performance
4.4.1	High	< 10 seconds after detection throughout the test bed	High	< 10 seconds after detection
4.4.2	High	< 10 seconds after verification throughout the test bed	High	< 10 seconds after verification
4.5	Low	< 10 seconds after verification throughout the test bed	High	< 10 seconds after verification
4.6	High	Within < 1 second of the action	High	Within < 1 second of the action
4.6.1	High	Within < 1 second of the action	High	Within < 1 second of the action
4.6.2	High	Within < 1 second of the action	High	Within < 1 second of the action
5. CLEAR				
5.1	High	< 10 minutes after confirmation of status change	High	< 1 minute after confirmation of status change
5.1.1	High	< 10 minutes after confirmation of status change	High	< 1 minute after confirmation of status change
5.1.2	High	< 10 minutes after confirmation of status change	High	< 1 minute after confirmation of status change
5.1.3	High	< 10 minutes after confirmation of status change	High	< 1 minute after confirmation of status change
5.2	High	< 5 minutes after report of status change	High	< 1 minute after report of status change
5.2.1	High	< 5 minutes after report of status change	High	< 1 minute after report of status change
5.2.2	Low	< 5 minutes after report of status change	Medium	< 30 seconds after report of status change
5.3	High	< 1 minute after receiving notification of the change	High	< 30 seconds after receiving notification of the change
5.3.1	High	< 1 minute after receiving notification of the change	High	< 30 seconds after receiving notification of the change
5.3.2	High	< 1 minute after receiving notification of the change	High	< 30 seconds after receiving notification of the change
5.3.3	High	< 1 minute after receiving notification of the change	High	< 30 seconds after receiving notification of the change
5.4	High	< 10 minutes after end of the event	High	< 2 minute after the end of the event

System Requirement	Test Bed Priority	Test Bed Performance	System Priority	System Performance
5.4.1	High	< 5 minutes after end of the event has been received by the TMC system	High	< 1 minutes after end of the event has been received by the TMC system
5.4.2	High	< 1 minute after receipt of end of alert message	High	< 20 seconds after receipt of end of alert message
5.4.3	High	< 10 Seconds after the message is received	High	< 5 Seconds after the message is received
5.5	High	Within < 1 second of the action	High	Within < 1 second of the action
5.5.1	High	Within < 1 second of the action	High	Within < 1 second of the action
5.5.2	High	Within < 1 second of the action	High	Within < 1 second of the action
6. SAFETY REQUIREMENTS				
6.1	High	> 30 minutes before entry of a wrong-way vehicle	N/A	N/A
6.2	High	> 30 minutes before the segment reverts to other usages	N/A	N/A

Table A3. Traceability Matrix for a CV WWD Detection and Management System.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
1. DETECTION				
1.1	1 1.1		Multiple Needs	N/A
1.1.1	1	1.1	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of detecting a vehicle potentially traveling in the wrong direction in the area of WWD protection using dedicated detection devices.
1.1.2	1	1.1	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of detecting a vehicle potentially traveling in the wrong direction in the area of WWD protection using dedicated detection devices.
1.1.3	1.2	1.1	A TME needs to determine the location at which the wrong-way vehicle was detected entering the facility.	The WWD System/Test Bed shall be capable of detecting a vehicle potentially traveling in the wrong direction in the area of WWD protection using dedicated detection devices.
1.1.4	1.4.3	1.1	The TME needs to update the time of the latest update of the location of the wrong-way vehicle.	The WWD System/Test Bed shall be capable of detecting a vehicle potentially traveling in the wrong direction in the area of WWD protection using dedicated detection devices.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
1.1.5	1.2	1.1	A TME needs to determine the location at which the wrong-way vehicle was detected entering the facility.	The WWD System/Test Bed shall be capable of detecting a vehicle potentially traveling in the wrong direction in the area of WWD protection using dedicated detection devices.
1.1.6	1	1.1	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of detecting a vehicle potentially traveling in the wrong direction in the area of WWD protection using dedicated detection devices.
1.1.7	2.2	1.1	The TME needs to issue an alert/notification immediately upon detection of a potential WWD event.	The WWD System/Test Bed shall be capable of detecting a vehicle potentially traveling in the wrong direction in the area of WWD protection using dedicated detection devices.
1.1.8	1	1.1	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of detecting a vehicle potentially traveling in the wrong direction in the area of WWD protection using dedicated detection devices.
1.1.9	1	1.1	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of detecting a vehicle potentially traveling in the wrong direction in the area of WWD protection using dedicated detection devices.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
1.1.10	1	1.1	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of detecting a vehicle potentially traveling in the wrong direction in the area of WWD protection using dedicated detection devices.
1.1.11	1.2	1.1	A TME needs to determine the location at which the wrong-way vehicle was detected entering the facility.	The WWD System/Test Bed shall be capable of detecting a vehicle potentially traveling in the wrong direction in the area of WWD protection using dedicated detection devices.
1.1.12	1.4.3	1.1	The TME needs to update the time of the latest update of the location of the wrong-way vehicle.	The WWD System/Test Bed shall be capable of detecting a vehicle potentially traveling in the wrong direction in the area of WWD protection using dedicated detection devices.
1.1.13	1.2	1.1	A TME needs to determine the location at which the wrong-way vehicle was detected entering the facility.	The WWD System/Test Bed shall be capable of detecting a vehicle potentially traveling in the wrong direction in the area of WWD protection using dedicated detection devices.
1.1.14	1	1.1	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of detecting a vehicle potentially traveling in the wrong direction in the area of WWD protection using dedicated detection devices.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
1.1.15	1.2, 1.2.1 1.2.2	1.1	Multiple Needs	The WWD System/Test Bed shall be capable of detecting a vehicle potentially traveling in the wrong direction in the area of WWD protection using dedicated detection devices.
1.1.16	1.2.3 1.2.4	1.1	Multiple Needs	The WWD System/Test Bed shall be capable of detecting a vehicle potentially traveling in the wrong direction in the area of WWD protection using dedicated detection devices.
1.1.17	1.4.3	1.1	The TME needs to update the time of the latest update of the location of the wrong-way vehicle.	The WWD System/Test Bed shall be capable of detecting a vehicle potentially traveling in the wrong direction in the area of WWD protection using dedicated detection devices.
1.2	1 1.1 1.4 1.6.5		Multiple Needs	N/A
1.2.1	1.2	1.2	A TME needs to determine the location at which the wrong-way vehicle was detected entering the facility.	The WWD System/Test Bed shall be capable of detecting a CV potentially traveling in the wrong direction in the area of WWD protection using Road Side Equipment.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
1.2.2	1.6.3 1.6.4	1.2	Multiple Needs	The WWD System/Test Bed shall be capable of detecting a CV potentially traveling in the wrong direction in the area of WWD protection using Road Side Equipment.
1.2.3	1.2	1.2	A TME needs to determine the location at which the wrong-way vehicle was detected entering the facility.	The WWD System/Test Bed shall be capable of detecting a CV potentially traveling in the wrong direction in the area of WWD protection using Road Side Equipment.
1.2.4	1.6.5	1.2	The TME needs to be able to process data elements from the Basic Safety Message to detect when a CV is traveling the wrong-way on a roadway.	The WWD System/Test Bed shall be capable of detecting a CV potentially traveling in the wrong direction in the area of WWD protection using Road Side Equipment.
1.2.5	2.2	1.2	The TME needs to issue an alert/notification immediately upon detection of a potential WWD event.	The WWD System/Test Bed shall be capable of detecting a CV potentially traveling in the wrong direction in the area of WWD protection using Road Side Equipment.
1.2.6	1	1.2	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of detecting a CV potentially traveling in the wrong direction in the area of WWD protection using Road Side Equipment.
1.2.7	1	1.2	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of detecting a CV potentially traveling in the wrong direction in the area of WWD protection using Road Side Equipment.

System Requirement	Traceability #		Traceability Statement	
	User Need	**Requirement**	**Need**	**Requirement**
1.2.8	1	1.2	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of detecting a CV potentially traveling in the wrong direction in the area of WWD protection using Road Side Equipment.
1.2.9	1	1.2	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of detecting a CV potentially traveling in the wrong direction in the area of WWD protection using Road Side Equipment.
1.2.10	1.4.3	1.2	The TME needs to update the time of the latest update of the location of the wrong-way vehicle.	The WWD System/Test Bed shall be capable of detecting a CV potentially traveling in the wrong direction in the area of WWD protection using Road Side Equipment.
1.2.11	1.2	1.2	A TME needs to determine the location at which the wrong-way vehicle was detected entering the facility.	The WWD System/Test Bed shall be capable of detecting a CV potentially traveling in the wrong direction in the area of WWD protection using Road Side Equipment.
1.2.12	1	1.2	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of detecting a CV potentially traveling in the wrong direction in the area of WWD protection using Road Side Equipment.
1.2.13	1.2 1.2.1 1.2.2	1.2	Multiple Needs	The WWD System/Test Bed shall be capable of detecting a CV potentially traveling in the wrong direction in the area of WWD protection using Road Side Equipment.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
1.2.14	1.2.3 1.2.4	1.2	Multiple Needs	The WWD System/Test Bed shall be capable of detecting a CV potentially traveling in the wrong direction in the area of WWD protection using Road Side Equipment.
1.2.15	1.4.3	1.2	The TME needs to update the time of the latest update of the location of the wrong-way vehicle.	The WWD System/Test Bed shall be capable of detecting a CV potentially traveling in the wrong direction in the area of WWD protection using Road Side Equipment.
1.3	1 1.1		Multiple Needs	N/A
1.3.1	1.2	1.3	A TME needs to determine the location at which the wrong-way vehicle was detected entering the facility.	The WWD System/Test Bed shall be capable of having a CV detect that it is traveling in the wrong direction in the area of WWD protection.
1.3.2	1.2	1.3	A TME needs to determine the location at which the wrong-way vehicle was detected entering the facility.	The WWD System/Test Bed shall be capable of having a CV detect that it is traveling in the wrong direction in the area of WWD protection.
1.3.3	1	1.3	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of having a CV detect that it is traveling in the wrong direction in the area of WWD protection.
1.3.4	1 1.2	1.3	Multiple Needs	The WWD System/Test Bed shall be capable of having a CV detect that it is traveling in the wrong direction in the area of WWD protection.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
1.3.5	1	1.3	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of having a CV detect that it is traveling in the wrong direction in the area of WWD protection.
1.3.6	1	1.3	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of having a CV detect that it is traveling in the wrong direction in the area of WWD protection.
1.3.7	1	1.3	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of having a CV detect that it is traveling in the wrong direction in the area of WWD protection.
1.3.8	1	1.3	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of having a CV detect that it is traveling in the wrong direction in the area of WWD protection.
1.3.9	1	1.3	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of having a CV detect that it is traveling in the wrong direction in the area of WWD protection.
1.3.10	1.2	1.3	A TME needs to determine the location at which the wrong-way vehicle was detected entering the facility.	The WWD System/Test Bed shall be capable of having a CV detect that it is traveling in the wrong direction in the area of WWD protection.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
1.3.11	1.2	1.3	A TME needs to determine the location at which the wrong-way vehicle was detected entering the facility.	The WWD System/Test Bed shall be capable of having a CV detect that it is traveling in the wrong direction in the area of WWD protection.
1.3.12	1	1.3	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of having a CV detect that it is traveling in the wrong direction in the area of WWD protection.
1.3.13	1.2 1.2.1 1.2.2	1.3	Multiple Needs	The WWD System/Test Bed shall be capable of having a CV detect that it is traveling in the wrong direction in the area of WWD protection.
1.3.14	1.2.3 1.2.4	1.3	Multiple Needs	The WWD System/Test Bed shall be capable of having a CV detect that it is traveling in the wrong direction in the area of WWD protection.
1.3.15	1.4.3	1.3	The TME needs to update the time of the latest update of the location of the wrong-way vehicle.	The WWD System/Test Bed shall be capable of having a CV detect that it is traveling in the wrong direction in the area of WWD protection.
1.4	1 1.6.2 1.6.3		Multiple Needs	N/A
1.4.1	1.2	1.4	A TME needs to determine the location at which the wrong-way vehicle was detected entering the facility.	The WWD System/Test Bed shall be capable of accepting a message from a CV that has detected that another vehicle is traveling in the wrong direction in the area of WWD protection.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
1.4.2	1	1.4	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of accepting a message from a CV that has detected that another vehicle is traveling in the wrong direction in the area of WWD protection.
1.4.3	1	1.4	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of accepting a message from a CV that has detected that another vehicle is traveling in the wrong direction in the area of WWD protection.
1.4.4	1 1.2	1.4	Multiple Needs	The WWD System/Test Bed shall be capable of accepting a message from a CV that has detected that another vehicle is traveling in the wrong direction in the area of WWD protection.
1.4.5	1	1.4	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of accepting a message from a CV that has detected that another vehicle is traveling in the wrong direction in the area of WWD protection.
1.4.6	1	1.4	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of accepting a message from a CV that has detected that another vehicle is traveling in the wrong direction in the area of WWD protection.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
1.4.7	1	1.4	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of accepting a message from a CV that has detected that another vehicle is traveling in the wrong direction in the area of WWD protection.
1.4.8	1	1.4	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of accepting a message from a CV that has detected that another vehicle is traveling in the wrong direction in the area of WWD protection.
1.4.9	1	1.4	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of accepting a message from a CV that has detected that another vehicle is traveling in the wrong direction in the area of WWD protection.
1.4.10	1.4.3	1.4	The TME needs to update the time of the latest update of the location of the wrong-way vehicle.	The WWD System/Test Bed shall be capable of accepting a message from a CV that has detected that another vehicle is traveling in the wrong direction in the area of WWD protection.
1.4.11	1.2	1.4	A TME needs to determine the location at which the wrong-way vehicle was detected entering the facility.	The WWD System/Test Bed shall be capable of accepting a message from a CV that has detected that another vehicle is traveling in the wrong direction in the area of WWD protection.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
1.4.12	1	1.4	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of accepting a message from a CV that has detected that another vehicle is traveling in the wrong direction in the area of WWD protection.
1.4.13	1.2.1 1.2.2	1.4	Multiple Needs	The WWD System/Test Bed shall be capable of accepting a message from a CV that has detected that another vehicle is traveling in the wrong direction in the area of WWD protection.
1.4.14	1.2.3 1.2.4	1.4	Multiple Needs	The WWD System/Test Bed shall be capable of accepting a message from a CV that has detected that another vehicle is traveling in the wrong direction in the area of WWD protection.
1.4.15	1.4.3	1.4	The TME needs to update the time of the latest update of the location of the wrong-way vehicle.	The WWD System/Test Bed shall be capable of accepting a message from a CV that has detected that another vehicle is traveling in the wrong direction in the area of WWD protection.
1.5	1.6 1.6.1 2.7		Multiple Needs	N/A

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
1.5.1	2.7	1.5	The ESP must be able to provide notifications of WWD events to the TME.	The WWD System/Test Bed shall be capable of accepting input from 911 calls reporting a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.5.2	2.7	1.5	The ESP must be able to provide notifications of WWD events to the TME.	The WWD System/Test Bed shall be capable of accepting input from 911 calls reporting a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.5.3	2.7	1.5	The ESP must be able to provide notifications of WWD events to the TME.	The WWD System/Test Bed shall be capable of accepting input from 911 calls reporting a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.5.4	2.7	1.5	The ESP must be able to provide notifications of WWD events to the TME.	The WWD System/Test Bed shall be capable of accepting input from 911 calls reporting a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.5.5	1	1.5	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of accepting input from 911 calls reporting a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.5.6	1.2.1 1.2.2	1.5	Multiple Needs	The WWD System/Test Bed shall be capable of accepting input from 911 calls reporting a vehicle potentially traveling in the wrong direction in the area of WWD protection.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
1.5.7	1.2.3 1.2.4	1.5	Multiple Needs	The WWD System/Test Bed shall be capable of accepting input from 911 calls reporting a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.5.8	1.4.3	1.5	The TME needs to update the time of the latest update of the location of the wrong-way vehicle.	The WWD System/Test Bed shall be capable of accepting input from 911 calls reporting a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.6	1		A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	N/A
1.6.1	1	1.6	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of accepting input from TME operators that they have detected a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.6.2	1	1.6	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of accepting input from TME operators that they have detected a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.7	2.7		The ESP must be able to provide notifications of WWD events to the TME.	N/A

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
1.7.1	2.7	1.7	The ESP must be able to provide notifications of WWD events to the TME.	The WWD System/Test Bed shall be capable of accepting input from emergency service personnel that they have detected a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.7.2	2.7	1.7	The ESP must be able to provide notifications of WWD events to the TME.	The WWD System/Test Bed shall be capable of accepting input from emergency service personnel that they have detected a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.7.3	2.7	1.7	The ESP must be able to provide notifications of WWD events to the TME.	The WWD System/Test Bed shall be capable of accepting input from emergency service personnel that they have detected a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.7.4	2.7.1 2.7.2	1.7	Multiple Needs	The WWD System/Test Bed shall be capable of accepting input from emergency service personnel that they have detected a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.7.5	2.7.3	1.7	The ESP needs to identify the mile marker reference point of the location at which the wrong-way vehicle was detected.	The WWD System/Test Bed shall be capable of accepting input from emergency service personnel that they have detected a vehicle potentially traveling in the wrong direction in the area of WWD protection.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
1.7.6	1.5	1.7	The TME needs to be able to estimate the arrival time of the wrong-way vehicle at access points upstream of the current position of the vehicle.	The WWD System/Test Bed shall be capable of accepting input from emergency service personnel that they have detected a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.7.7	2.7	1.7	The ESP must be able to provide notifications of WWD events to the TME.	The WWD System/Test Bed shall be capable of accepting input from emergency service personnel that they have detected a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.7.8	1	1.7	A TME needs to be able to detect vehicles that are traveling in the wrong direction (i.e., against the normal direction of flow) on a controlled-access facility.	The WWD System/Test Bed shall be capable of accepting input from emergency service personnel that they have detected a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.7.9	1.2.1 1.2.2	1.7	Multiple Needs	The WWD System/Test Bed shall be capable of accepting input from emergency service personnel that they have detected a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.7.10	1.2.3 1.2.4	1.7	Multiple Needs	The WWD System/Test Bed shall be capable of accepting input from emergency service personnel that they have detected a vehicle potentially traveling in the wrong direction in the area of WWD protection.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
1.7.11	1.4.3	1.7	The TME needs to update the time of the latest update of the location of the wrong-way vehicle.	The WWD System/Test Bed shall be capable of accepting input from emergency service personnel that they have detected a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.7.12	2.7	1.7	The ESP must be able to provide notifications of WWD events to the TME.	The WWD System/Test Bed shall be capable of accepting input from emergency service personnel that they have detected a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.8	5		The TME needs to maintain a record of each action taken by the TME for each WWD event.	N/A
1.8.1	5.1.1	1.8	The TME needs to record the time when and by whom the event was detected.	The WWD Test Bed shall maintain a record of the detection of a vehicle potentially traveling in the wrong direction in the area of WWD protection.
1.8.2	5.1.1	1.8	The TME needs to record the time when and by whom the event was detected.	The WWD Test Bed shall maintain a record of the detection of a vehicle potentially traveling in the wrong direction in the area of WWD protection.
2. VERIFICATION				
2.1	3		The stakeholders need to be able to verify the location and direction of travel of a wrong-way vehicle.	N/A

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
2.1.1		2.1	N/A	The WWD Test Bed shall provide the capability to allow operators to verify the detection of a vehicle traveling in the wrong direction in the area of WWD protection.
2.1.2		2.1	N/A	The WWD Test Bed shall provide the capability to allow operators to verify the detection of a vehicle traveling in the wrong direction in the area of WWD protection.
2.2	1.3 1.4		Multiple Needs	N/A
2.2.1	1.4	2.2	The TME needs to be able to update the current location of the wrong-way vehicle as it travels upstream of the detection point at a user defined frequency.	The WWD System/Test Bed shall provide the capability for TMC operators to enter additional information for WWD events.
2.2.2	1.3.1 1.3.2	2.2	Multiple Needs	The WWD System/Test Bed shall provide the capability for TMC operators to enter additional information for WWD events.
2.2.3	1.3.3	2.2	The TME needs to be able to obtain the color of the wrong-way vehicle.	The WWD System/Test Bed shall provide the capability for TMC operators to enter additional information for WWD events.
2.2.4	1.3.4	2.2	The TME needs to be able to obtain the license plate of the wrong-way vehicle.	The WWD System/Test Bed shall provide the capability for TMC operators to enter additional information for WWD events.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
2.2.5	1.4.3	2.2	The TME needs to update the time of the latest update of the location of the wrong-way vehicle.	The WWD System/Test Bed shall provide the capability for TMC operators to enter additional information for WWD events.
2.2.6	1.4.4 1.4.5	2.2	Multiple Needs	The WWD System/Test Bed shall provide the capability for TMC operators to enter additional information for WWD events.
2.2.7	1.5	2.2	The TME needs to be able to estimate the arrival time of the wrong-way vehicle at access points upstream of the current position of the vehicle.	The WWD System/Test Bed shall provide the capability for TMC operators to enter additional information for WWD events.
2.3	5		The TME needs to maintain a record of each action taken by the TME for each WWD event.	N/A
2.3.1	5.1.2	2.3	The TME needs to record the time when and by whom the event was verified.	The WWD Test Bed shall maintain a record of the verification of a vehicle traveling in the wrong direction in the area of WWD protection.
2.3.2	5.1.2	2.3	The TME needs to record the time when and by whom the event was verified.	The WWD Test Bed shall maintain a record of the verification of a vehicle traveling in the wrong direction in the area of WWD protection.
3. NOTIFICATION				
3.1	2 2.1 2.1.1 2.2 3.1		Multiple Needs	N/A

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
3.1.1		3.1	N/A	The WWD Test Bed shall provide the capability to allow TMC operators to notify other stakeholders of the detection of a vehicle traveling in the wrong direction in the area of WWD protection.
3.1.2		3.1	N/A	The WWD Test Bed shall provide the capability to allow TMC operators to notify other stakeholders of the detection of a vehicle traveling in the wrong direction in the area of WWD protection.
3.1.3	2.1.2	3.1	The TME needs to notify other TMEs of when a wrong-way vehicle has been detected on a facility	The WWD Test Bed shall provide the capability to allow TMC operators to notify other stakeholders of the detection of a vehicle traveling in the wrong direction in the area of WWD protection.
3.1.4	2.1.3	3.1	The TME needs to notify the Public Information Officer (PIO) when a wrong-way vehicle has been detected on a facility.	The WWD Test Bed shall provide the capability to allow TMC operators to notify other stakeholders of the detection of a vehicle traveling in the wrong direction in the area of WWD protection.
3.1.5	2.2.1	3.1	The TME needs to include information about the location of the wrong-way vehicle on the facility.	The WWD Test Bed shall provide the capability to allow TMC operators to notify other stakeholders of the detection of a vehicle traveling in the wrong direction in the area of WWD protection.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
3.1.6	2.2.2	3.1	The TME needs to include a description of the wrong-way vehicle on a facility.	The WWD Test Bed shall provide the capability to allow TMC operators to notify other stakeholders of the detection of a vehicle traveling in the wrong direction in the area of WWD protection.
3.1.7	2.2.3	3.1	The TME needs to include the estimate arrival time of the wrong-way vehicle at points upstream of its current position.	The WWD Test Bed shall provide the capability to allow TMC operators to notify other stakeholders of the detection of a vehicle traveling in the wrong direction in the area of WWD protection.
3.1.8	2.3.2 4.4	3.1	Multiple Needs	The WWD Test Bed shall provide the capability to allow TMC operators to notify other stakeholders of the detection of a vehicle traveling in the wrong direction in the area of WWD protection.
3.2	2.7		The ESP must be able to provide notifications of WWD events to the TME.	N/A
3.2.1		3.2	N/A	The WWD Test Bed shall provide the capability to allow Emergency Service Center operators to notify TMC operators of the detection of a vehicle traveling in the wrong direction in the area of WWD protection.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
3.2.2		3.2	N/A	The WWD Test Bed shall provide the capability to allow Emergency Service Center operators to notify TMC operators of the detection of a vehicle traveling in the wrong direction in the area of WWD protection.
3.3	2.3.1		The TME needs to be able to update the initial alert/notification when the event is verified.	N/A
3.3.1		3.3	N/A	The WWD Test Bed shall provide the capability to allow TMC operators to notify Emergency Service Center operators of the verification of a vehicle traveling in the wrong direction in the area of WWD protection.
3.3.2		3.3	N/A	The WWD Test Bed shall provide the capability to allow TMC operators to notify Emergency Service Center operators of the verification of a vehicle traveling in the wrong direction in the area of WWD protection.
3.4	3.2		The ESP needs to notify the TME when a WWD event has been verified through their 911 dispatchers and/or officers in the field.	N/A

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
3.4.1		3.4	N/A	The WWD System/Test Bed shall provide the capability to allow Emergency Service Center operators to notify TMC operators of the verification of a vehicle traveling in the wrong direction in the area of WWD protection.
3.4.2		3.4	N/A	The WWD System/Test Bed shall provide the capability to allow Emergency Service Center operators to notify TMC operators of the verification of a vehicle traveling in the wrong direction in the area of WWD protection.
3.5			N/A	N/A
3.6	5		The TME needs to maintain a record of each action taken by the TME for each WWD event.	N/A
3.6.1	5.1	3.6	The TME needs to record the time at which actions associated with each event occurred.	The WWD Test Bed shall maintain a record of the notifications of a vehicle traveling in the wrong direction in the area of WWD protection.
3.6.2	5.1	3.6	The TME needs to record the time at which actions associated with each event occurred.	The WWD Test Bed shall maintain a record of the notifications of a vehicle traveling in the wrong direction in the area of WWD protection.
4. ALERT				
4.1	4		The TME needs to provide warning messages to both CV and non-CVs upstream of the wrong-way driver.	N/A

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
4.1.1	4.3.1	4.1	The TME may alert non-CVs by implementing pre-programmed message on DMSs.	The WWD System/Test Bed shall provide the capability to allow TMC operators to provide an alert to drivers of oncoming non-CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.
4.1.2	4.3.1	4.1	The TME may alert non-CVs by implementing pre-programmed message on DMSs.	The WWD System/Test Bed shall provide the capability to allow TMC operators to provide an alert to drivers of oncoming non-CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.
4.1.3	4.3 4.3.1.	4.1	Multiple Needs	The WWD System/Test Bed shall provide the capability to allow TMC operators to provide an alert to drivers of oncoming non-CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.
4.1.4	4.3.3	4.1	The TME may alert non-CVs by activating special LED signs.	The WWD System/Test Bed shall provide the capability to allow TMC operators to provide an alert to drivers of oncoming non-CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
4.1.5	4.3.4	4.1	The TME may alert non-CVs by activating a special display on a ramp control signal.	The WWD System/Test Bed shall provide the capability to allow TMC operators to provide an alert to drivers of oncoming non-CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.
4.1.6	4.3.5	4.1	The TME may activate ramp control gates in response to a WWD event.	The WWD System/Test Bed shall provide the capability to allow TMC operators to provide an alert to drivers of oncoming non-CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.
4.2	4		The TME needs to provide warning messages to both CV and non-CVs upstream of the wrong-way driver.	N/A
4.2.1	4.7	4.2	A CV needs to be able to process the RSA to generate an appropriate warning alert display to the driver.	The WWD System/Test Bed shall provide the capability to alert drivers of on-coming CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.
4.2.2	4.7	4.2	A CV needs to be able to process the RSA to generate an appropriate warning alert display to the driver.	The WWD System/Test Bed shall provide the capability to alert drivers of on-coming CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
4.2.3	4.1	4.2	The TME needs to broadcast information about the WWD event to CVs through properly formatted SAE J2735 road safety alert messages.	The WWD System/Test Bed shall provide the capability to alert drivers of on-coming CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.
4.2.4	4.6	4.2	A CV must be able to receive a properly formatted roadside alert (RSA) issued by the TME.	The WWD System/Test Bed shall provide the capability to alert drivers of on-coming CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.
4.2.5	4.7	4.2	A CV needs to be able to process the RSA to generate an appropriate warning alert display to the driver.	The WWD System/Test Bed shall provide the capability to alert drivers of on-coming CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.
4.3	2.6		The TME needs to be able to receive notification of WWD events from other stakeholders (e.g., law enforcement)	N/A
4.3.1		4.3	N/A	The WWD System/Test Bed shall provide the capability to alert drivers of emergency service CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
4.3.2		4.3	N/A	The WWD System/Test Bed shall provide the capability to alert drivers of emergency service CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.
4.3.3	4.1	4.3	The TME needs to broadcast information about the WWD event to CVs through properly formatted SAE J2735 road safety alert messages.	The WWD System/Test Bed shall provide the capability to alert drivers of emergency service CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.
4.3.4	4.6	4.3	A CV must be able to receive a properly formatted roadside alert (RSA) issued by the TME.	The WWD System/Test Bed shall provide the capability to alert drivers of emergency service CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.
4.3.5	4.7	4.3	A CV needs to be able to process the RSA to generate an appropriate warning alert display to the driver.	The WWD System/Test Bed shall provide the capability to alert drivers of emergency service CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.
4.4	2.1.1		The TME needs to notify ESPs when a wrong-way vehicle has been detected.	N/A

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
4.4.1		4.4	N/A	The WWD System/Test Bed shall provide the capability to alert drivers of emergency service non-CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.
4.4.2		4.4	N/A	The WWD System/Test Bed shall provide the capability to alert drivers of emergency service non-CVs that a vehicle has been detected traveling in the wrong direction in the area of WWD protection.
4.5	4.2		The TME needs to broadcast information about the WWD event to information service providers.	N/A
4.6	5		The TME needs to maintain a record of each action taken by the TME for each WWD event.	N/A
4.6.1	5.2	4.6	The TME needs to record the time at which actions associated with each event occurred.	The WWD Test Bed shall maintain a record of the verification of a vehicle traveling in the wrong direction in the area of WWD protection.
4.6.2	5.2	4.6	The TME needs to record the time at which actions associated with each event occurred.	The WWD Test Bed shall maintain a record of the verification of a vehicle traveling in the wrong direction in the area of WWD protection.
5. CLEAR				
5.1	2.3 5.1		Multiple Needs	N/A

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
5.1.1		5.1	N/A	The WWD System/Test Bed shall provide emergency service personnel the capability to indicate to the emergency dispatch operator that the status of a WWD event has been changed.
5.1.2		5.1	N/A	The WWD System/Test Bed shall provide emergency service personnel the capability to indicate to the emergency dispatch operator that the status of a WWD event has been changed.
5.1.3		5.1	N/A	The WWD System/Test Bed shall provide emergency service personnel the capability to indicate to the emergency dispatch operator that the status of a WWD event has been changed.
5.2	2.7		The ESP must be able to provide notifications of WWD events to the TME.	N/A
5.2.1		5.2	N/A	The WWD System/Test Bed shall provide the capability for Emergency Service Center operators to alert the TMC operators that the status of a WWD event has been changed.
5.2.2		5.2	N/A	The WWD System/Test Bed shall provide the capability for Emergency Service Center operators to alert the TMC operators that the status of a WWD event has been changed.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
5.3	2.3		The TME needs to be able to update the information contained in a WWD alert/notification.	N/A
5.3.1	2.5 4.5	5.3	Multiple Needs	The WWD System/Test Bed shall provide TMC operators the capability to modify the alerts to the general public when WWD event status changes.
5.3.2		5.3	N/A	The WWD System/Test Bed shall provide TMC operators the capability to modify the alerts to the general public when WWD event status changes.
5.3.3		5.3	N/A	The WWD System/Test Bed shall provide TMC operators the capability to modify the alerts to the general public when WWD event status changes.
5.4	2.4		The TME needs to be able assign a time-to-live value to each notification.	N/A
5.4.1		5.4	N/A	The WWD System/Test Bed shall cease alerting oncoming CVs of the WWD event when it has been cleared.
5.4.2		5.4	N/A	The WWD System/Test Bed shall cease alerting oncoming CVs of the WWD event when it has been cleared.
5.4.3		5.4	N/A	The WWD System/Test Bed shall cease alerting oncoming CVs of the WWD event when it has been cleared.

System Requirement	Traceability #		Traceability Statement	
	User Need	Requirement	Need	Requirement
5.5	5		The TME needs to maintain a record of each action taken by the TME for each WWD event.	N/A
5.5.1	5.1.3	5.5	The TME needs to record the time and how the event was cleared (terminated).	The WWD Test Bed shall maintain a record of the status changes (including termination of the wrong-way event) of a vehicle traveling in the wrong direction in the area of WWD protection.
5.5.2	5.1.3	5.5	The TME needs to record the time and how the event was cleared (terminated).	The WWD Test Bed shall maintain a record of the status changes (including termination of the wrong-way event) of a vehicle traveling in the wrong direction in the area of WWD protection.
6. SAFETY REQUIREMENTS				
6.1			N/A	N/A
6.2			N/A	N/A