TTI: 0-7119

Texas A&M Transportation Institute

Evaluation of Wrong-Way Driving Detection Technologies

Technical Report 0-7119-R1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

sponsored by the
Federal Highway Administration and the
Texas Department of Transportation
https://tti.tamu.edu/documents/0-7119-R1.pdf

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-23/0-7119-R1		

4. Title and Subtitle	5. Report Date
EVALUATION OF WRONG-WAY DRIVING DETECTION TECHNOLOGIES	Published: January 2024
	6. Performing Organization Code
7. Author(s) Melisa D. Finley, Steven P. Venglar, David Florence, Hassan Charara, Robert E. Brydia, and Marcus A. Brewer	8. Performing Organization Report No. Report 0-7119-R1
9. Performing Organization Name and Address Texas A&M Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project 0-7119
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office 125 E. 11th Street Austin, Texas 78701-2483	13. Type of Report and Period Covered Technical Report: September 2021–August 2023 14. Sponsoring Agency Code

15. Supplementary Notes

Project sponsored by the Texas Department of Transportation and the Federal Highway Administration.
Project Title: Develop Standardized Operational Evaluation of Wrong-Way Driving Detection Technologies
URL: https://tti.tamu.edu/documents/0-7119-R1.pdf

16. Abstract

Wrong-way driving (WWD) crashes occur when a motorist either inadvertently or deliberately drives in the opposite direction of travel on a divided roadway. For this research project, Texas A&M Transportation Institute researchers assessed the state-of-the-practice regarding WWD detection technology, developed a standardized testing mechanism to assess performance of WWD detection technologies, and evaluated select off-the-shelf technologies in closed-course and field environments. Based on the findings, researchers developed implementation guidance that can be used by practitioners to inform decisions regarding the selection of WWD detection technology. Researchers also recommended language for future technical specifications for WWD detection systems.

17. Key Words	18. Distribution Statement
Wrong-Way Driving, Detection, Traffic Control Devices, False Calls	No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia https://www.ntis.gov

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	166	

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

EVALUATION OF WRONG-WAY DRIVING DETECTION TECHNOLOGIES

by

Melisa D. Finley, P.E.
Senior Research Engineer
Texas A&M Transportation Institute

Steven P. Venglar, P.E.
Research Engineer
Texas A&M Transportation Institute

David Florence, P.E.
Assistant Research Engineer
Texas A&M Transportation Institute

Hassan Charara
Software Applications Developer V
Texas A&M Transportation Institute

Robert E. Brydia
Senior Research Scientist
Texas A&M Transportation Institute

and

Marcus A. Brewer, P.E., PMP
Research Engineer
Texas A&M Transportation Institute

Report 0-7119-R1
Project 0-7119
Project Title: Develop Standardized Operational Evaluation of Wrong-Way Driving Detection Technologies

Sponsored by the
Texas Department of Transportation
and the
Federal Highway Administration

Published: January 2024

TEXAS A&M TRANSPORTATION INSTITUTE
College Station, Texas 77843-3135

DISCLAIMER

This research was sponsored by 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.

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.

This report is not intended for construction, bidding, or permitting purposes. The engineer in charge of this project was Melisa D. Finley, P.E. #TX-90937.

ACKNOWLEDGMENTS

This project was sponsored by TxDOT and FHWA. Joanne Steele of TxDOT served as the project manager. The authors gratefully acknowledge the assistance and direction that the TxDOT Project Monitoring Committee (PMC) provided over the course of the project. The members of the PMC included:

- Eduardo Adame (TxDOT).
- John Gianotti (TxDOT).
- Jeff Miles (TxDOT).
- Theresa Poer (TxDOT).
- Eric Hemphill (North Texas Tollway Authority [NTTA]).
- Elizabeth Mow (NTTA).

The Texas A&M Transportation Institute (TTI) researchers would also like to acknowledge the contributions of the many other TTI staff who assisted with various aspects of this project.

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

CHAPTER 1: INTRODUCTION

Wrong-way driving (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.

From 2010 to 2019, approximately 1700 WWD crashes occurred in Texas on controlled-access highways (e.g., freeways and interstates). As seen in Figure 1, the maximum number of WWD crashes (210) was observed in 2015, while the minimum (113) was observed in 2017. On average, about 170 WWD crashes occurred each year and 10 percent resulted in a fatality.

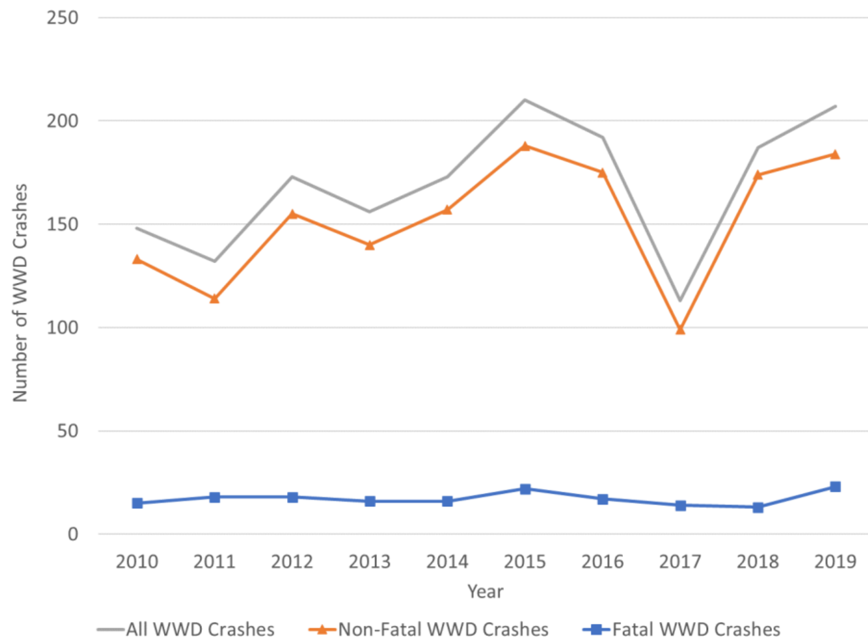


Figure 1. Number of WWD Crashes on Controlled-Access Highways in Texas (2010–2019).

To reduce the number of wrong-way (WW) maneuvers and associated crashes on Texas freeways, the Texas Department of Transportation (TxDOT) purchases, installs, and maintains intelligent transportation systems (ITS) that can detect WW drivers, alert the WW drivers of their error via signs, and notify the traffic management center (TMC). However, since there is not a TxDOT standard specification for WWD detection systems nor a standardized testing mechanism to assess system performance, TxDOT personnel are often unaware of the benefits and limitations of systems prior to activation in the field. This results in systems not functioning as expected, high false-alarm rates, and increased workload for agency staff. In addition, TxDOT district staff are continually asked to install and test a variety of emerging WWD detection systems.

For this research project, Texas A&M Transportation Institute (TTI) researchers assessed the state-of-the-practice regarding WWD detection technology, developed a standardized testing mechanism to assess performance of WWD detection technologies and evaluated select off-the-shelf technologies in closed-course and field environments. Based on the findings, researchers developed implementation guidance that can be used by practitioners to inform decisions regarding the selection of WWD detection technology. Researchers also recommended language for future technical specifications for WWD detection systems.

CHAPTER 2: STATE-OF-THE-PRACTICE REVIEW

To determine the state-of-the-practice regarding WWD detection technology, in the fall of 2021 TTI researchers reviewed previous literature and state agency testing procedures, assessed the current practice in Texas, and identified commercially available off-the-shelf WWD detection systems.

LITERATURE REVIEW AND STATE AGENCY TESTING PROCEDURES

Motorists driving the WW on divided roadways has been a concern for transportation agencies and the traveling public for over 50 years. Since the 1960s, transportation agencies have been identifying and testing various methods to detect and warn WW drivers. Most of the prior research focused on assessing the effectiveness of such systems to stop WW drivers from entering freeways. More recently, research efforts have begun investigating the accuracy and reliability of WWD detection systems. The summary contained in this chapter provides a brief overview of historical and recent (i.e., within the last 10 years) WWD detection system implementations and testing.

Historical WWD Detection Systems

The California Department of Transportation (Caltrans) developed and tested one of the first WWD detection and warning systems (*1*, *2*). It featured an illuminated and retroreflective sign (GO BACK YOU ARE GOING WRONG WAY), a 12-inch red traffic light, and two horns. These devices were activated when a WW vehicle was detected using directional induction loop detectors. In the 1970s, Caltrans used a modified form of the WW vehicle detection system for surveillance at exit ramps to quantify the WWD issues and evaluate several countermeasures (*3*). The modified system used a pneumatic road tube to detect the vehicle, electronic circuity to identify the WW movement, and a single frame camera to verify the WW movement.

In the 1980s, the Illinois Department of Transportation experimented with sensors embedded in the roadway to detect WW vehicles, which, if activated, would lower a signal arm across the road and initiate a dynamic message sign (DMS) to alert exiting traffic about the hazard ahead (*4*). In New Mexico in the 1990s, a directional traffic sensor system was implemented on an exit ramp near Albuquerque (*5*). This system used loop sensors and a modified 3M Canoga TMI C400 vehicle detector to detect WW vehicles and activate red flashers on a WRONG WAY sign to warn the WW driver.

In the 2000s, the Washington Department of Transportation used sensors (i.e., two induction loops connected to a Reno S-Series loop detector to provide directional detection) and digital video cameras on select exit ramps to detect and record WW events (*6*). When a WW vehicle was detected, a blank-out sign with the message WRONG WAY and flashers were activated.

Concurrently, the system videotaped the vehicle's movements and the driver's behavior to further assess the problem.

In 2006, the Florida Department of Transportation (FDOT) implemented a WWD detection system on the Pensacola Bay Bridge in Florida (*7*). This system used a low-power microwave radar detector mounted approximately 20 ft above the roadway and could detect a WW movement at approximately 1000 ft prior to the bridge. When a WW movement was detected, flashing beacons visibly enhanced the DO NOT ENTER and WRONG WAY signs above the travel way. In 2010, FDOT tested video for WW detection on an exit ramp (*8*). Simulated test runs over a 27-day period found a number of false alarms due to vehicles on the shoulder, dark shadows, headlight reflection on wet pavement, and insufficient minimum tracking distances.

By 2009, the Harris County Toll Road Authority (HCTRA) was operating a WWD detection system on a 13.2-mi portion of the Westpark Tollway, a controlled-access roadway in Houston (*9*). The system used Doppler radar detection sensors supplemented with in-pavement loop sensors at 14 points along the tollway. TMC personnel received all WW movement detections and monitored the system 24 hours a day and 7 days a week. Once a vehicle was detected, TMC operators could immediately dispatch law enforcement officers, monitor the vehicle's whereabouts via closed-circuit television (CCTV) and a geographic information system WW detection map integrated into the software platform, and warn other motorists of the detected WW vehicle using DMSs. This deployment was the first of its type in the United States and incorporated several innovative aspects including site-specific design, configuration, and communications dispatch and response protocols.

Recent WWD Detection Systems

In 2013, the New York State Thruway Authority installed an ITS-based warning system at one exit along I-190 in Buffalo (*10*). The system used Doppler radar detection and a small DMS that activated after a WW vehicle was detected. The initial installation displayed the following sequence of messages to a WW driver via the DMS: WRONG WAY, STOP, and PULL OVER. The system was also designed to send alerts to the TMC, police, and other DMSs along the main lanes.

In 2014, Florida's Turnpike Enterprise installed WWD detection systems comprised of two radar devices, LED border-illuminated WRONG WAY signs, and a camera for verification at 17 ramps in South Florida (*11*). Detection of a WW vehicle activated the signs, captured an image of the vehicle, and sent an alert to the TMC. DMSs were used to warn right-way drivers. Similarly, from 2015 to 2017, the Central Florida Expressway Authority (CFX) implemented WWD detection systems at 35 ramps in Central Florida (*11*). These systems included multiple radars for detection, cameras for visual verification, and two sets of red rectangular rapid flashing beacons (RRFBs) on WRONG WAY signs, which were illuminated when a WW driver was detected. An alert, including a photo, was also sent to the TMC. Both systems reduced WWD incidents and resulted in WW drivers self-correcting.

In 2015, a study sponsored by the Arizona Department of Transportation (ADOT) (*12*) developed a conceptual system to detect WW vehicles, warn the errant driver of their mistake, notify the ADOT Traffic Operations Center (TOC) and law enforcement, track the WW vehicle, and warn right-way drivers in the vicinity of the oncoming vehicle. As part of this effort, researchers examined available detection technologies, including loop detectors, radar detectors, microwave sensors, and video.

Prior testing (*8*) of non-intrusive detection technologies (i.e., Doppler radar, microwave sensors, video imaging, thermal sensors, and magnetic sensors) found that all the technologies could detect WW vehicles at varying levels of efficiency and reliability, and that no technology outperformed the others. The testing included one week of field testing under normal conditions, which primarily focused on false calls, and controlled field testing in which a researcher intentionally drove a vehicle the WW to evaluate missed calls and missed email notifications to the ADOT TOC. With respect to false calls, the detector system needed to be at least 90 percent accurate. During field testing, if a system produced a false detection more than 25 percent of the time, the manufacturer was notified and allowed to recalibrate the system. Additional qualification measures included: ease of installation, ability to install the WW device on a system-wide basis, and the cost of the equipment. Researchers conducted the controlled field testing at night, and it involved 14 test runs. For the first three tests, researchers drove the vehicle in each lane. In the next two tests, the vehicle straddled the lane lines (i.e., swerving between two lanes). For the final two tests, the vehicle swerved down the entire ramp beginning in the right lane and then beginning in the left lane. All tests were conducted at approximately 7 and 20 mph. If a test failed, researchers ran it again to confirm. Overall, the study results verified that WW vehicles can be detected with readily available off-the-shelf detection equipment. Recommendations included:

- Develop WW detection specifications.
- Consider detector redundancy.
- Prepare guidelines for WW detection that consider most applicable uses and limitations.
- Address maintenance issues.
- Consider training required.
- Address installation requirements and technical support of the system.

As part of the 2015 study (*12*), researchers established performance measures and a scoring system based on input from an advisory committee, decision-makers, and the findings from a literature review to select the detection, notification, and warning elements for the proposed system. The performance measures were constructible, reliable, accurate, cost, maintenance, integration with ADOT system, adaptable for future changes, resistance to vandalism, redundancy, dual functionality, response time, data logging, safety, and tested by ADOT. All the performance measures were given equal weight, but not all performance measures were applicable to every element. Therefore, the score was computed as the average for every element. The researchers noted that assigning a score (i.e., 1 to 5, with one being the least and five being the most) required engineering judgment and knowledge of each element. The detection technologies that scored the highest were loop detectors (4.45) and radar (4.18). The same study also developed a monitoring plan for a pilot deployment. Below are the recommended component tests intended to verify functionality of the detection technologies.

- Detect vehicles as slow as 10 mph.
- Detect vehicles as small as a 90-cc motorcycle.
- Distinguish a vehicle traveling in the wrong direction.
- Verify triggering of verification camera to allow for confirmation of a WW vehicle.
- Provide video imaging necessary to determine whether the WW driver self-corrects or continues onto the facility.
- Log date, time, location, and any malfunction codes for all detection and verification activations.
- Verify initiation of message to ADOT TOC.
- Verify receipt of message at ADOT TOC.
- Confirm consistently reliable transmission of message to ADOT TOC.
- Identify any transmission latency issues.

In January 2018, ADOT began operating a robust WW driver detection pilot program along a 15-mile section of I-17 in Phoenix (*13*, *14*). This system consisted of 90 thermal detection cameras located at exit ramps and along the main lanes, as well as many other components to warn WW drivers and alert ADOT TOC, law enforcement, and right-way drivers. Video clips generated by the thermal cameras allow ADOT TOC staff to visually verify and track WW vehicles. Once verified, a custom-built decision support system software package automatically deploys several countermeasures. ADOT collected and analyzed WWD event data in the pilot corridor from January 2018 to December 2019. Overall, the system components performed as intended. However, initially the thermal cameras registered false positive detections due to wind, pedestrians, truck occlusions, birds, and other factors. ADOT mitigated these issues by improving mounting locations and adjusting the cameras' detection zones and algorithms. Based on the pilot evaluation, ADOT developed a plan for expanding the use of some system components, including thermal cameras.

In 2016, the ENTERPRISE Pooled Fund Study (*15*) published a report that summarized the current practice of WW countermeasures on freeways, including those that use ITSs. The goal of the project was to increase understanding of the countermeasure types and evaluation efforts and results and create a repository of WW countermeasure deployments. The report includes details on WW countermeasures used by 13 agencies (i.e., ADOT, Connecticut Department of Transportation [DOT], CFX, FDOT, Iowa DOT, Michigan DOT, Missouri DOT, Ohio DOT, Rhode Island DOT, HCTRA, TxDOT, Washington State DOT, and Wisconsin DOT). Most of the active deployments with ITSs included multiple sensors for detection and at least one camera for verification. Researchers noted that several agencies preferred redundant detection systems to minimize false positives.

Around the same time, Caltrans initiated pilot projects in San Diego and Sacramento to test new and emerging WWD countermeasures, including advanced detection and notification systems (*16*, *17*). These systems included dual radars to detect WW drivers, activated red flashing border-illuminated signs, and transmitted notifications to Caltrans and law enforcement at the TMC. In San Diego, between May 10, 2017, and November 11, 2019, the advanced detection and notification systems at six ramps detected 20 actual WW events (two bicycles and 18 vehicles), 32 maintenance or construction vehicles going the wrong direction, and one emergency vehicle going in the wrong direction to respond to an incident. The systems also produced 60 false positive detections for varied reasons (e.g., weather and queueing traffic on the ramp). In Sacramento, between March 25, 2017, and October 27, 2019, the same type of system at four ramps detected 17 actual WW events, 17 maintenance or construction vehicles going the wrong direction, four emergency vehicles going in the wrong direction to respond to an incident, and nine pedestrians. The systems produced 13 false positives. In both cities, the systems also occasionally failed to activate the red flashing border-illuminated signs and/or send an alert to the TMC.

As part of the Caltrans pilot projects, the Advance Highway Maintenance and Construction Technology (AHMCT) Research Center developed a vision-based site monitoring (VBSM) system for monitoring WWD events (*18*). The system integrated a camera, solar power, and a cellular data modem into a pole-mounted package. Researchers installed the VBSM system at 12 exit ramps to capture video of WWD events for 39 months (June 5, 2016–August 31, 2019). Video analytics software detected WWD events and captured short video clips of all WWD events. Overall, the results showed the effective performance of the VBSM system as a self-contained system for monitoring WWD events.

FDOT also sponsored research (*19*) to evaluate video analytics for WWD vehicle detection on freeways and TMC notification. Researchers tested fixed-camera video streams with defined regions of interest from three manufacturers at six testing locations in the Tampa Bay area for one week (i.e., five weekdays and two weekend days). Since WWD events are rare, researchers monitored for actual WWD events at one location. At the other five locations, researchers simulated WWD events by either treating all right-way traffic as WW traffic (one location) or treating all inside lane traffic in the opposite direction as WW traffic (four locations). The testing locations were assigned one of four testing scenarios: (1) normal daily traffic conditions, (2) consecutive WWD in both directions, (3) normal-light nighttime traffic conditions, and (4) low-light nighttime traffic conditions. Performance measures included: (1) WWD detection system accuracy (i.e., number of true WWD calls divided by the total number of calls),

(2) percentage of false calls (i.e., number of false calls divided by the total number of calls), (3) actual WWD detection accuracy (i.e., number of true WWD calls divided by the total number of WWD vehicles), and (4) percentage of missed calls (i.e., number of missed calls over total number of WWD vehicles). To test TMC notifications, each manufacturer reported WWD event information (i.e., occurrence date, time, and location [site milepost and lane number]) to a project-related email account.

Early on, researchers noted issues with the use of video analytics and pan-tilt-zoom (PTZ) cameras. In some cases, FDOT staff needed to change the camera view to monitor traffic. However, the PTZ cameras did not always return to the exact pre-set position used to set up the WWD defined regions. As a result of this issue, researchers used fixed cameras for this study. The test results showed that WWD detection varied significantly among the three manufacturers. However, all three systems were able to send an email notification to the TMC when a WW vehicle was detected. Overall, researchers concluded that the ability of real-time video-analytic systems to detect WW vehicles on freeways is highly dependent upon the manufacturer. Researchers also noted that simulated WWD events are good indicators of WWD detection system accuracy and actual WWD detection accuracy. However, they do not indicate actual detection accuracy.

FDOT District 7 and Johnson, Mirmiran, & Thompson, Inc. also sponsored a project (*20*) to evaluate a thermal camera-based detection system and a video-analytic system to identify WWD events. Researchers tested the thermal camera-based detection system at the Sunshine Skyway Bridge (two locations) and the video-analytic system at the Howard Frankland Bridge (six locations). The performance measures included WWD detection system accuracy and percentage of false calls. Although no actual WW vehicles were observed, the detection systems did trigger WWD events when vehicles (private or on-duty) were reversing down the shoulder and when on-duty vehicles were moving in the opposite direction of traffic to perform work tasks. Overall, the detection system accuracy for the thermal camera-based detection system and video-analytic system was 100 percent and 84.6 percent, respectively. Incorrect detections were the result of boats in the water next to the bridge, slow-moving vehicles in the mainlanes, vehicles stopped on the shoulder, and camera vibrations.

FDOT's Standard Specifications for Road and Bridge Construction (*21*) contains specifications for WW vehicle detection systems. These systems must meet all relevant subsections within Sections 660 and 995, as well as a supplemental requirement (*22*). WW vehicle detection systems are also addressed in Section 230.4 of FDOT's Design Manual (*23*) and FDOT's Standard Plans Index 700-120 (see sheet 9 in *24*). Key highlights include:

- May use any of the technology types listed in the specification (i.e., inductive loop, video, thermal, microwave, wireless magnetometer, and automatic vehicle identification systems).

- Mainlane and ramp installations must monitor all lanes for one direction, including shoulders.
- May consist of more than one detection zone.
- Shall include a minimum of one serial or Ethernet communications interface.
- Shall be compatible with FDOT's SunGuide® software.
- Produce an alarm output when a WW vehicle is detected. For systems installed on ramps, send alert to SunGuide® software, send sequence of images (up to 10 seconds that covers time before and after detection), and activate all signs associated with system.
- Shall provide software that allows local and remote configuration and monitoring.
- Installed in accordance with contract documents, manufacturer's recommendations, and as directed by the engineer.
- Must submit a test plan for field acceptance to the engineer. Test plan must include a detection accuracy test and false positive test for each location.

FDOT's testing for WW vehicle detection systems includes controlled environment testing at FDOT's Traffic Engineering Research Laboratory (TERL) to list manufacturers on the Approved Products List and field testing for acceptance of the system after installation by the contractor. The TERL uses product compliance/requirement matrices derived from specifications to assess conformance (*25*). Most of the requirements involve hardware quality/construction and communications testing. However, one requirement addresses system functionality. The WW vehicle detection system must be capable of meeting a detection accuracy of 100 percent and have zero false positive readings using a sample of 200 vehicles in a controlled environment at TERL.

In 2019, the Colorado Department of Transportation (CDOT) Region 1 began a pilot study to test the capabilities of four WW detection systems (i.e., one radar, one video camera, and two thermal cameras) (*26*, *27*). The radar-based system (TraffiCalm®) consisted of a series of radar detection units that are typically used to create four different detection zones along an exit ramp (i.e., flasher activation zone, pre-alert zone, alert zone, and confirmation zone). During testing, only the alert and confirmation zones were configured. The video camera-based system (Image Sensing Systems, Inc. [ISS]) was embedded in a radar detection device but used video image detection technology to detect WW vehicles. One of the thermal camera-based systems (TAPCO®) had a two-zone detection system (i.e., alert activation closer to the stop bar and confirmation detection further away from the stop bar) that could send notifications independently from one another, so they were tested as two different systems. The second thermal camera-based system (BOSCH/MH Corbin) used multiple defined detection zones within the camera's view and an onboard algorithm that differentiates the zones such that one can be used for identification and the other used for confirmation.

CDOT conducted the pilot study for six months (October 2019–March 2020) at a single location to evaluate the systems' accuracy and provide insights into their operational feasibility when subjected to severe weather conditions. Each manufacturer was responsible for installing, maintaining, and operating their system, and the cellular communications needed to send an alert via email to the project team when a WWD vehicle was detected. Due to the different installation requirements, identical detection zones were not possible. Instead, the detection zones for the four systems were spread along the exit ramp. For this study, no additional infrastructure-based warning devices were installed.

The field evaluation consisted of controlled and uncontrolled testing. The controlled testing was conducted to evaluate each systems' accuracy for 15 different WWD scenarios during the day and at night (see Table 1). For the controlled testing, CDOT staff closed the ramp and drove a vehicle in the wrong direction. Multiple test runs were completed for each scenario resulting in 90 total test runs (45 day and 45 night). Controlled testing was not conducted during inclement weather or with the vehicle's headlights off. The controlled testing performance measures were accurate calls (i.e., detection system sent alert and was a true WWD event), missed calls (i.e., detection system did not sent alert and was a true WWD event), false positives (i.e., detection system sent alert when no WWD event occurred), and average latency of the system (i.e., average difference in time between notification receipt and the event occurring).

Table 1. CDOT Controlled Testing WWD Scenarios (adapted from *26*).

Category	Subcategory	Number of Runs
Small profile	Bicycle	2
	Pedestrian	4
Detector proximity	Car in lane 1	9
	Car in lane 2	5
	Car straddling both lanes	5
	Truck straddling both lanes	2
At an angle	Car "S" curves	7
Vehicle speed	Fast car (approximately 35 mph)	8
	Slow car (approximately 5 mph)	7
	Slow truck (approximately 5 mph)	1
Generic	WW vehicles in both lanes	11
	WW vehicle back-to-back	7
	Lane 1—right-way vehicle Lane 2—WW vehicle	5
	Lane 1—WW vehicle Lane 2—right-way vehicle	7
	WW vehicle and stationary vehicle in detection zone	11

The uncontrolled testing was used to assess how the systems performed under changing weather conditions. For each notification received, CDOT assessed:

- Alert type (i.e., false, missed, or accurate).
- Nighttime and daytime.
- Weather condition (i.e., clear, snow, rain, or hail).
- Surface condition (i.e., dry, wet, snow, ice, or fog).
- Date and time incident occurred (i.e., timestamp on image or video).
- Date and time notification received (i.e., timestamp on email).
- Average latency.
- Notes describing the reason for the notification.

For the controlled testing, the TAPCO® system alert zone triggered the most detections (86), followed by the TAPCO® system confirmation zone (74), TraffiCalm® (72), ISS (50), and BOSCH/MH Corbin (49). CDOT staff performed statistical analysis using odds ratios to compare the accuracy of the four systems. The TAPCO® and TraffiCalm® systems yielded statistically significant higher odds of accurately detecting WWD than the BOSCH/MH Corbin and ISS systems. In addition, statistical analysis found that time of day only impacted the ISS system (i.e., detects better during the day than at night). Overall, the TAPCO® and TraffiCalm® systems were found to have similarly high odds ratios in detecting WW vehicles.

During the uncontrolled testing, CDOT received a total of 491 notifications from all the systems. A review of the data showed that only one accurate call should have been sent from each of the systems. Ninety-five percent of the false calls were from ISS, 2 percent from BOSCH/MH Corbin, 2 percent from TraffiCalm®, and 1 percent from the TAPCO® confirmation zone. Further review found that 98 percent of the ISS false calls were due to shadows during the day and headlight reflection at night. Based on the small sample size, CDOT could not make conclusions about the impact of weather. Average latency also could be not evaluated since the communications systems were not on CDOT network. Instead, each manufacturer used their cellular provider and email service. Thus, it was difficult to trace the source of the delay.

Based on the controlled and uncontrolled testing, CDOT made several observations, three of which are related to this research effort. CDOT noted the need to develop standard procedures and guidelines for testing new technology prior to implementation. CDOT preferred video notification over a snapshot since the latter does not confirm if there were multiple vehicles involved or if the vehicle self-corrects. Redundant detection zones improve the reliability and accuracy of the WWD detection system.

Around the same time, Tennessee DOT sponsored research to investigate and test WWD prevention systems currently on the market (*28*). Prior to testing, researchers reviewed literature and existing deployments in other states and surveyed companies (identified through literature review and on-line search) to collect detailed information on a variety of technologies. Ten companies responded to the survey. Researchers screened the technologies based on their responses and developed a weighted score based on eight aspects (i.e., total system cost, installation time and cost, expected lifetime, maintenance cost, number of DOTs using, accuracy, and whether the technology could be used for other applications). Ultimately, three companies were selected for testing (i.e., TraffiCalm®, MH Corbin, and Wavetronix [although at the time they did not provide a complete WWD package]). Researchers tested these systems in a controlled environment and field installation.

For the controlled environment testing, researchers evaluated missed detections, false detections, and two aspects of warning delay (i.e., the time between when the vehicle crosses the alert zone and the activation of the flashing WRONG WAY sign, and the time between when the vehicle exceeds the confirmation zone and an alert is sent to authorities). To test for missed detections and warning delay, researchers drove two types of vehicles (i.e., car and pickup truck) at different speeds (i.e., 10, 20, 30 and 40 mph [car only]) in the wrong direction. For each vehicle/speed scenario, researchers performed the test three times for a total of 21 tests. For the first two tests, the driver drove through both the alert and confirmation zones. For the third test, the driver stopped after the alert zone and made a U-turn before the confirmation zone. TraffiCalm® and Wavetronix successfully detected all the WW movements (i.e., no missed detections). Initially, MH Corbin had two missed detections for the car driving 30 and 40 mph. After raising the height of the detection component and adjusting the speed sensitivity, the MH Corbin device successfully detected the WW vehicle driving at 30 and 40 mph. TraffiCalm® had close to zero delay for the activation of the WRONG WAY sign. Researchers noted that this was most likely due to the use of multiple radars to scan a larger area and multiple controllers for faster processing power. The activation delay for the other two companies averaged between 2.5 and 3.5 seconds.

To test for false detections, researchers drove a vehicle (i.e., car and pickup truck) at different speeds (i.e., 10, 20, 30 and 40 mph [car only]) in the correct direction. Researchers also had pedestrians walk through the two zones in the wrong direction (five tests) and had a person bicycle through the two zones in the wrong direction (five tests). Wavetronix had no false detections since the system is not calibrated to detect pedestrians or bicycles. The TraffiCalm® system was calibrated with a minimum speed of 10 mph, so it detected one pedestrian and all the bicycles. When the pedestrian/bicycle detection was turned off for the MH Corbin system (three tests), it did not detect any pedestrians or bicycles. When the pedestrian/bicycle detection was turned on (two tests), the MH Corbin system did detect the pedestrians and bicycles.

For the real-world testing, researchers installed the three systems on an exit ramp for one month each. Researchers collected data to assess false and missed detections. Whenever one of these types of detections occurred, a researcher would fill out a report, export the video, and identify one or more contributing factors (if possible). However, none of the systems had any false or missed detections as part of the performance evaluation.

CURRENT TEXAS PRACTICE

For more than 10 years transportation management agencies in Texas have employed advanced technologies to combat WWD behavior. These systems usually include a sensing technology that can detect a vehicle going the wrong direction on a freeway frontage road or ramp and communicate an alert to the agency's TMC and law enforcement. To accurately catalog WWD technology-based countermeasures around the state and gauge the evolution of such technologies and deployments in Texas, researchers contacted TxDOT districts and Texas tollway authorities known to operate, or planning to install, such systems.

TxDOT Districts

Austin

The TxDOT Austin District (AUS) WWD countermeasure program began in 2016 with lowering wrong-way signing on some frontage roads and planning for future sensing technology deployments. By 2021 AUS had six sites along Interstate 35 with thermal camera-based detection systems and one location along SH 45 in shared operation with the Central Texas Regional Mobility Authority (see Figure 2). Each system activates LED border-illuminated WRONG WAY signs when a wrong-way driver is detected, but do not currently send a warning back to the TMC, which in this case is the Combined Transportation, Emergency & Communications Center (CTECC). No formal evaluation of the equipment has been performed.

AUS staff were considering signing and marking options to reduce WWD behavior and intend to integrate field WWD detection systems into CTECC operations when these devices can be fully linked through the TxDOT Lonestar® traffic management system software. Plans for future use of WWD sensing technologies (all thermal camera-based) include:

- Interstate 35/US Highway 183 interchange; four ramps, currently under construction.
- Interstate 35 North (SH 45 North to US 290 East); half of ramps by 2026.
- Interstate 35 South (SH 45 South to US 290 West); half of ramps by 2026.
- Interstate 35 Central (US 290 East to SH 45 South); all ramps by 2029.

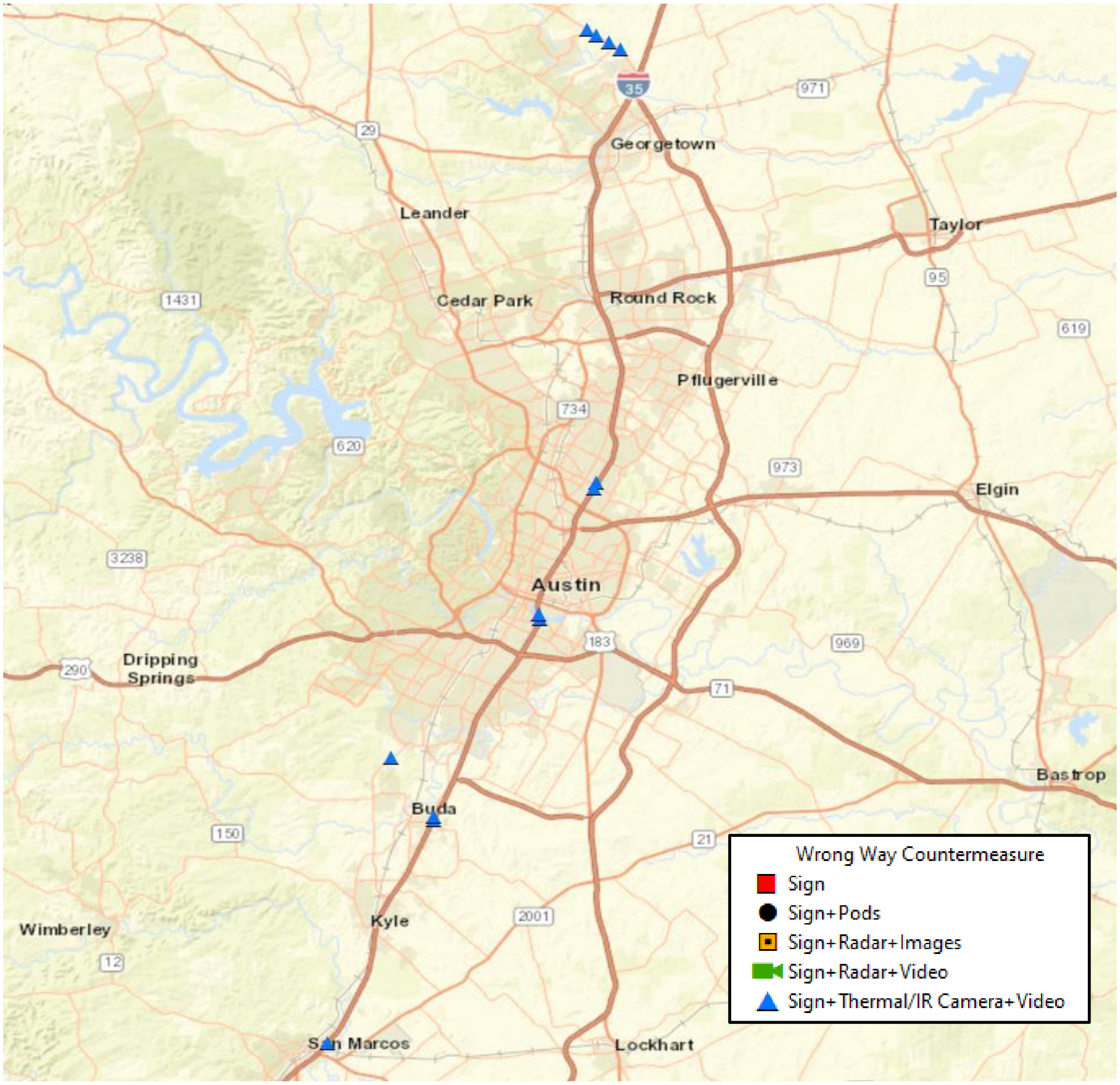


Figure 2. TxDOT AUS Detection-Based Wrong-Way Countermeasures.

Dallas

In 2019 the TxDOT Dallas District (DAL) was in discussions with the North Central Texas Council of Governments about the possibility of obtaining funding for WWD countermeasure system deployments that included detection technology. DAL staff had analyzed TxDOT Crash Record Information System (CRIS) data and identified candidate locations for WWD countermeasures, but funding for these systems was not ultimately available. DAL had been in discussions with a manufacturer for a test installation of a thermal camera system along US Highway 75 in 2020, but this also did not come to fruition.

Based on their own WWD countermeasure technology tracking efforts, DAL staff will likely install thermal camera-based detection systems when funding becomes available. The system design preferred by DAL staff includes TMC alerts and video of each WWD event for verification and to determine if the WWD is attempting to take corrective action. Until funding is available for detection-based countermeasure systems, DAL staff will continue with a signing and markings-based countermeasure program that has been in place for over five years, including monitoring and replacing missing wrong-way signing and installing red retroreflective tape on WRONG WAY and DO NOT ENTER signposts.

El Paso

While TxDOT El Paso District (ELP) staff noted that the number of WW crashes had increased slowly over time since 2011, more detailed analysis began around 2019. ELP staff and their consultants developed a tiered response approach based on WWD event activity and CRIS crash history. ELP does not currently have technology-based WWD sensing systems in place but anticipated having several systems in place beginning in 2022. Funding for these installations was through the Highway Safety Improvement Program. Both light detection and ranging (lidar) and thermal camera-based systems will be used. The planned installations include:

- Interstate 10; several ramps east of El Paso around Fabens, TX.
- US Highway 54; short section in northern El Paso.
- Loop 375; several ramps south of downtown El Paso.

The ELP WWD countermeasure program includes three tiers of deployment. The first tier of static signing and markings includes auditing all exit ramps to ensure applicable devices are in place and installing red retroreflective tape on WRONG WAY and DO NOT ENTER signposts. The second tier includes static signing modifications, such as lowering WW signing and passive light emitting diode (LED) border-illuminated WRONG WAY signs (i.e., flash continuously; not activated based on detection). The highest tier of WWD countermeasures includes detecting WW drivers and locally activating embedded lighting on WRONG WAY signs. This tier is designed for deployment at locations with the highest concentration of historical WW events and includes the option for communication of event alerts and video back to the TMC.

Fort Worth

The TxDOT Fort Worth District's (FTW) WWD countermeasure program began in 2015 following an upturn in serious WWD events. TxDOT and TTI analyzed CRIS WW crash data and 911 call event data to identify portions of regional freeways with the highest level of WWD activity. In early 2017, WWD detection systems using dual radar signals (detection and verification) were deployed at 24 ramps along Interstate 30 on the east side of Fort Worth, from downtown to Loop 360 (see Figure 3). The LED border-illumination on the WRONG WAY signs is activated upon WWD verification by the radar sensors. Prior to installation, the equipment was field tested in a closed area. Connection with the Lonestar® TMC software and the generation of TMC WWD alerts were verified. System requirements included integration with Lonestar® and providing pictures and/or video to the TMC to clarify whether WW drivers are taking any corrective actions.

Maintenance issues for the WWD sensing equipment have involved replacement of damaged equipment and the repositioning of radar sensors when false call rates rise. Though not originally planned during system design, the pictures or video associated with each WWD TMC event allowed FTW staff to estimate the WWD self-correction rate and formulate the multi-agency response to evolving WWD events. TxDOT and TTI tracking of WWD warning system events from 2017 to early 2019 revealed that approximately 90 percent of WWDs self-correct, and only about 9 percent result in 911 calls to initiate cooperative response with law enforcement to track and stop a WW driver.

Figure 3. TxDOT FTW Detection-Based Wrong-Way Countermeasures.

District staff keep informed of technology developments in WWD sensing, including newer video-based detection systems. However, the are no current plans or funding currently identified for additional field installations. Open research questions and interests for FTW staff include the ability of modern sign enhancement systems (e.g., LED border-illuminated signing or RRFBs) to capture the attention of WW drivers, and the extent to which other signing techniques (e.g., multiple signs, paired signs, and lowered signs) capture WW drivers' attention in real-world applications.

Houston

The TxDOT Houston District (HOU) implementation of WWD countermeasures with detection began in 2017 with the installation of 17 dual-radar systems (see Figure 4) on radial freeway sections between downtown and Loop 610 that had higher frequency of WWD crashes, as reported in CRIS. Additional sites employing newer detection technology (i.e., thermal cameras) were installed in 2020 on US Highway 59 at the Kirby Drive interchange and the Loop 610 South interchange with Broadway Street. All WWD warning systems generate emails that are archived, allowing HOU staff to analyze past system performance (e.g., WWD detection rates, false call rates, diagnostic messages alerts) when needed.

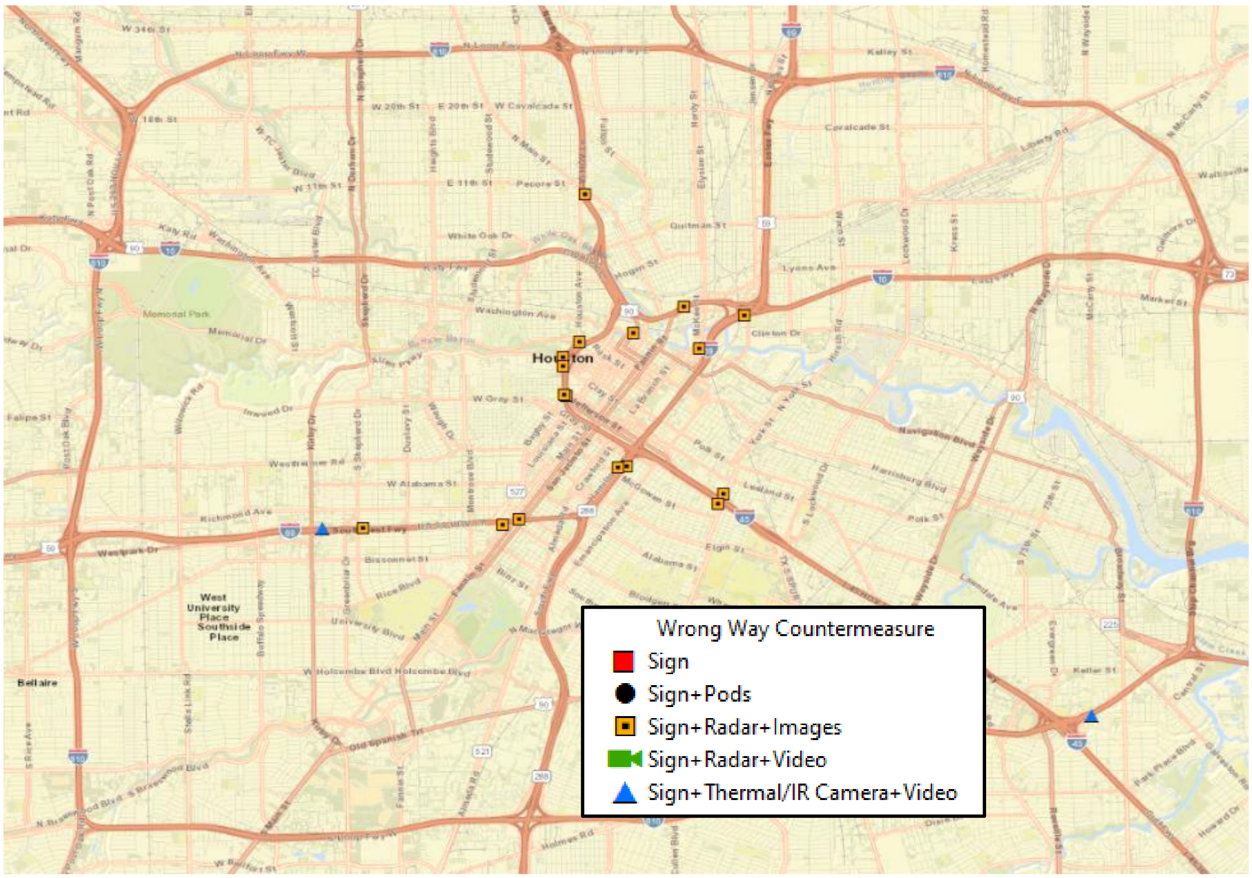


Figure 4. TxDOT HOU Detection-Based Wrong-Way Countermeasures.

A power management issue with the initial deployment of the 17 original dual-radar solar-powered WWD detection and warning systems was not revealed until installation. In areas with overpasses and tall trees, the indirect light in these environments did not provide sufficient input to the solar panels to sufficiently charge the systems such that they could maintain full power for 24-hour operation. As a result, system power alerts and periods of system downtime were experienced in early morning hours at the end of nightly power draw cycles. Further, the dual-radar systems had substantially higher false call rates than the thermal camera systems HOU has recently been testing. To avoid power cycling problems, solar equipment maintenance issues, and issues with previous-generation detection equipment, HOU staff have determined that future installations will utilize thermal imaging detection technology and will be permanently powered by the electrical grid.

HOU's nearly five years of WWD detection system operating experience have provided staff with additional insights and preferred requirements for future WWD detection systems installations; these include:

- Sensing technology must provide "zone" coverage along a roadway, not "point" detection at one fixed location.
- WWD system must be able to illuminate the WW vehicle so that photos/video can uniquely identify the vehicle (e.g., color, vehicle type/size), enabling more informed interaction with law enforcement to identify and stop the WW driver.
- System design and communications should not be managed with recurring cost, if possible. Improved Lonestar® integration and data sharing with WWD detection technologies may provide a future means of minimizing future second- or third-party communications needs.
- System must have the ability to flexibly manage LED border-illuminated signing, including active or passive sign illumination combinations if several rows/series of signs are located along a longer exit ramp.

HOU is planning the installation of 14 additional WWD warning systems employing thermal camera detection technology and powered by the electrical grid. The 14 locations are effectively an expansion of the 17-site original system to additional higher-frequency WWD event sites along the radial freeway network between downtown Houston and Loop 610.

Pharr

The TxDOT Pharr District (PHR) is in the planning stages of a WWD countermeasure system that includes the initial treatment of higher-frequency WWD crash locations (based on CRIS data) with signing and markings improvements, including red retroreflective tape on WRONG WAY and DO NOT ENTER signposts. The tiered response program the district is currently considering will ultimately include the deployment of static signing improvements, such as passive LED border-illuminated signing and detection technology with active warning systems along corridor sections with higher frequencies of WWD crashes in the future. However, funding has not yet been identified for these countermeasures. PHR staff stay in regular communication with urban districts currently using technology-based WWD countermeasures to stay up-to-date on WWD detection technologies and track long-term experience with manufacturers and systems.

San Antonio

Long-term history of WWD activity in the San Antonio area and a severe WW collision causing the fatality of a San Antonio Police Department (SAPD) officer in early 2011 prompted the TxDOT San Antonio District (SAT), SAPD, San Antonio Fire Department, Bexar County Public Works, and Bexar County Sheriff's Office to create a multi-agency WWD Task Force. Countermeasure ideas and concepts ultimately formulated into a plan to install solar-powered radar WWD sensors and passive LED-border illuminated WRONG WAY signs (continuously flashed under low ambient light conditions) along exit ramps in the US 281 freeway corridor (downtown to Loop 1604) since this corridor experienced the highest concentration of CRIS crashes and WWD events (documented in 911 WWD event-related calls and TxDOT TransGuide TMC operator logs). The US 281 WWD system became operational in mid-2012 and included simple integration with the Lonestar® TMC software used by SAT TransGuide staff. This permitted the activation of an operator workstation alert when a US 281 WW sensor detected a WWD.

These early single-radar WWD detection systems were plagued with high false detection rates, prompting SAT to have independent testing performed on radar sensors and technology. The result was the development of dual-radar systems with management software that independently detected and verified a WW vehicle. This system concept was carried into 18 additional SAT WWD detection locations along the US Highway 90 West corridor between downtown San Antonio and Loop 410. Within this same time frame (2013–2015), additional WWD detection technologies (i.e., in-pavement "puck" sensors and thermal cameras) were deployed in real-world field testing at several downtown ramps along Interstate 35. All these systems included a WWD alert sent (via cellular modem) to the TransGuide TMC and images of the WW vehicle causing the alert. Multi-radar WWD detection systems of this generation were installed along 16 Interstate 35 exit ramps in northeast San Antonio between downtown and Loop 410. Updates in these systems allowed for the sharing of video of each WWD event rather than several photographs, and these systems linked with LED border-illuminated WW signing in an active mode (i.e., flashing only when a WW vehicle was detected). A map of all current SAT WWD systems that have at least passive LED border-illuminated signing is provided in Figure 5.

SAT continues to expand its WWD sensor technology deployment and will be installing devices at new locations along State Highway 151 (10 optical camera detection systems on exit ramps between US Highway 90 and Loop 1604), Wurzbach Parkway (20 optical camera detection systems on exit ramps between NW Military Highway and Thousand Oaks), and Interstate 35 South (18 thermal camera exit ramp systems between downtown and Loop 410). Interstate 37 in south San Antonio between downtown and Loop 410 will also have exit ramp WWD detection, but the technology has not yet been determined. SAT staff have tested both new system types in the field, and both technologies largely alleviate false calls that affect some San Antonio multi-radar systems in locations where two-way roads or circulation driveways are found proximate to and parallel with freeway frontage roads.

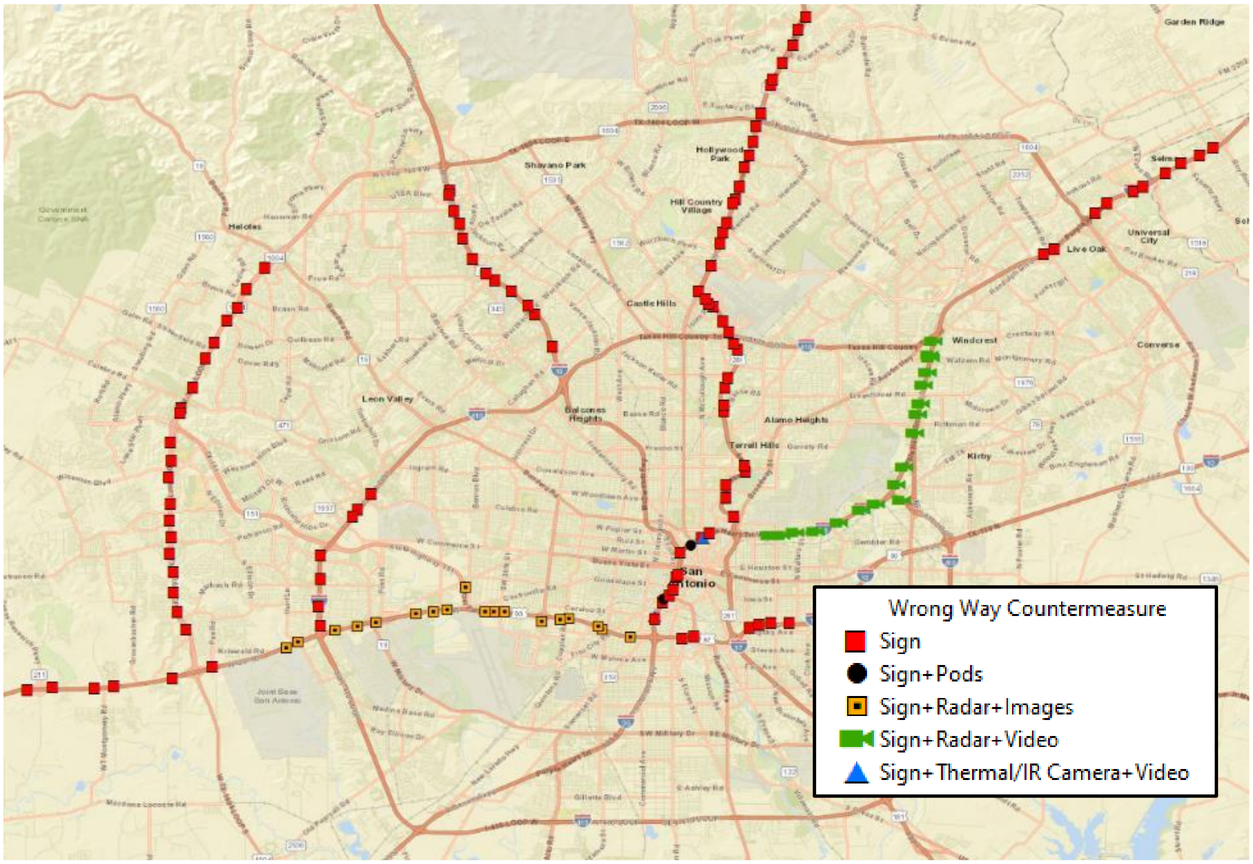


Figure 5. TxDOT SAT Improved Signing Wrong-Way Countermeasures.

Several practices have evolved that help SAT staff ensure that WWD detection systems are fully functional on "day one" and remain fully operational over time. Procurement practice has changed to now require WWD detection equipment manufacturers on site (not just TxDOT installation contractors) when all WW detection equipment is installed in the field. SAT staff are currently in discussions about long-term maintenance of WWD detection systems. The issue is whether TxDOT staff or contractors under a maintenance agreement should be responsible for maintaining the WWD detection equipment. Finally, SAT staff retain a full archive of all WWD email alerts (including photos and video) that can be analyzed for reliability and false call rates.

Tollway Authorities

Central Texas Regional Mobility Authority

Though researchers were unable to reach Central Texas Regional Mobility Authority (CTRMA) staff directly, TxDOT Austin District staff had some information about WWD detection technologies operated by CTRMA. A thermal camera WW detection system belonging to CTRMA is located on State Highway 45 Southwest along the southbound exit ramp to FM 1626.

This system is linked to both the TxDOT and CTRMA TMCs and sends images of the WWD event to both agencies.

Harris County Toll Road Authority

HCTRA began its WWD countermeasure program involving WWD detection in 2009 following several WWD fatalities in previous years, including a multi-fatality WWD event in 2007. Single radar systems (using side-fire radar) were used along 17 exit ramps to detect WWDs and issue alerts in the TMC. WWD event data from these systems ultimately identified a single exit ramp (at an interchange with non-traditional design) as the site with the greatest WWD activity. Additional signing countermeasures (i.e., LED border-illuminated wrong-way signs and retroreflective tape on signposts) were deployed at this location and have significantly reduced WWD activity at the ramp.

Since 2009, HCTRA has been through four generations of refinements and improvements to its WWD detection system design. Technology implementations have included side-fire radar, "puck" in-pavement systems, radar with photo documentation, and radar coupled with thermal cameras. The current technology using radar and thermal cameras will be used going forward as it minimizes false calls (dual, independent detection technologies) and eliminates the maintenance requirements with "puck" systems (which also involved the safety concern of maintenance staff being on the road adjacent to open lanes of traffic). Nineteen ramps (18 on the Westpark Tollway and one at the westbound entrance to the Interstate 10/Katy Freeway managed lanes) are currently equipped with HCTRA's dual-technology systems. All other technologies have been phased out.

WWD sensing is fully integrated with HCTRA's TMC operations. Alerts are generated by the field sensors, and this generates an automated response within the TMC, including an audible alert and the auto-zooming of the eight closest pan-tilt-zoom traffic monitoring cameras in the area the alert is generated. With operator verification of the event, DMS messages are posted on area signs with the click of a button. HCTRA's system management contractor keeps abreast of technology innovations and stays in touch with operators and manufacturers to see if emerging technologies should be integrated into HCTRA's WWD systems. As previously noted, no changes in WWD detection technology are currently anticipated. No formal evaluations of the HCTRA systems have been performed, but TMC software logs all events so that statistics about WWD system detection operation can be reviewed and analyzed at any time.

HCTRA staff and their system management contractor continue to monitor WWD-related technology developments in the system management area. Things that may eventually improve system operation include connected vehicle technologies (communicating the WWD hazard to right-way vehicles directly) and self-checking TMC software that more comprehensively automatically tests field devices and their communications. Current testing of WWD devices is performed by staff weekly in the TMC (communications with field equipment) and monthly in the field (on-site verification of detection system function involving a “test” WW vehicle on a closed ramp), but future technology enhancements may enable this testing remotely and automatically as part of everyday operations.

North Texas Tollway Authority

North Texas Tollway (NTTA) staff first noted an increase in WWD fatalities in 2009, prompting the development of a WWD Task Force. A finding from their data analysis not reported in the literature was that roughly 30 percent of freeway WWDs were the result of the driver making U-turn maneuvers. To combat WWD, NTTA began using its detector loop arrays on ramps and mainlanes—normally used for sensing vehicles for tolling—to detect any vehicles driving the wrong way. NTTA also experimented with video tracking systems in 2012 and single radar and microwave radar systems in 2013, but these technologies had high false detection rates at the time. In 2015, NTTA began using thermal camera systems with good results and have used that technology since then.

The extent of NTTA’s WWD sensor network includes loops on all tolled ramps and loops on mainlanes every 8 to 10 miles. Thermal camera systems are in 23 strategic locations across all four NTTA tollways (i.e., Sam Rayburn Tollway, President George Bush Tollway, Dallas North Tollway, and Central Texas Parkway). In general, the more WWD activity detected along a freeway section, the higher the level of technology deployment. Some mainlane sites have a WRONG WAY blank-out sign in the median and a WRONG WAY sign with RRFBs on the right shoulder. Expansion will most likely include thermal camera detection, but some sites may also utilize video analytics. NTTA staff are also examining the potential of connected and automated vehicle technology to combat WWD in the future and are working with both TTI and manufacturers to prepare for advanced communications made possible by 5G. To best prepare for any future monitoring technology implementation, NTTA has contractors on expansion projects place conduit and, in some locations, even mounting infrastructure for power and communications.

Multipurpose traffic management system components have allowed NTTA to have efficient monitoring system design and minimized infrastructure costs, fully utilizing capital investment for equipment and adding functionality. For example, thermal cameras for WWD detection also allow operators to monitor the tollway system for crashes. All loop reverse flow sensing and thermal cameras currently deployed send WWD alerts to the TMC via Lonestar® and by email (backup). NTTA software automatically creates a WW alert pop-up and identifies cameras to track the WW vehicle and find dynamic message signs in the area that should display a WWD alert to right-way drivers.

COMMERCIALLY AVAILABLE WWD DETECTION TECHNOLOGIES

Researchers identified 28 potential WWD detection devices or systems through the literature review, prior contact, and exhibits at professional meetings. As part of an initial review, researchers determined that five of the potential systems did not offer a readily available off-the-shelf function for detecting WWD events. Three other manufacturers no longer had active websites and their contact information was outdated (i.e., emails and phone number no longer valid). Thus, researchers assumed these manufacturers were either no longer in business or marketing in the United States. In addition, one product previously marketed for WWD detection was no longer recommended for such applications by the new owner.

Researchers contacted manufacturers about the remaining 19 WWD detection technologies via email and phone to collect information about readily available off-the-shelf WWD detection devices/systems. Several of the manufacturers reported that they partner to create a combined WWD system. Manufacturers whose technology was solely included within another manufacturer's system and not sold separately were merged. Overall, researchers identified 17 readily available off-the-shelf WWD detection technologies (i.e., BOSCH/MH Corbin, Carmanah® Technologies Corp. [Carmanah®], Citilog, CUBIC™ Transportation Systems [CUBIC™], GovComm, Inc. [GovComm], Teledyne FLIR [FLIR], ISS, IntelliSite, K&K Systems, Inc. [K&K], NavTech Radar, NoTraffic, SICK, Inc. [SICK], TAPCO®, Tattile, TraffiCalm®, TrafficVision™, and 360 Network Solutions). A general summary of the WWD detection technologies follows.

The major components of a WWD system are detection, warning, and notification. While this project was focused on detection technologies, researchers also collected limited information regarding warning (i.e., signing integration) and notification (i.e., alert types and content). Some manufacturers primarily sell software that can be used with an agency's existing cameras to detect a WW driver and notify an agency. A few manufacturers only sell a detection sensor that must be paired with other technologies to constitute a compete system. Most manufacturers sell complete WWD detection systems comprised of multiple detection, verification, and warning technologies.

Cameras are the most common technology used to detect WW vehicles. Thermal cameras are used by six manufacturers. Thermal cameras sense differences in heat (typically shown as black [cold] to hot [white]) instead of light. Infrared (IR) cameras are used by four manufacturers. IR cameras gauge the amount of short wavelength infrared light reflected back to the camera to form an image. Both thermal and IR cameras use imaging processing and sophisticated algorithms to detect vehicles and their direction of travel. Traditional optical cameras are used by many manufacturers in conjunction with other types of cameras and/or radar to capture clear still images and/or video of the WW vehicle. Optical cameras can also be used with imaging processing software and sophisticated algorithms to detect vehicles and their direction of travel. Researchers only identified two systems that solely provided radar. Most systems use more than one sensor and/or multiple zones in conjunction with algorithms to verify a WW vehicle before notifying an agency. Ultimately, the number of sensors used in each system varies and depends on the complexity of the geometry of the site where the system is deployed and the number of detection confirmation zones that are required by the deploying agency.

Most of the identified WWD detection products are designed for use on freeway ramps and freeway main lanes and have the capability to integrate with WW signing via a contact closure connection or wireless connection. The coverage range and mounting height are dependent upon the type of detection technology used. The two most widely used types of alerts are short message service (SMS) and email. Other types of alerts include advanced traffic management system software, proprietary software, phone calls, and audible. Most alerts include still photos. With some systems, video can be sent via the alerts, streamed to a central system, and/or stored on the local WWD system for upload.

Most of the WWD systems and associated components can be powered either via alternating current (AC), solar power, or a combination of both. Some of the WWD system components might require power-over-ethernet (POE) adapters. Most of the WWD systems can be connected to the internet to provide remote access to the system via an Ethernet connection. Some of the WWD systems have Wi-Fi connectivity in the field for system configuration.

Most the WWD systems provide an application programming interface (API) that provides the user with the ability to develop applications to interface with the system and integrate the system with the agency's central system. In addition, all but one of the WWD systems provides the user with the capability to remotely access and configure the system via the graphical user interface (GUI). A few of the WWD systems are already integrated with TxDOT's Lonestar® software. Some of the other WWD systems are already integrated with Florida's SunGuide® and/or New Mexico's RoadRunner.

SUMMARY

In the fall of 2021, TTI researchers reviewed previous literature, assessed the current practice in Texas, and identified commercially available off-the-shelf WWD detection systems to determine the state-of-the-practice regarding WWD detection technology. The literature review provided insight into previous evaluations of WWD detection technology, including closed-course and field testing protocols and performance measures. The literature review also revealed conditions that cause WWD detection technology to produce false alarms, and included recommendations that transportation agencies should consider when developing guidance, standards, and specifications for WWD detection technologies. The catalog of WWD detection technologies implemented in Texas shows that TxDOT is actively addressing the WWD issue. However, it also revealed some challenges with deploying and maintaining WWD detection technologies. Researchers identified and obtained information about 17 commercially available off-the-shelf WWD detection systems.

CHAPTER 3:
CLOSED-COURSE TESTING

In the fall of 2022, TTI researchers tested 10 commercially available off-the-shelf WWD detection technologies in a closed-course environment at the Texas A&M-RELLIS campus in Bryan, Texas. This chapter documents the study experimental design, the technologies tested, and the results of the testing.

EXPERIMENTAL DESIGN

This section describes the development of the test matrix, the mock exit ramp design, and the equipment used during testing. In addition, this section defines the measures of effectiveness (MOEs) used for testing.

Test Matrix and Exit Ramp Design

Based on the findings from a review of literature and state agency testing procedures, researchers initially considered the following test parameters:

- Vehicle type (e.g., passenger car, passenger truck, commercial motor vehicle, or motorcycle).
- Vehicle speed.
- Time of day (e.g., day or night).
- Exit ramp design (e.g., straight or curved).
- Driving path (e.g., in lane, on shoulder, straddling lane/shoulder, or swerving).
- Driving direction (e.g., WW and right-way [RW]).
- Weather condition.

Early in the process, researchers decided to test each scenario (i.e., combination of parameters) three times to validate repeatability. Therefore, researchers had to reduce the initial number of test parameters to conduct tests on 10 technologies within the designated timeline.

To reduce equipment installation and configuration time, researchers decided to test all devices in one ramp configuration (i.e., straight) under clear conditions (i.e., no rain) with dry pavement (see Figure 6). Researchers designed the exit ramp for speeds reducing from 60 mph (highway design speed) to 50 mph (on the frontage road) based on Table 3-23 of the *Texas Roadway Design Manual*. Figure 6 shows the exit ramp dimensions and terminology for the driving paths (note the shoulders are labeled as viewed from the WW driving direction).

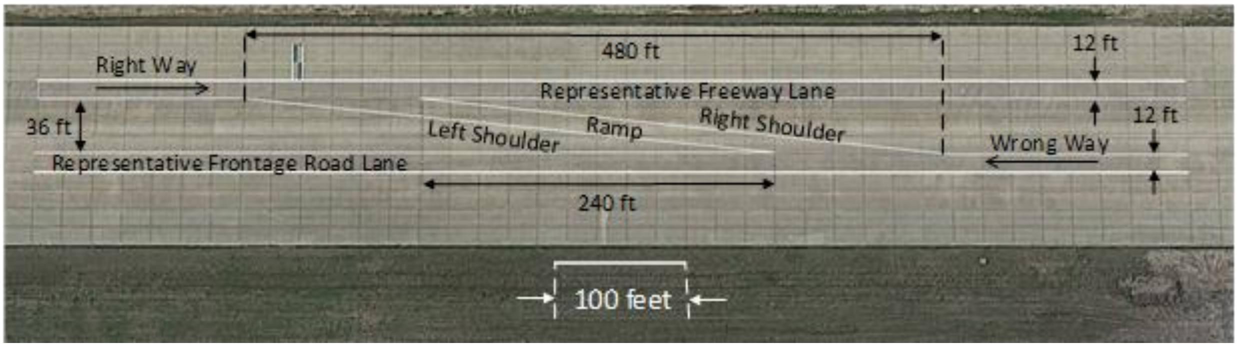


Figure 6. Ramp Design for Testing.

With input from the Project Monitoring Committee (PMC), researchers selected the following test parameters for the closed-course testing:

- Driving direction (i.e., WW and RW).
- Driving path (i.e., in the center of the ramp, on the right shoulder, on the left shoulder, in the freeway lane, and in the frontage road lane).
- Vehicle speed (i.e., 10 mph, 40 mph, and 60 mph).
- Time of day (i.e., day or night).
- Vehicle type (i.e., passenger car and passenger truck).

The WW driving tests included the center of the ramp and both shoulder driving paths. For the shoulder driving paths, the right or left tires of the vehicle were adjacent to the applicable edgeline. The 10-mph and 40-mph tests were conducted for all three of these paths. The 60-mph tests were only completed for the center of the ramp driving path. The RW driving tests included the center of the ramp, freeway lane, and frontage road driving paths at all three speeds.

Overall, there were seven WW test scenarios and three RW test scenarios for each vehicle and time period (yielding 40 total test scenarios). Since each scenario was tested three times, the total number of tests equaled 120.

Researcher Provided Equipment

Each manufacturer was responsible for providing, installing, configuring, and removing all the necessary equipment for their device/system to function. Researchers provided the following equipment for manufacturers to use, as needed:

- Three portable trailers to provide power and 30-ft telescoping poles (see Figure 7).
- Cellular router with cellular service to provide internet service.
- Four-port power over ethernet switch to place multi-device system components on the same local area network.
- Lift truck to aid with equipment installation.
- Various tools to aid with installation.

Figure 7. Example of a Portable Trailer.

Researchers used the following equipment to conduct the tests:

- Ledertech® Leddar™ IS16 to obtain the time when the test vehicle entered the test area (see Figure 8).
- Field hardened laptop to run manufacture software or web-based applications, run TTI-developed software program, and check email.
- Weather station to monitor weather conditions (i.e., outside temperature, outside humidity, and wind speed during testing) (see Figure 8).
- Two vehicles (i.e., 2012 Ford Fusion and 2015 Ford F150) for testing.
- Cell phone with TextNow app to receive text messages.

The Ledertech® Leddar™ IS16 is a multi-segment flash lidar sensor that researchers secured to a pole (see sensor above yellow sheeting in Figure 8) and configured to detect objects 5–30 ft away from the sensor. Since the test area entry locations varied by driving path, researchers placed the pole in two different locations (see Figure 9). The entry point for the right shoulder and ramp were the same, while the entry point for the left shoulder was different. Researchers moved the pole and associated equipment dependent upon the test run.

Researchers also developed a software application to interface with the Ledertech® Leddar™ IS16 sensor and receive a trigger output when a vehicle was detected by the sensor. The software application received the detection message from the sensor, decoded the message, and logged the detection into a file with a timestamp (i.e., date and time) and other information about the test run (i.e., run number, vehicle speed, driving path, and vehicle type).

Figure 8. Leddar™ IS16 Sensor and Weather Station.

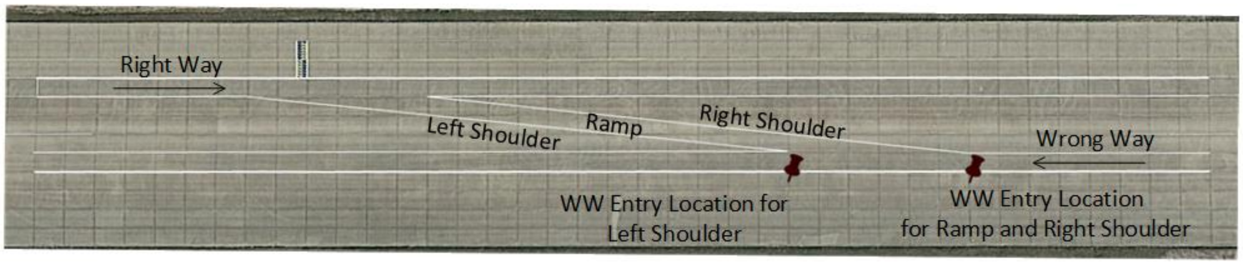


Figure 9. Test Area Entry Locations.

Measures of Effectiveness

Researchers, with input from the PMC, selected the following MOEs for the closed-course tests:

- WW vehicle detection accuracy (i.e., correct detections, missed detections, and false detections) (required).
- WW vehicle detection latency (required).
- Sign activation accuracy (optional).
- Email notification accuracy to a project-related email account (optional).
- SMS notification accuracy to a project-related cell phone (optional).

Since some detection technologies were stand-alone devices (i.e., not multi-component WWD systems), researchers only required each detection technology tested to produce proof that a WW vehicle was detected with an associated timestamp. All the other MOEs were optional, and their testing was dependent upon the capabilities of the detection technology tested. If available, researchers also reviewed software or web-based applications associated with the detection technologies.

Researchers defined WW vehicle detection latency as the amount of time from when the test vehicle entered the test area (i.e., right shoulder, ramp, or left shoulder) to the point where the WW vehicle was detected by the WWD technology. To compute detection latency, researchers compared the timestamp of the vehicle detected by the Ledertech® Leddar™ IS16 sensor with the timestamp of the WWD technology being tested. Researchers synched the clock on the field hardened laptop used to run the TTI-developed software application with the time source used by each WWD technology to generate the timestamp of the WW vehicle detection. Synching these time sources insured that both systems' clocks were using the same time reference.

For the sign activation, email notification, and SMS notification, researchers simply tracked whether the feature functioned properly for each test run. Researchers did not evaluate email or SMS notification latency since these communication methods can be impacted by the cellular network and email software systems.

Researchers utilized a free text messaging application called TextNow for testing SMS alerts. This application uses the internet to enable a user to send and receive text messages at no cost. However, the phone number assigned by the application is not able to receive text messages sent via an email address that includes a phone number and cell provider (e.g., 1234567890@cellprovider.net). Some WWD systems tested used an email to send text alerts to phones and thus were not able to test SMS notification accuracy because the project phone could not receive text messages via email.

WRONG-WAY DETECTION TECHNOLOGIES TESTED

Based on a review of available technologies and with input from TxDOT, researchers initially contacted the following 10 manufacturers to participate in the closed-course testing: BOSCH/MH Corbin, Carmanah®, CUBIC™, FLIR, GovComm, ISS, K&K, NavTech Radar, TAPCO®, and TraffiCalm®. All these manufacturers except NavTech Radar accepted the invitation. Since the research project required testing a minimum of 10 technologies, researchers extended an invitation to SICK, and they accepted.

This section contains descriptions of each WWD detection technology tested during the closed-course evaluations. Each explanation includes a summary of the device or system components, how the technologies detected a WW vehicle, how the device/system issued alerts, and how researchers computed WW vehicle detection latency. If available, researchers also included information about software or web-based manufacturer tools that can be used to configure and/or monitor the devices/systems.

BOSCH and MH Corbin

BOSCH and MH Corbin partner for a WWD detection system that utilizes BOSCH cameras and artificial intelligence (AI) and the MH Corbin Connect:ITS edge platform to distribute information about the event to transportation agency staff and other intelligent transportation system (ITS) devices on the facility. The BOSCH system offers several camara options for WW vehicle detection. During daytime testing, the BOSCH system used a BOSCH DINION inteox 7100i IR optical camera with a built-in infrared transmitter to detect WW vehicles. At night, the BOSCH system used a BOSCH DINION IP 8000 thermal camera to detect WW vehicles. Figure 10 shows the BOSCH equipment on a portable trailer. Figure 11 shows the BOSCH device location relative to the ramp configuration and the WW entry locations.

Figure 10. BOSCH Equipment on Portable Trailer.

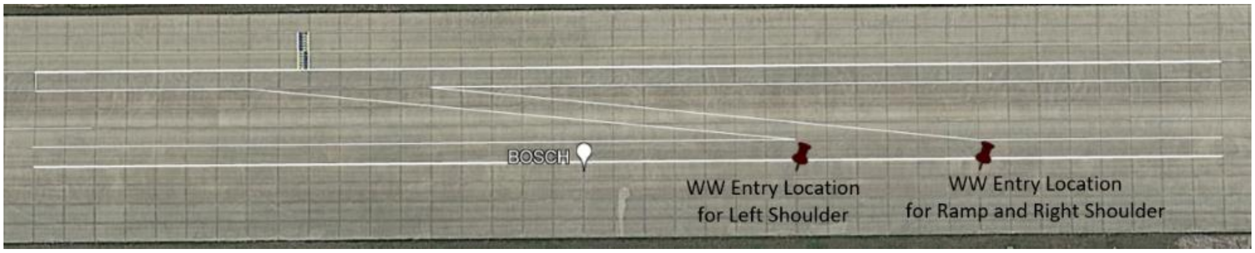


Figure 11. BOSCH Device Location on Closed-Course.

To search for WW vehicles, the user must configure detection zones in BOSCH-developed software. The configuration allows the user to define up to three detection zones and select one of three actuation methods. One method for WW vehicle detection requires the sequential actuation of zones (e.g., Zone 1 then Zone 2) to detect a vehicle traveling in the incorrect direction (see Figure 12). A second option uses a single zone that can be set to activate only if a vehicle is traveling a certain direction. In both these options, zones can be any size. The third option allows the user to configure a line of detection with a direction of travel to trigger a WW vehicle detection. The BOSCH team recommended the system operate using the first option, so that is what the researchers tested.

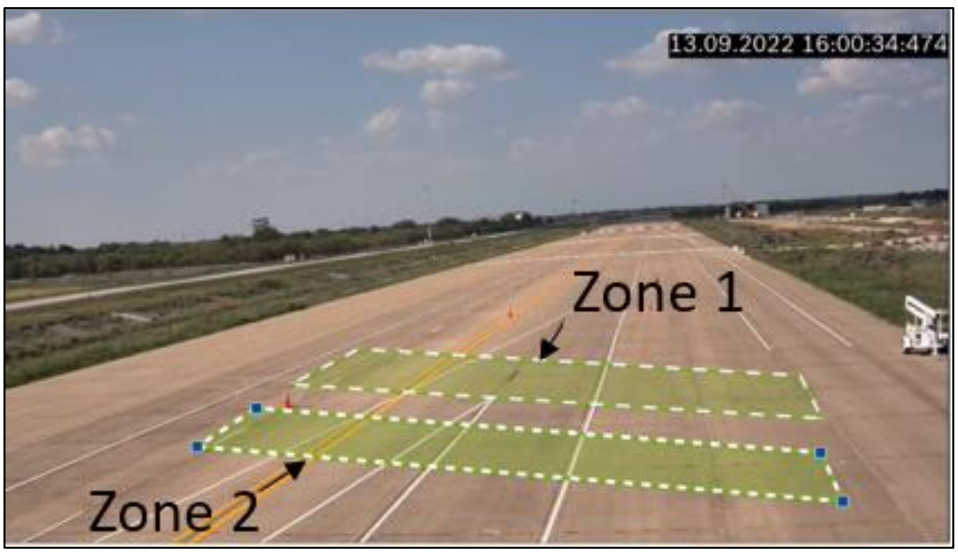


Figure 12. BOSCH Detection Zone Configuration.

For both daytime and nighttime testing, the system used a second camera (MIC inteox 7100i) to capture photos and monitor the WW vehicle. This camera was a pan-tilt-zoom (PTZ) camera with the same AI tools as the DINION cameras. BOSCH configured the MIC camera to rest at a preset view. When a WW vehicle was detected, the MIC camera would find and follow the WW vehicle within the camera view. All BOSCH cameras are configurable to communicate to other cameras in the system and can enable tracking or change the camera view to a preset based on a triggered task.

The BOSCH cameras can be configured to send email alerts, but the system tested used the MH Corbin Connect:ITS edge platform for all alerting. The platform received WW vehicle detections from a BOSCH camera, sent email and SMS alerts, logged actuations, and activated a beacon light to represent sign activation (see Figure 10). The email alert contained information about the location, device, alert reason, alert parameters, operation type, event timestamp, and two still photos (each with an embedded timestamp). The SMS alert stated "WRONGWAY VEHICLE at TTI Test: TTI WWD Test." To calculate the WW vehicle detection latency, researchers used the timestamp in the first email photo because the time used by the camera was synched with the field hardened laptop time (see Figure 13).

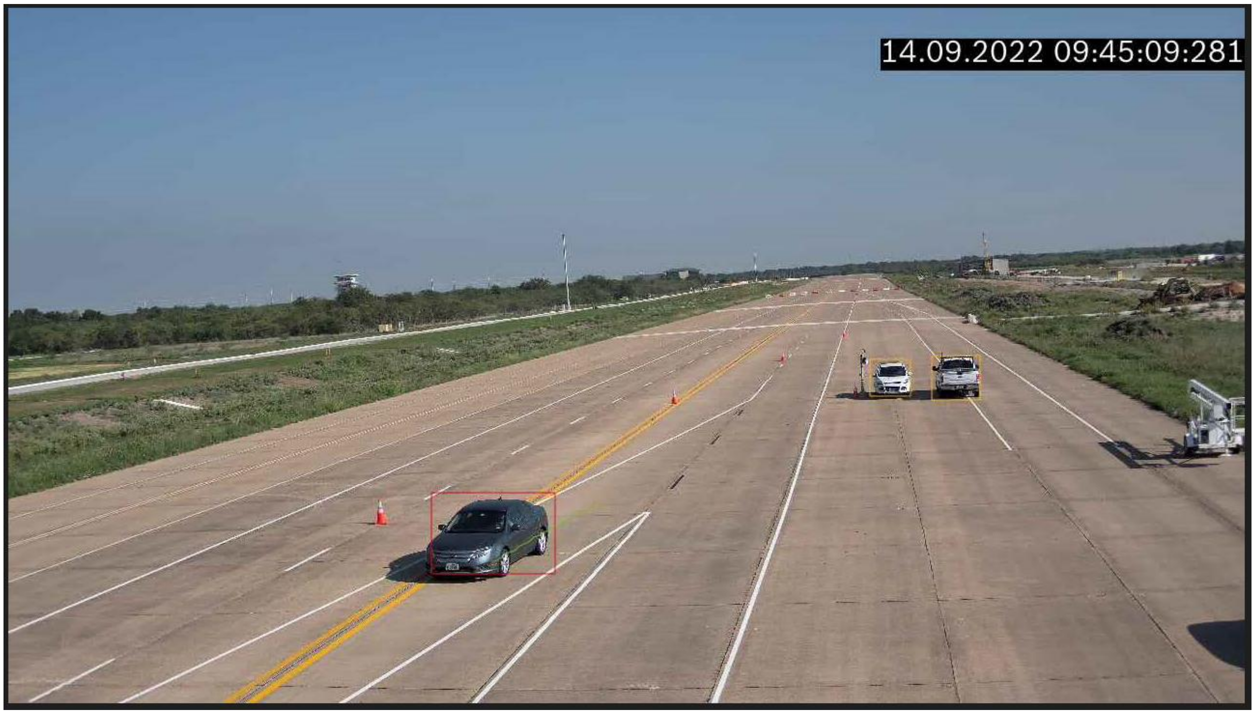


Figure 13. Example of Connect:ITS Photo with Timestamp.

The MH Corbin Connect:ITS platform offers two web-based dashboards. The first dashboard connects to the platform via a web-browser and allows the user to configure the following for alerts:

- Camera for still photos.
- Camera for video recording.
- Email recipients.
- SMS recipients.
- Sign activations.

The second web-based dashboard, called Metiri, allows the user to monitor alerts and system health (i.e., temperature, system load, memory usage, and system heartbeat). WW events are listed on a timeline (see Figure 14). The second dashboard also stores the still photos and video files with an event (see Figure 15). Once an event is selected, users can resolve it using a pre-defined list of nine resolutions (e.g., wrong way vehicle, emergency response vehicle, false positive, and vehicle backed up) and a text field for notes (see Figure 16).

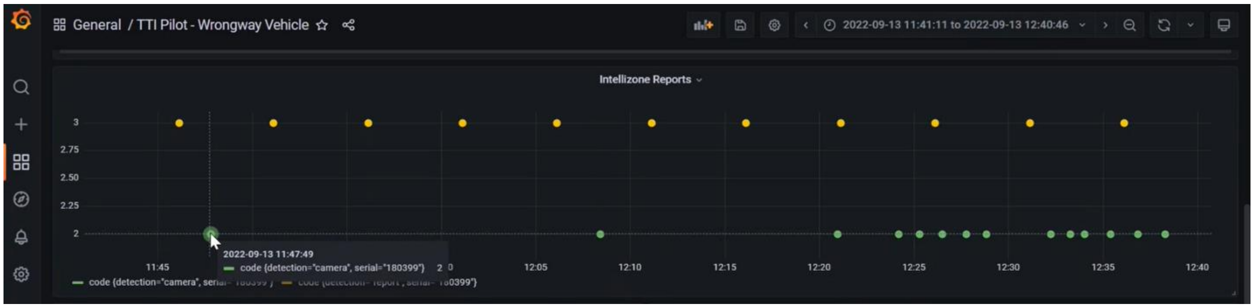


Figure 14. Example of MH Corbin Dashboard Event Timeline.

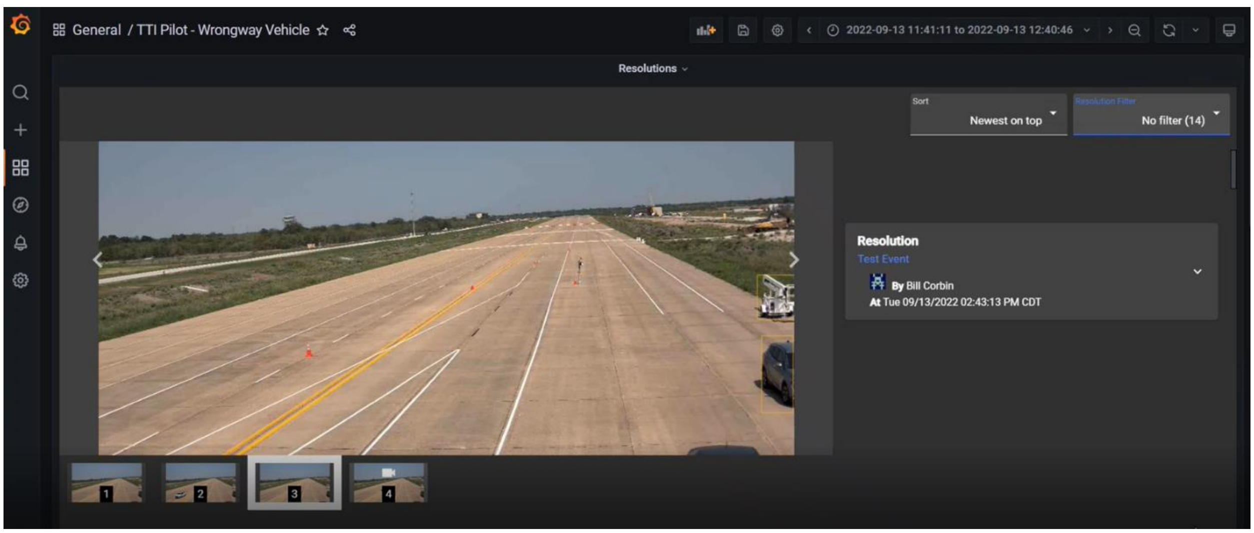


Figure 15. Example of MH Corbin Dashboard Alert.

Figure 16. Example of MH Corbin Event Dashboard Resolution Window.

Carmanah®

The Carmanah® WWD detection system utilized a combination of radar and camera technology to identify WW vehicles, activate LED lights on a WRONG WAY sign, and monitor for self-correction. Figure 17 shows the Carmanah® equipment on a portable trailer. Figure 18 shows the MS-Sedco TC-CK1-SBE2.0 Intersector Microwave Vehicle Motion Sensor radar and two Viion TC400GC cameras (intersection camera for monitoring [facing to the right] and freeway camera for confirmation [facing to the left]). Figure 19 depicts the Carmanah® device location relative to the ramp configuration and the WW entry locations.

Carmanah® used the radar to search for an initial alert and the freeway camera to confirm the WW vehicle detection. The radar unit used several zones to determine the vehicle direction of travel along the ramp. If two zones were activated, the system triggered the sign lights and recorded an associated timestamp. After three zones were activated, the radar logged an event as “Radar Detect” and communicated to the freeway camera to begin searching for a vehicle traveling the wrong way using image processing that looks for ray tracing of components of the vehicle (see Figure 20). The radar also sent a command to the intersection camera to capture photos and video. If the freeway camera detected a vehicle going the wrong way, the event label was changed to “Camera Validated” event (see Figure 21). If the freeway camera did not detect a WW vehicle, the event label remained as “Radar Detect.”

Email alerts were sent regardless of the event’s label. The email contained an event timestamp and color and infrared (IR) photos from the intersection and freeway cameras with or without ray tracing visualized. If the freeway camera did not confirm a WW vehicle, the intersection camera photos would show the WW vehicle but the freeway camera photos would not (indicating that the vehicle self-corrected). The email did not contain the “Radar Detect” or “Camera Validated” label. Alerts can also be sent via SMS, but researchers did not test this function since Carmanah® sends text messages via an email address.

Figure 17. Carmanah® Equipment on Portable Trailer.

Figure 18. Carmanah® Radar and Camera Devices.

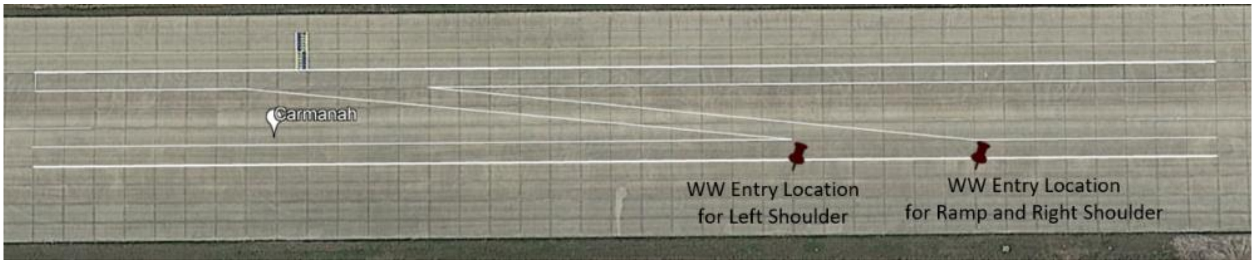


Figure 19. Carmanah® Device Location.

The Carmanah® system can be monitored through software developed by VIION that shows the history of events at a given site (see Figure 21, accessed via arrow buttons next to WWD Events red box) and a system heartbeat. Researchers installed this software on a TTI field hardened laptop configured on the same local area network as the Carmanah® cameras to enable real-time monitoring. To calculate the WW vehicle detection latency, researchers used the timestamp in the software once the detection was labeled “Camera Validated.”

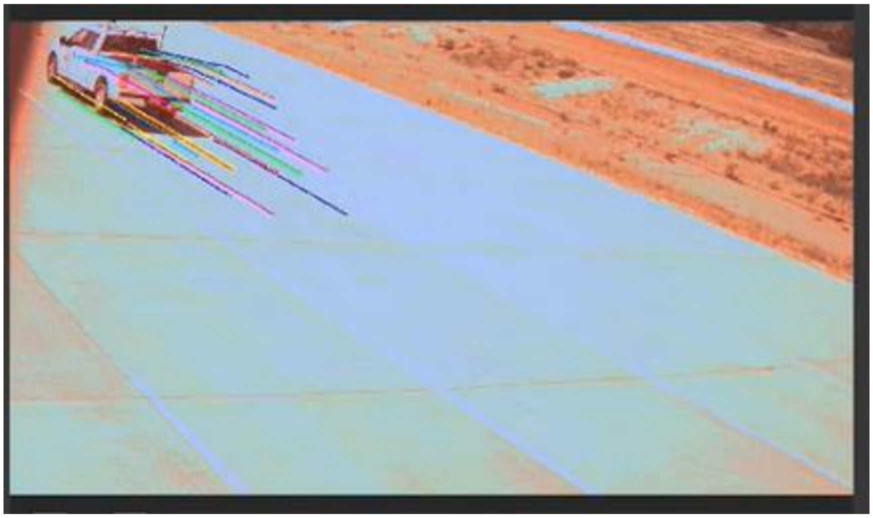


Figure 20. Example of Carmanah® Ray Tracing Photo.

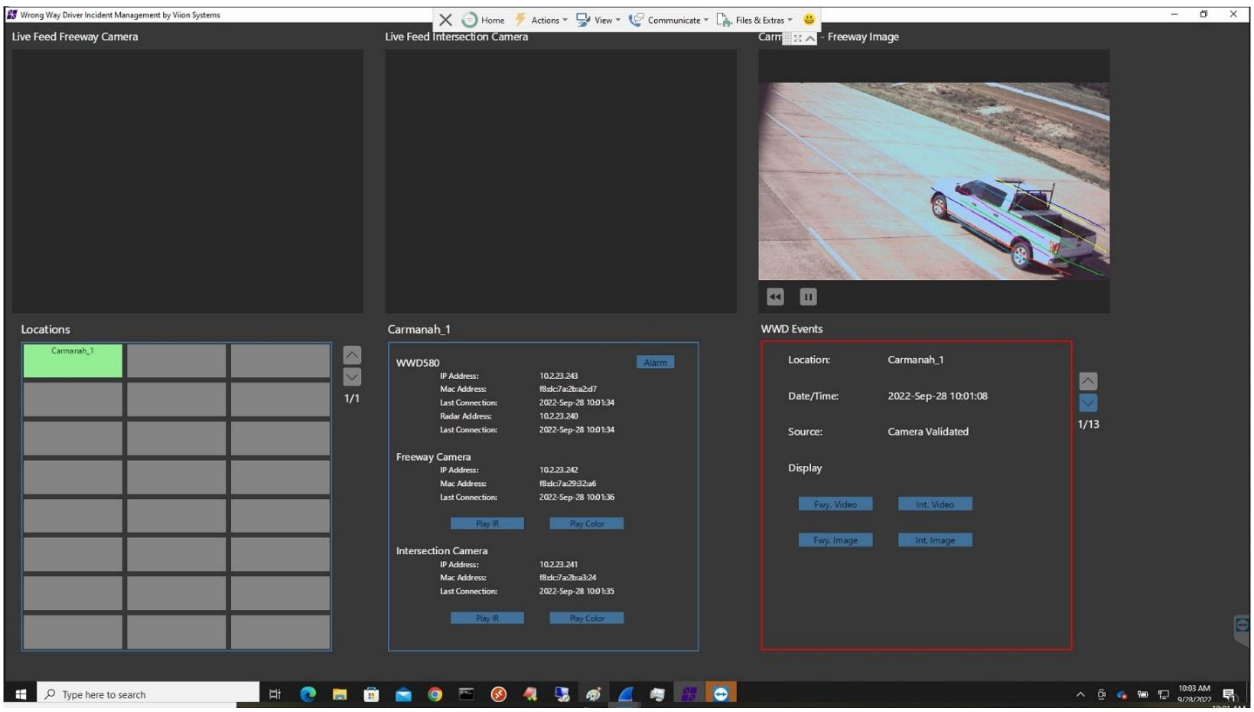


Figure 21. Example of Carmanah® Camera Validated Event.

CUBIC™

CUBIC™ traditionally installs the Gridsmart camera and GS2 processor at intersections. Since the system can search for WW movements and connection to a traffic signal is not required for the system to function, researchers were able to test the system at the closed-course. Figure 22 shows the CUBIC™ equipment on a portable trailer. Figure 23 depicts the CUBIC™ device location relative to the ramp configuration and the WW entry locations.

Figure 22. CUBIC™ Equipment on Portable Trailer.

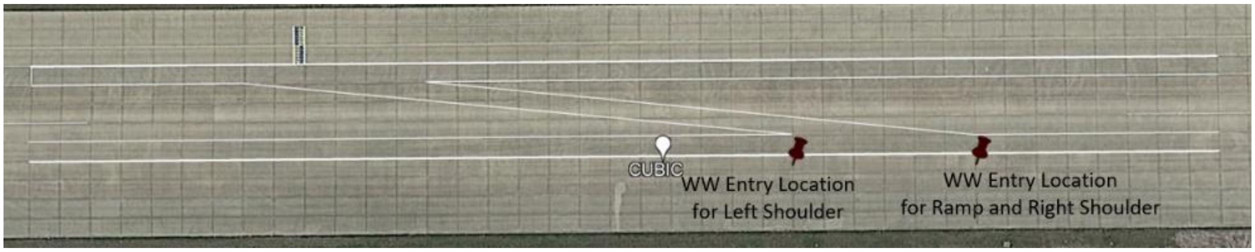


Figure 23. CUBIC™ Device Location.

CUBIC™ utilized a fisheye camera unit (see Figure 24) that has optical video processing on an edge computing device developed by CUBIC™ called a GS2. The GS2 configuration has inputs for the camera name, northbound direction, and the height of the camera. Physically, the Gridsmart camera resided in a bell-shaped camera enclosure that was attached to the end of a L-shaped pole mounted high above the site. The camera must be leveled manually after it is installed.

Figure 24. CUBIC™ Gridsmart Fisheye Camera.

To detect a WW vehicle, zones drawn for the GS2 must point in the incorrect direction of travel. For the closed-course testing, CUBIC™ configured three zones to search for WW vehicles using the Gridsmart App software (see Figure 25). CUBIC™ does not provide an event monitoring mechanism.

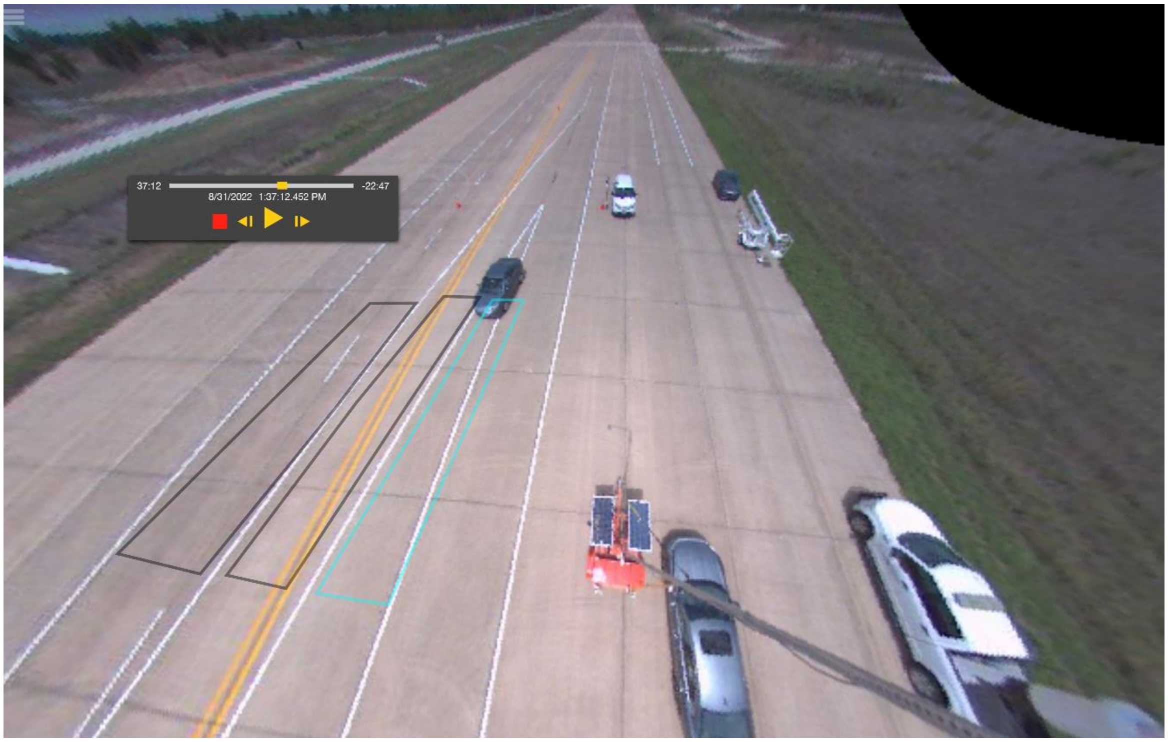


Figure 25. CUBIC™ Detection Zones.

The GS2 sent email alerts that included an event timestamp, the zone activated, and one still photo. To calculate the WW vehicle detection latency, researchers used the timestamp provided in the email. The GS2 had a hard coded limit of 12 email alerts per hour. This is a limit that is assigned to the individual zone. If the limit is reached, the next alert can be transmitted one hour after the first alert. In other words, the 12-per-hour alert limit is a rolling limit.

FLIR

The FLIR camera is a thermal camera built for transportation applications with the ability to search for various types of incidents. Figure 26 shows the FLIR equipment on the portable trailer. Figure 27 shows the FLIR device location relative to the ramp configuration and the WW entry locations.

Figure 26. FLIR Equipment on Portable Trailer.

Figure 27. FLIR Device Location.

To detect WW vehicles, the camera must be configured using manufacturer developed software called FLUX. Multiple zones pointing in the correct direction of travel were used with an inverse direction of travel triggering an email plugin (see Figure 28). The desired recipients for the alert emails must be configured within the "inverse direction" settings for the deployed system.

Figure 28. FLIR Detection Zones.

For each event, the device sent two emails. The first email contained a still photo, event timestamp, type of event (i.e., inverse direction), source (i.e., name of camera), and the zone activated (e.g., ZoneId = 1). The second email contained the same information but also included an event video. The first email was sent immediately after an event was triggered, and the second email was sent after the video had finished recording. Alerts can also be sent via SMS, but researchers did not test this function since FLIR sends text messages via an email address.

The FLUX software allows a user to monitor a real-time event management screen alongside all other events for the device (e.g., user logins, communication losses, and triggered events). The FLUX software also stores logs of WW vehicle detections with the photos and videos (see Figure 29).

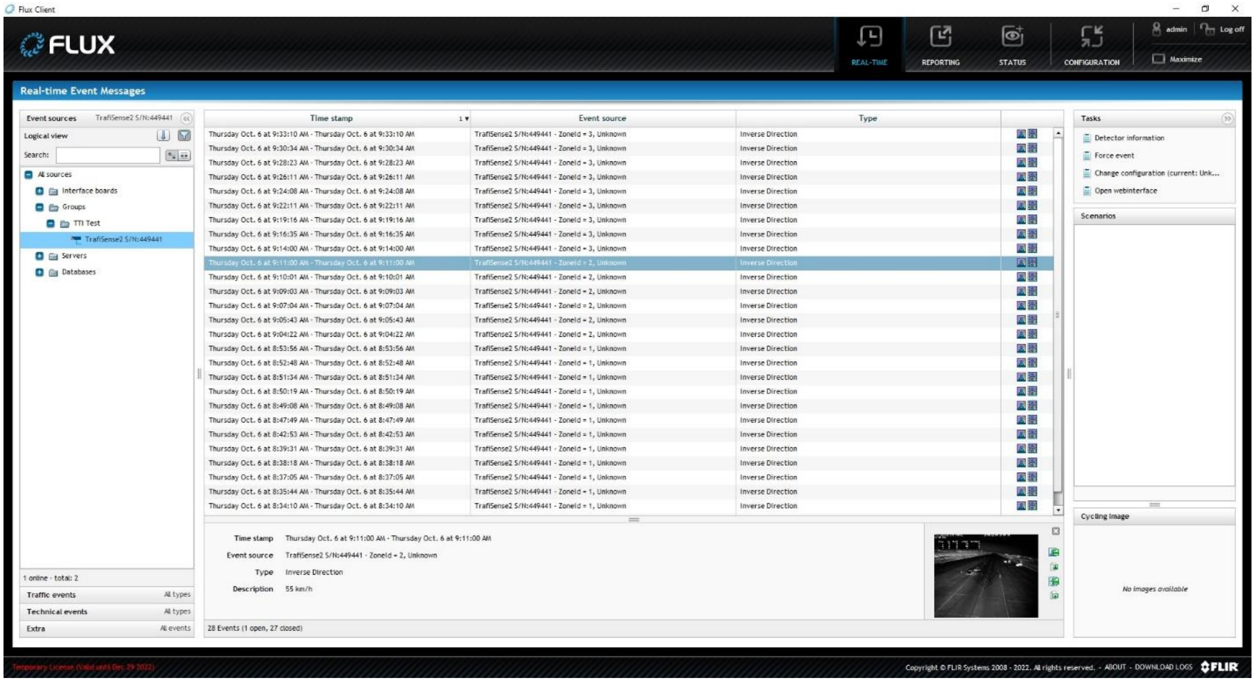


Figure 29. Example of FLIR Alert Log.

Researchers installed the FLUX software on the field hardened laptop and connected via the internet to the FLIR camera. Researchers used the FLUX software to monitor the WW driver detection alerts generated by the FLIR camera in real-time. To calculate the WW vehicle detection latency, researchers used the timestamp in the software log (see Figure 29).

GovComm

GovComm used a dual optical and thermal camera housing with an edge computing device that simultaneously processed the two video streams, using AI, to determine if a WW vehicle was present. The installation also included a rear facing camera to capture photos of the WW vehicle after entering the ramp. Figure 30 shows the GovComm equipment on a portable trailer. GovComm configured its system to activate a string of lights to represent a WRONG WAY sign activation. Figure 31 shows the GovComm device location relative to the ramp configuration and the WW entry locations.

Figure 30. GovComm Equipment on Portable Trailer.

Figure 31. GovComm Device Location.

To search for WW vehicles, the processor used zone configurations from both the optical and thermal cameras. An outer zone defined the region of view to process to limit the computation needs (see blue shaded area in Figure 32). A detection zone with an arrow pointed downstream defined the correct direction of travel (see yellow arrow in the light brown shaded area in Figure 32). If the processor determined that both video streams identified a WW vehicle within the two zones at the same time, a WW vehicle detection was triggered and an alert was transmitted.

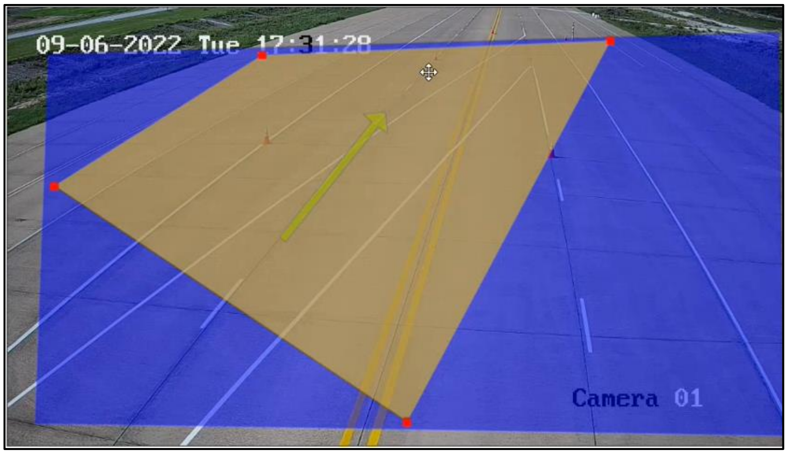


Figure 32. GovComm Detection Zone Configuration.

GovComm stores alert details in a web-based monitoring tool called Compass. The system sent emails that contained an event timestamp and a link to Compass for photos and videos. Researchers clicked on the link in the email alerts to view a list of timestamps for the before and after images captured by the system (see Figure 33). Upon clicking on a timestamp, the associated photo/video was displayed (see Figure 33). The image included a timestamp for when it was captured that was slightly different than the timestamp in the list (see Figure 33). Since the camera time was synched with the field hardened laptop time, researchers used the timestamp from the image when the vehicle was classified as a WW vehicle (see Figure 33, WW alert in the lower right of the photo) to calculate the WW vehicle detection latency.

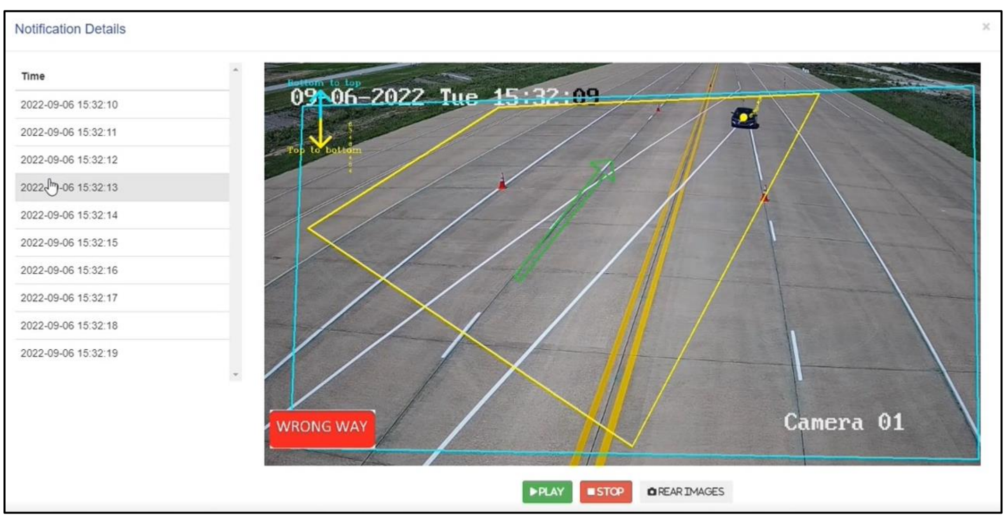
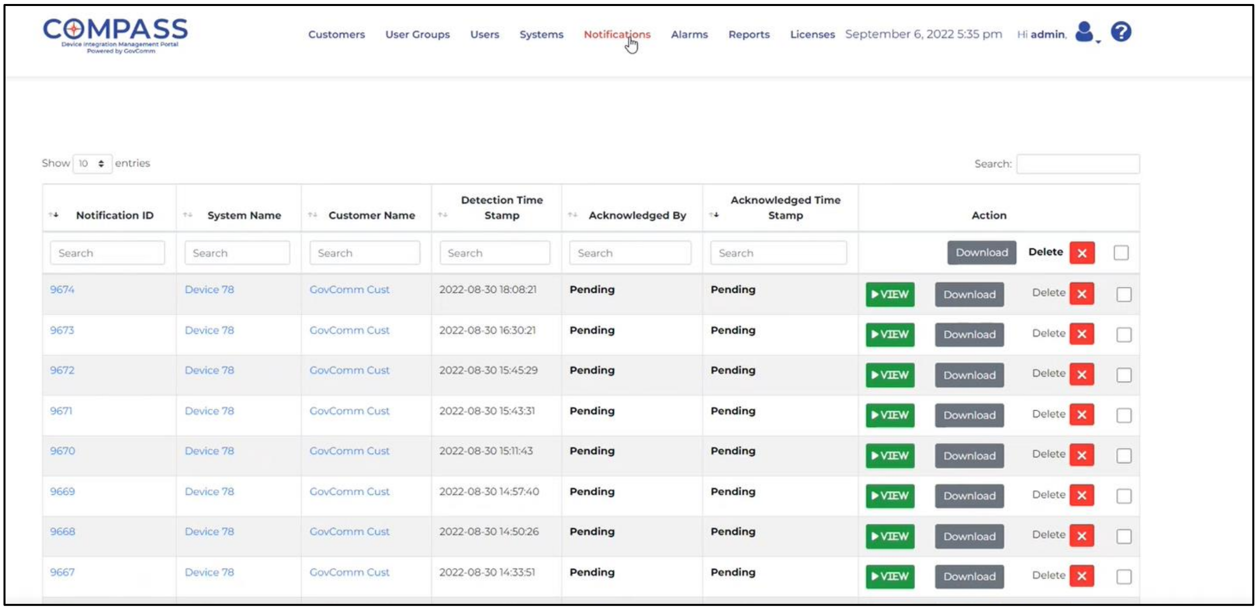


Figure 33. Example of GovComm Alert Details.

The main Compass window summarizes alarms and notifications (see Figure 34). Alarms give information about system health and operation. Notifications describe the data around WWD events. The user can resolve events and review system health characteristics (e.g., CPU usage, storage, and processing ability).



Notification ID	System Name	Customer Name	Detection Time Stamp	Acknowledged By	Acknowledged Time Stamp	Action
Search	Search	Search	Search	Search	Search	Download Delete
9674	Device 78	GovComm Cust	2022-08-30 18:08:21	Pending	Pending	VIEW Download Delete
9673	Device 78	GovComm Cust	2022-08-30 16:30:21	Pending	Pending	VIEW Download Delete
9672	Device 78	GovComm Cust	2022-08-30 15:45:29	Pending	Pending	VIEW Download Delete
9671	Device 78	GovComm Cust	2022-08-30 15:43:31	Pending	Pending	VIEW Download Delete
9670	Device 78	GovComm Cust	2022-08-30 15:11:43	Pending	Pending	VIEW Download Delete
9669	Device 78	GovComm Cust	2022-08-30 14:57:40	Pending	Pending	VIEW Download Delete
9668	Device 78	GovComm Cust	2022-08-30 14:50:26	Pending	Pending	VIEW Download Delete
9667	Device 78	GovComm Cust	2022-08-30 14:33:51	Pending	Pending	VIEW Download Delete

Figure 34. Example of GovComm Alert Log.

ISS

ISS utilized an AXIS four-camera housing for detection. Three of the cameras monitored the ramp. ISS aimed one ramp camera upstream and one downstream for WWD event context and monitoring. The third ramp camera was pointed at the exit ramp and was used for detection of WW vehicles. The fourth camera in the housing was aimed at the frontage road. All four cameras were optical cameras. The detection camera used a wide angle lens. The other cameras used standard lenses. Figure 35 shows the ISS equipment on the portable trailer. Figure 36 shows a closeup of the four-camera housing. Figure 37 shows the ISS device location relative to the ramp configuration and the WW entry locations.

Figure 35. ISS Equipment on Portable Trailer.

Figure 36. ISS Optical Cameras for Detection.

Figure 37. ISS Device Location.

ISS used a single detection zone with an arrow pointed in the correct direction of travel (see Figure 38). The system processed the optical video for vehicles within the detection zone traveling in the opposite direction of the arrow. ISS saved a video of the triggered events that contained 15 seconds before triggering the event and 15 seconds after the event detection. The video can be configured to use a single camera or multiple cameras. ISS recommended the four-camera grid view for entire context. The video can be configured to include a timestamp that can be placed in any corner of the saved video. Videos are visible through the ISS monitoring software called Supervisor. To keep videos of events they must be downloaded from the software. Otherwise, the software only keeps the video of the latest event. The software keeps a log of the event timestamps and stores event data in the system for seven days before clearing the event from the history (see Figure 39). The software also shows system health monitoring including system heartbeat and data steaming information.

Researchers installed the Supervisor software on the field hardened laptop, which allowed them to monitor WW vehicle alerts generated by the ISS system in real time. To calculate the WW vehicle detection latency, researchers used the timestamp in the software (see Figure 39).

For the closed-course testing, the ISS system sent a WW vehicle alert email. The email contained a still photo (with an embedded timestamp), incident type, incident description, and device name. The still photo was from the camera used for detection. Images captured during daylight conditions included a color photo, a depiction of the detection zone, and a timestamp. Photos from nighttime conditions were black-and-white and included the timestamp, but not a representation of the detection zone. The ISS system can also send SMS alerts via an email address and place phone calls about WW vehicle detections. However, researchers did not test these functions.

ISS offers a third-party validation of the WW vehicle detections. This feature sends the WW alert to another entity to review the photo and decide if the event was valid prior to pushing the alert to a transportation agency. Researchers discussed the use of third-party review with ISS and decided to conduct most of the closed-course testing without the third-party reviewing alerts due to the quick repetitive nature of the tests and the use of the ISS software to obtain detection timestamps. However, ISS helped researchers configure the system to perform a portion of the testing with the third-party review (i.e., daytime left shoulder tests).

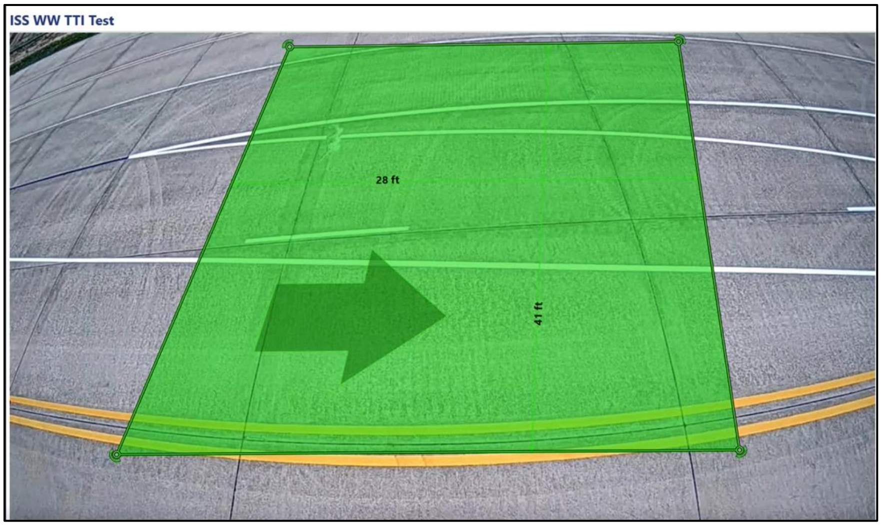


Figure 38. ISS Detection Zone Configuration.

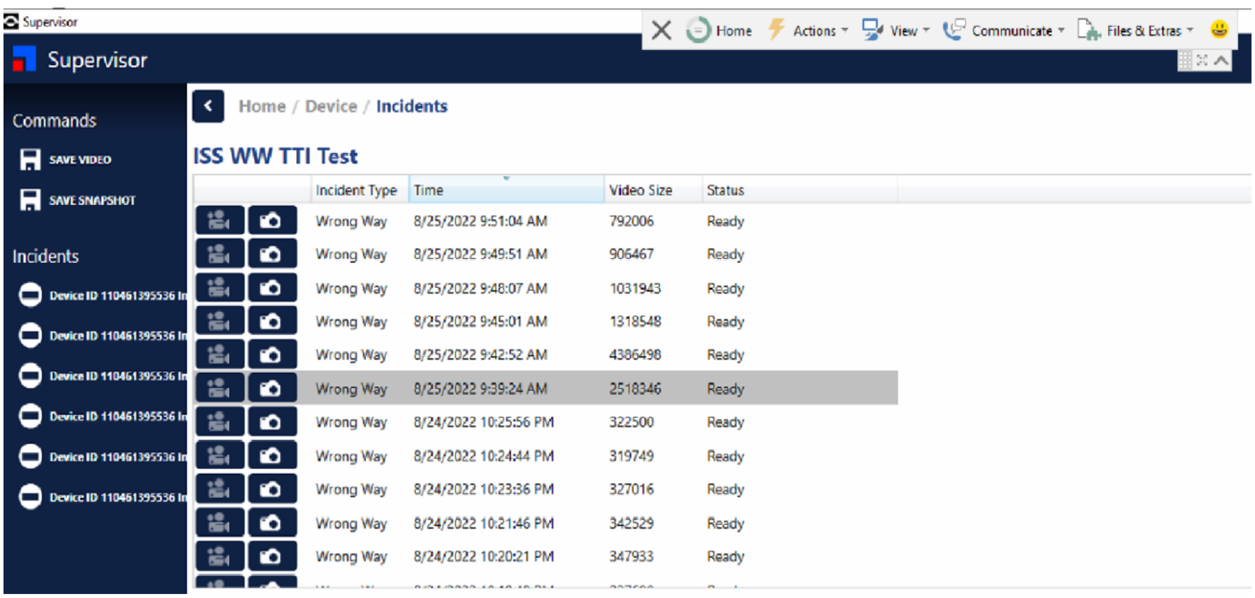


Figure 39. Example of ISS Alert Log.

K&K

The K&K WW detection technology was a three-camera system (one thermal and two optical) in separate housings. Figure 40 shows the portable trailer K&K brought for testing. Figure 41 shows the K&K device location relative to the ramp configuration and the WW entry locations.

Figure 40. K&K Systems Equipment for Testing.

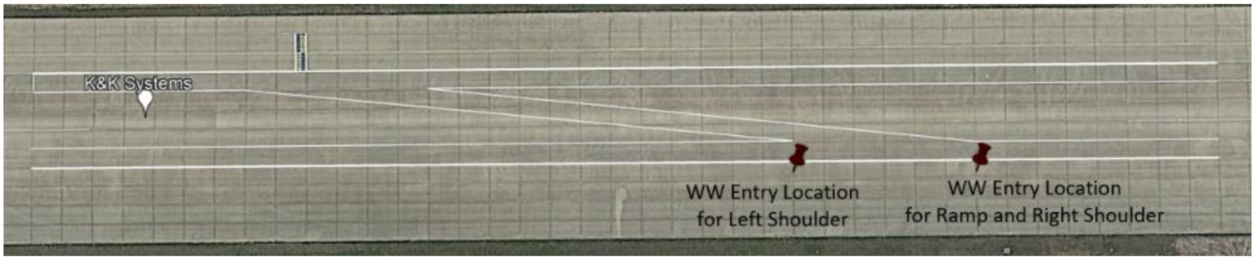


Figure 41. K&K Device Location.

The thermal camera was the detection device, and the optical cameras were for photo capture and WW vehicle monitoring. On the thermal camera, the detection zone was drawn such that the arrows point in the incorrect direction of travel (see Figure 42). K&K uses a time threshold before signaling an alert to prevent false detections. K&K recommended a threshold of 1 second, which was the setting used for closed-course testing.

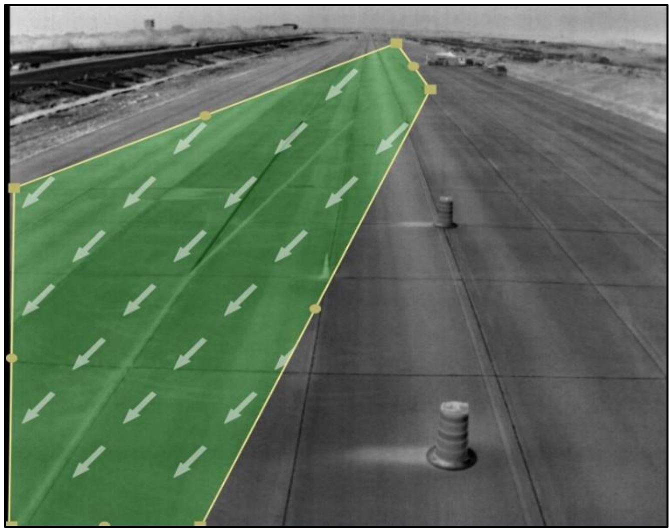


Figure 42. K&K Detection Zone.

Upon a WW vehicle detection, the system activated lights on a WRONG WAY sign. Although not tested due to a server error, the K&K system can transmit alerts to email addresses and text messages via an email address. K&K uses manufacturer-developed software (Avigilon) for configuration of the cameras and monitoring events. The software logs and stores event details such as a timestamp for sign light activations, a timestamp for WW vehicle warnings, event videos (typically 30 seconds long after the onset of the warning), still photos, and system response logs (see Figure 43). The video places a box around the object that triggered the detection, so a user can identify what the system thought was the WW vehicle (see Figure 43).

Researchers connected the field hardened laptop directly to the K&K system to remotely monitor the system in real-time via a web browser. To calculate the WW vehicle detection latency, researchers used the “Warning” timestamp in the software (see Figure 43).

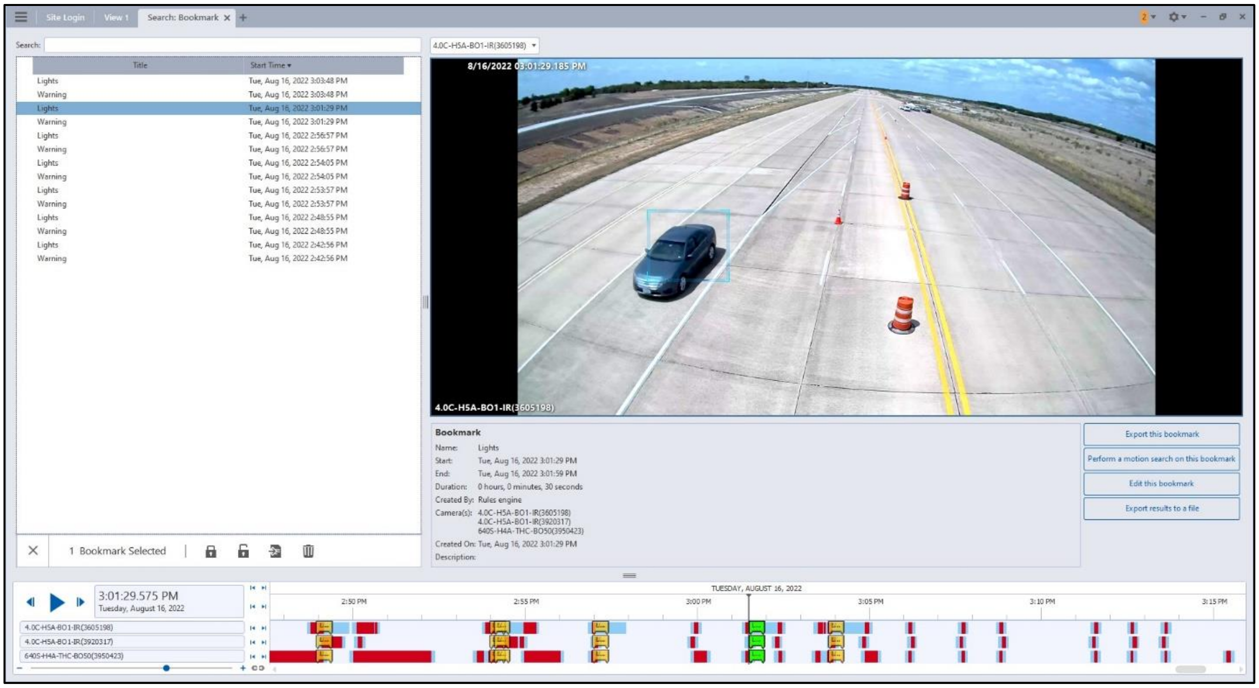


Figure 43. Example of K&K Alert Log.

SICK

SICK is a radar and lidar sensor manufacturer that is entering the WW vehicle detection market. Thus, the SICK Advanced Object Detection System WWD system tested by researchers was still under development. The SICK system utilized a single radar unit placed 6.5 ft off the ground and pointed down the ramp. The radar communicated with a cellular SIM card equipped modem to send emails and SMS messages. Figure 44 shows the SICK system on the portable trailer. Figure 45 shows the radar used for detecting the WW vehicle. Figure 46 shows the SICK device location relative to the ramp configuration and the WW entry locations.

The radar was configured through a web portal called a Traffic Enhanced Management System (TEMS) Manager. To generate a detection zone, a user enters coordinates of the region of interest into the TEMS Manager, where the correct direction of travel is in the positive z-axis direction. Figure 47 shows the detection zone (within the blue rectangle) and the field of view of the radar (gold lines around the rectangle). In the region of interest, the device generated a log of all vehicles. Each object found by the radar was assigned either a "Normal Way" or "Wrong Way" label, and the object trajectory data were logged based on the direction of travel in the z-axis. A "valid" status meant that the object trajectory was sufficient to trigger a WW alert. An "incomplete trajectory" or "incomplete trajectory, few objects" status meant that the object trajectory was not adequate to trigger an alert.

Figure 44. SICK Equipment on Portable Trailer.

Figure 45. SICK Radar for Detection.

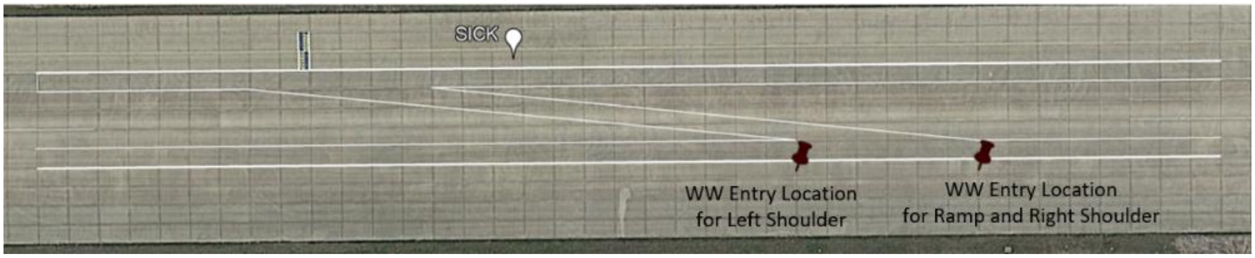


Figure 46. SICK Device Location.

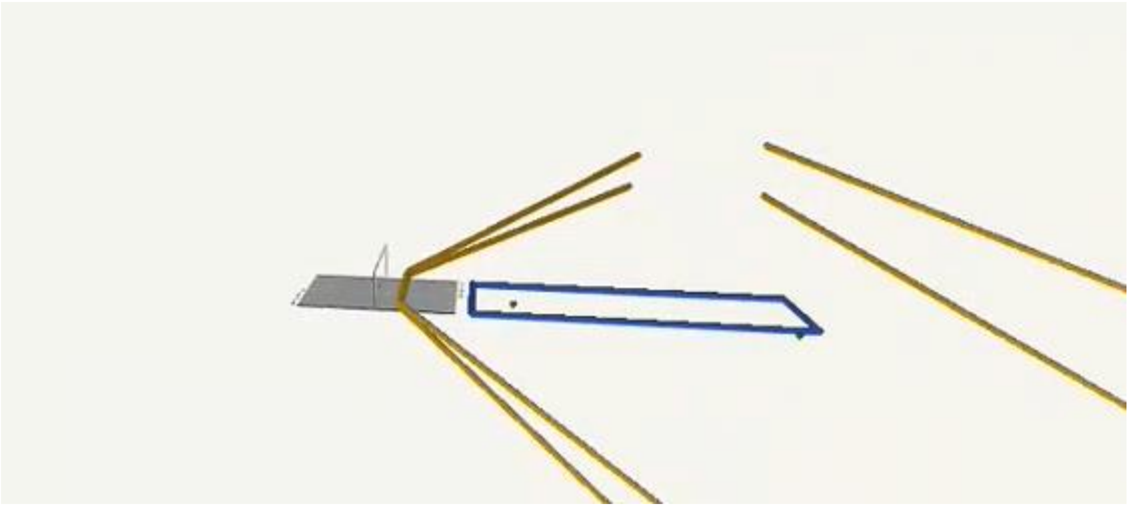


Figure 47. SICK Detection Zone and Radar Field of View.

Researchers connected the field hardened laptop directly to the SICK edge computer to provide remote access to the system. Researchers monitored the SICK TEMS Manager and gathered information on "Wrong Way" and "Normal Way" objects traveling in the detection zone of the sensor. To calculate the WW vehicle detection latency, researchers used the timestamp of the last "valid" detection (see Figure 48). The TEMS manager also allows users to view a representation of the object trajectory based on the saved data (see Figure 49).

Alerts were configured through the TEMS manager. An email plugin allowed the system to send alerts to a designated email. However, the SICK system tested did not have a connection to a mail server. Therefore, researchers did not evaluate email alerts. Text message alerts were also generated through a plugin into the TEMS Manager. The SMS plugin utilized a SIM card to transmit alert messages when a WW vehicle was detected. The text messages stated "Wrong Way Driver Detected! YYYY-MM-DDTHH:MM:SS.SSSZ, status: Valid, speed: -#.###," with the speed reported in meters per second.

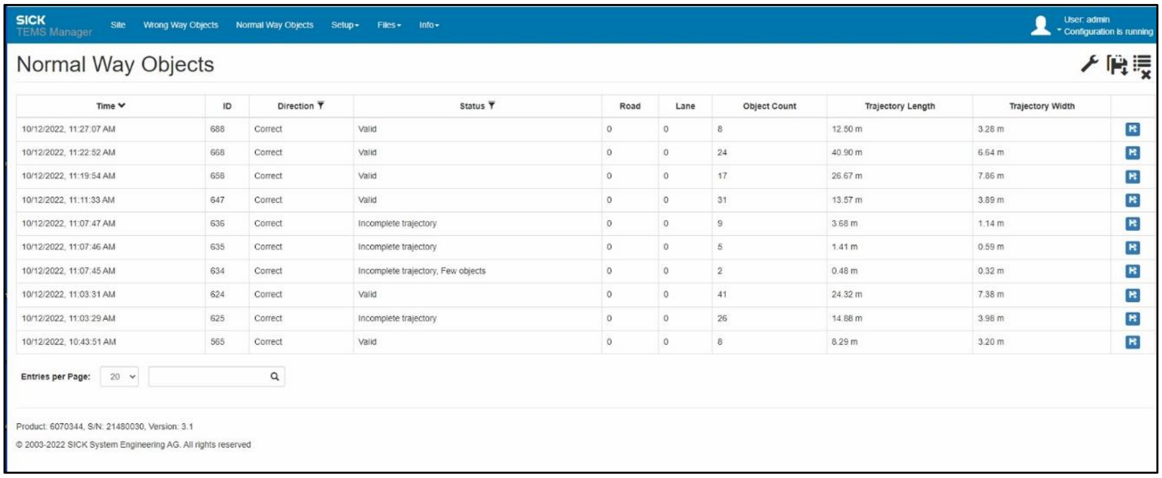


Figure 48. Example of SICK Alert Log.

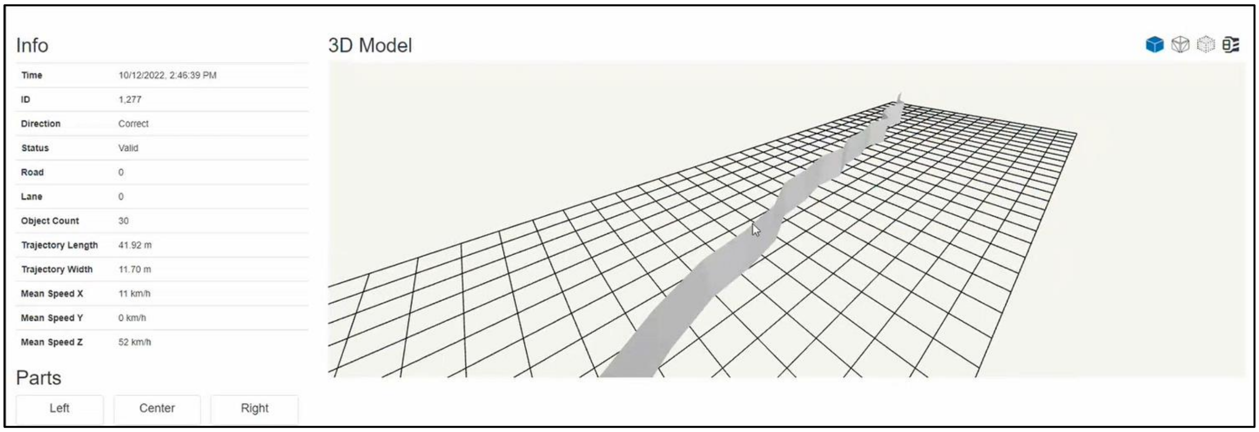


Figure 49. Exampled of SICK Trajectory Visualization.

TAPCO®

The TAPCO® WW detection system was comprised of one thermal camera, two optical cameras, one radar unit, and two illuminators. TAPCO® worked with researchers to install a pole on the runway system for testing since the portable trailers provided by TTI did not meet the TAPCO® deflection requirements. Figure 50 shows the TAPCO® detection equipment installed on the pole. A WRONG WAY sign and the system's controller cabinet were placed on a portable trailer. Figure 51 shows the TAPCO® device location relative to the ramp configuration and the WW entry locations.

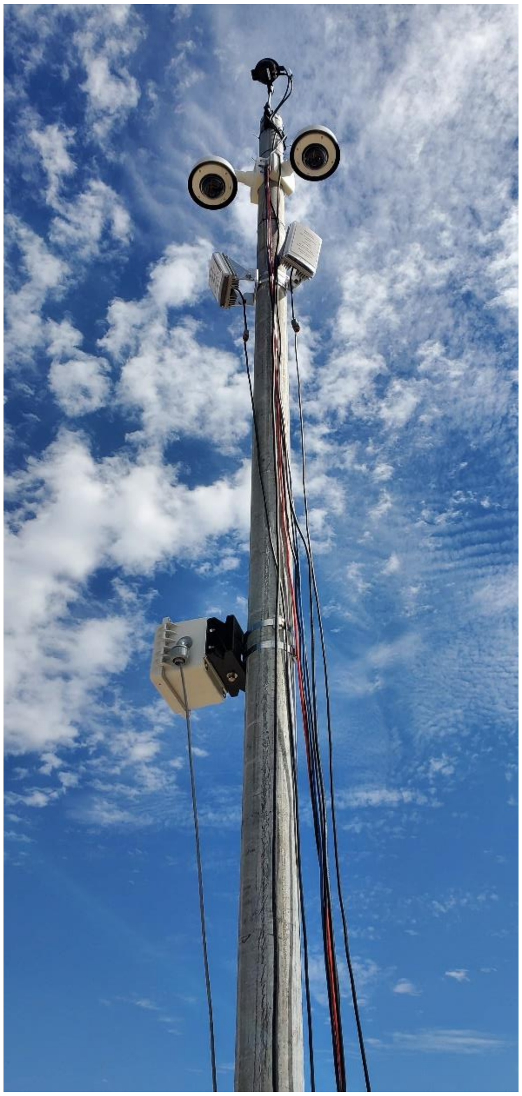


Figure 50. TAPCO® Equipment for Testing.

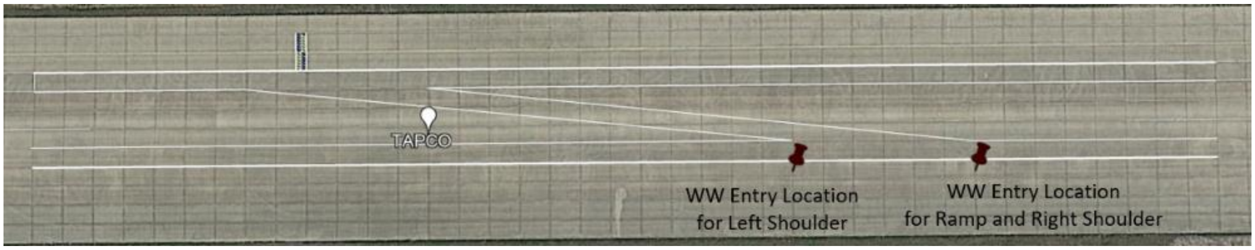


Figure 51. TAPCO® Device Location.

The system utilized a combination of radar and thermal camera technology to identify WW vehicles in two stages. The first stage (called sign activation zone) used the radar to search for a WW vehicle on the ramp. Once a WW vehicle was detected, the system illuminated the legend of a WRONG WAY sign. The first stage also triggered a detection alert to users through TAPCO's web-based monitoring system called BlinkLink®. These alerts can be configured to send a pop-up and/or play an alert (see Figure 52). The first stage also activated the optical cameras to record and store video of the event in BlinkLink®.

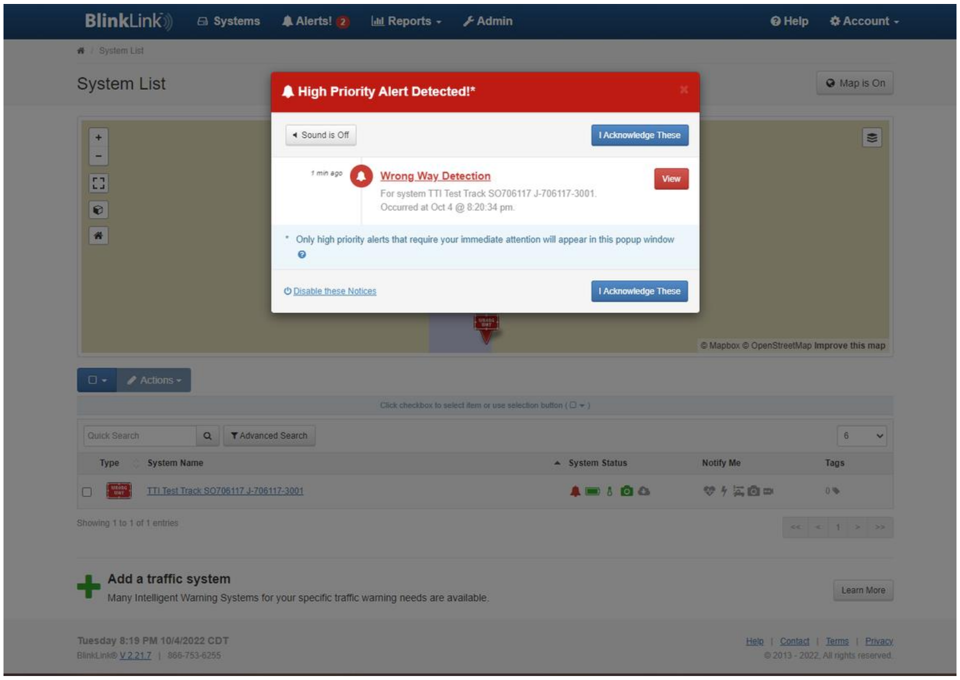


Figure 52. Example of a TAPCO® Wrong-Way Detection Alert.

If the WW vehicle proceeded through the second zone monitored by the thermal camera (second stage called wrong-way alert zone), the system sent a confirmation alert. At this point the system activates the illuminators and optical cameras capture upstream and downstream ramp views with still photos and videos.

Users can choose to receive alerts for both stages or only confirmation events. Alerts can also be sent via email, SMS, and phone call. For the closed-course testing, researchers monitored the events in real-time via BlinkLink® on the field hardened laptop and received alerts via email and SMS message. To calculate the WW vehicle detection latency, researchers used the wrong way detection timestamp in the software log (see Figure 53). Email alerts contained a series of 15 still photos, system details, asset name, event timestamp, and a link to the notification in BlinkLink®. The SMS detection alert contained "BLINKLINK ALERT – Wrong Way Detection – For System Labeled TTI Test Track." The SMS confirmation alert was the same except it stated, "Wrong Way Confirmation."

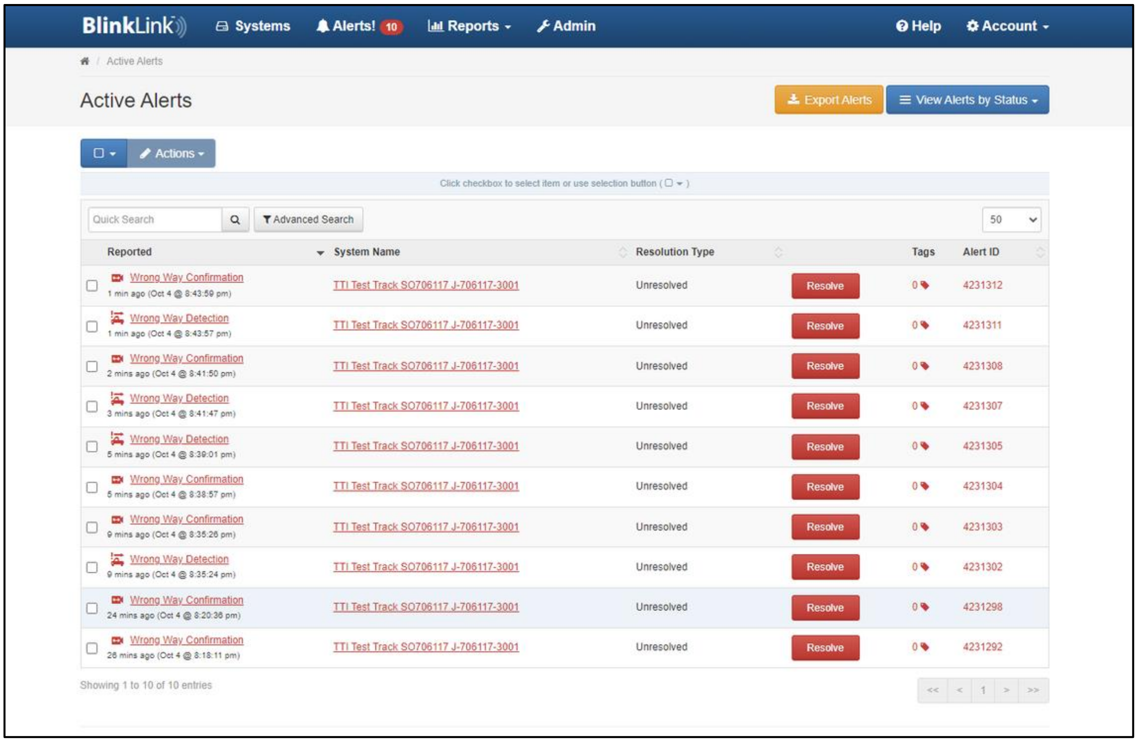


Figure 53. Example of a TAPCO® Active Alert Log.

BlinkLink® logs the detection and confirmation events such that users can review and manage the events (see Figure 53). Users can resolve an event by selecting from a pre-defined list of 15 choices that allows the user to document the characteristics of the event (e.g., non-vehicle bicycle, false positive—weather trigger, wrong-way vehicle—self corrected) (see Figure 54). There is also a place to enter additional notes about the event (see Figure 54). The alert event log notes a timestamp for when the alert was reported and the camera photo was processed (see Figure 55). The log also documents a when (timestamp) and who (name) the email, text, and phone (not tested) notifications were sent (see Figure 55). BlinkLink® offers health monitoring options including system heartbeat, voltage, temperature, camera status, and data usage with a 15-minute ping.

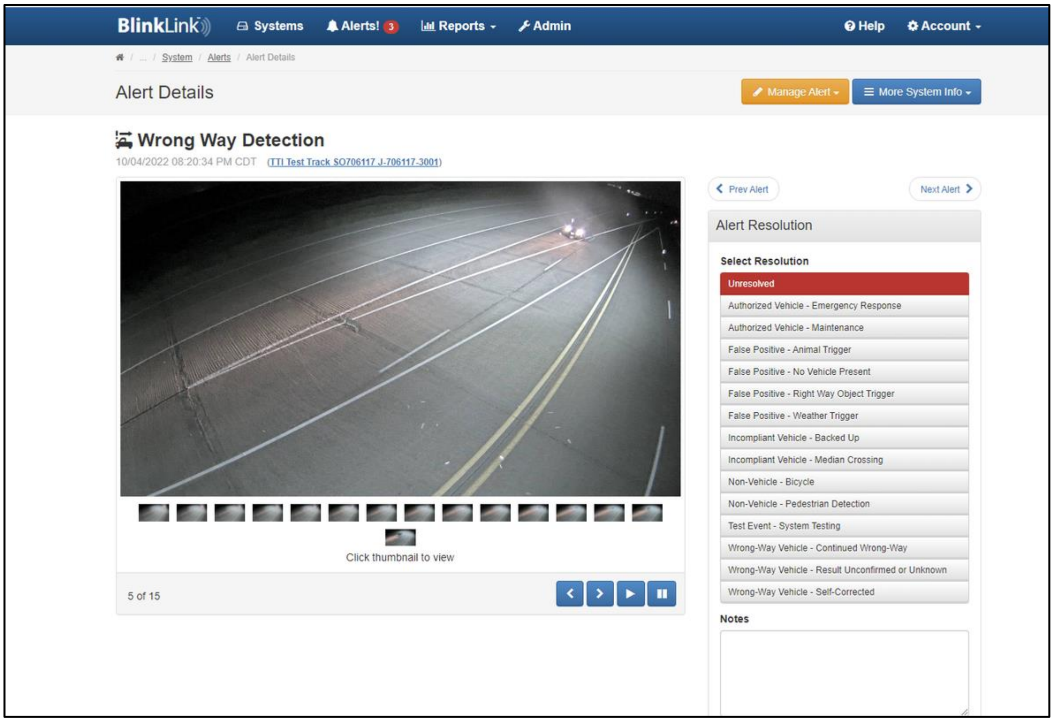


Figure 54. Example of a TAPCO® Alert Details Screen 1.

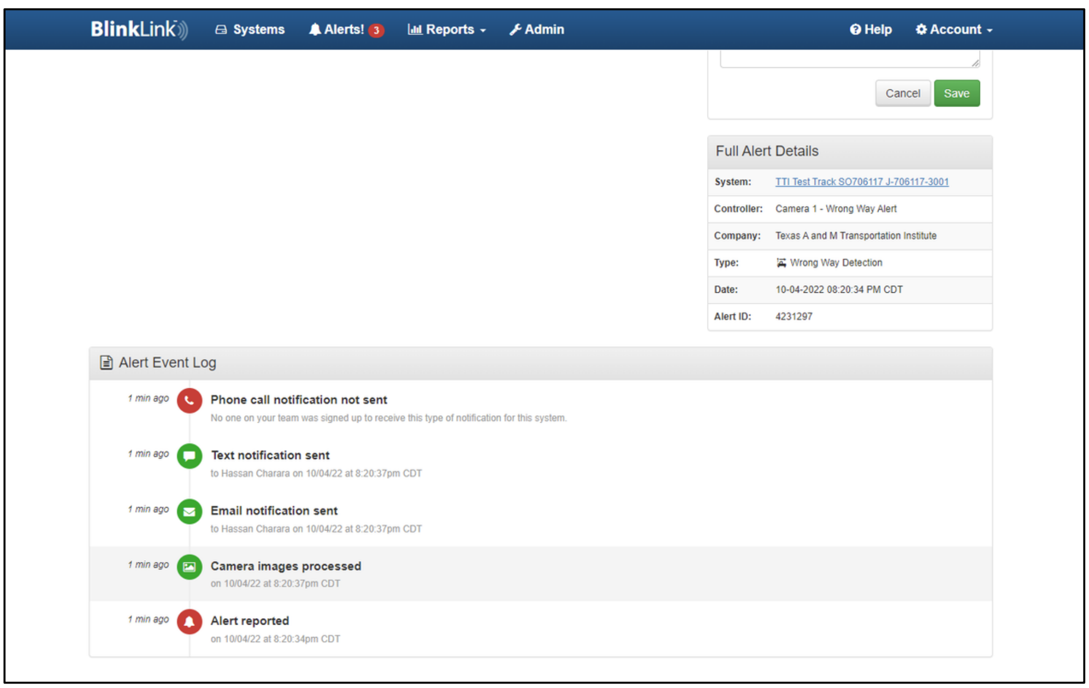


Figure 55. Example of a TAPCO® Alert Details Screen 2.

TraffiCalm®

The TraffiCalm® WWD system utilized four radar units placed around the exit ramp to search for a WW vehicle (see Figure 56, Figure 57, Figure 58, Figure 59, and Figure 60). The system also included a camera solely for recording a video to document the WWD event (see Figure 60). The camera unit was built into the controller device that acted as a wireless network hub for the radars and issued the warnings to the intended recipients. Figure 61 shows the location of the TraffiCalm® devices relative to the ramp configuration and the WW entry locations.

Figure 56. TraffiCalm® Equipment.

Figure 57. TraffiCalm® Radar 1.

Figure 58. TraffiCalm® Radar 2.

Figure 59. TraffiCalm® Radar 3.

Figure 60. TraffiCalm® Radar 4 with Camera and Controller.

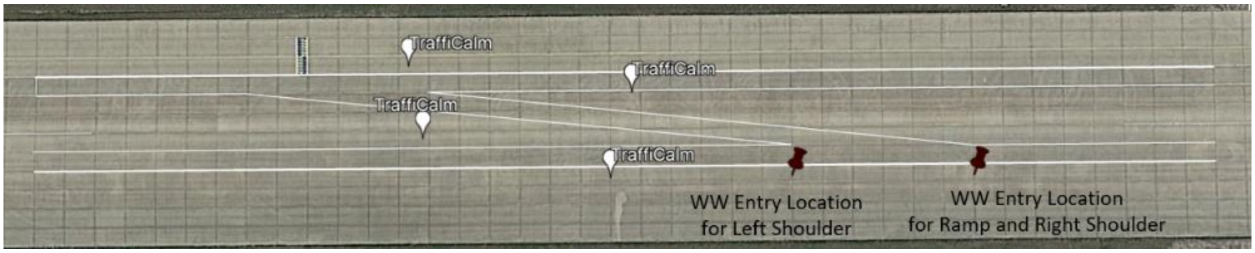


Figure 61. TraffiCalm® Device Locations.

The TraffiCalm® system tested used four radars that operated in two pairs (see Figure 61, one pair is near the WW entry locations [locations on the right] and the other pair is near the representative freeway lane [locations on the left]). Each radar unit was pointed in the correct direction of travel, had a single detection zone, and determined the speed and direction of objects on the ramp. Within each pair, the system required the speeds from both radars to match to activate the corresponding zone. For the closed-course testing, the pair of radars near the WW entry locations activated flashing lights on the WRONG WAY signs and participated in the algorithm used for detection (called the pre-alert zone). The other pair of radars worked together to create an alert zone that is the primary zone for detection. The alert zone was used in conjunction with the pre-alert zone, such that both radar pairs (i.e., all four radars) had to agree that a WW vehicle was detected for the system to issue an alert email. The TraffiCalm® system used a zone length threshold (i.e., distance the vehicle must travel) between the radar detection zones to ensure that zones activated consistent with a WW vehicle and were not noise detected by the radar units.

When the system detected a WW vehicle, it sent an email that contained a video and link to the TraffiCalm® web-based monitoring interface (Bluesentry), where a user can view additional details (e.g., timestamp) and deactivate the alarm (see Figure 62). Bluesentry keeps a log of WWD events, but only stores the latest video. However, each email alert has the corresponding video attached. Alerts can also be sent via SMS, but researchers did not test this function since TraffiCalm® sends text messages via an email address.

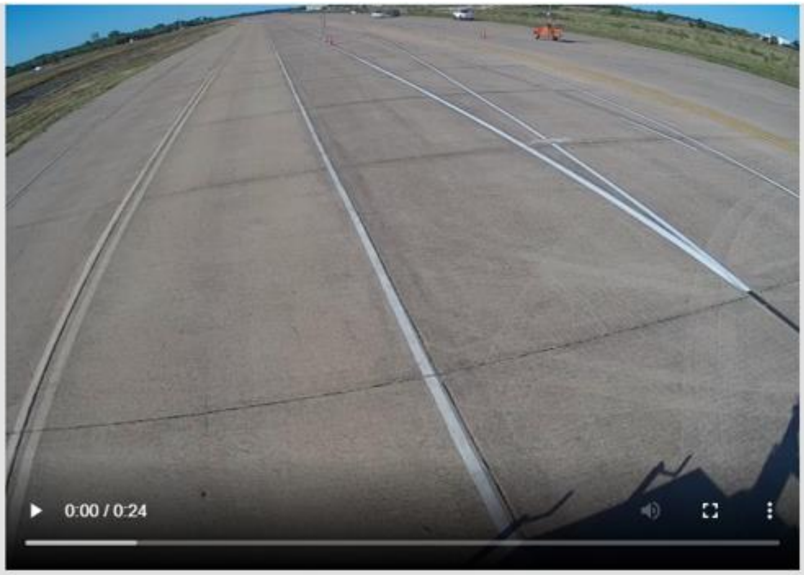
Researchers used the Bluesentry web-based application to monitor the system in real time during testing. To calculate the WW vehicle detection latency, researchers used the timestamp in the software log (see Figure 62).

The TraffiCalm® system can include additional pairs of radars, other zone types (i.e., flasher activation and confirmation), and different alert configurations. The flasher activation zone only activates the sign lights. It does not participate in the detection logic. Confirmation zones are used after the alert zones to ensure a low false positive rate. The alert configurations vary the required agreement settings for the radar units prior to sending an alert. Other agreement options include no agreement (one radar alone) and only the radar pair in the alert zone. Researchers did not test the additional zones or alert configurations.

Currently, only TraffiCalm® personnel can access device status information. However, TraffiCalm® is in the process of updating their system to enable users to view system health information.

TESTING PROTOCOL

Prior to testing, researchers corresponded with each manufacturer and provided a document that contained information about the testing procedure, equipment provided, shipping information, and answers to manufacturer questions. Researchers revised the document as needed and shared updates with manufacturers. One week prior to testing, researchers corresponded with the manufacturer and provided information about the schedule, meeting location, parking, and contact information.



Events

Date/Time	User	Property	Value
10/18/2022 17:01:22 CDT	<device>	alarm	on
10/18/2022 16:59:22 CDT	<device>	alarm	on
10/18/2022 16:57:19 CDT	<device>	alarm	on
10/18/2022 16:55:08 CDT	<device>	alarm	on
10/18/2022 16:52:27 CDT	<device>	alarm	on
10/18/2022 16:50:31 CDT	<device>	alarm	on
10/18/2022 16:48:08 CDT	<device>	alarm	on
10/18/2022 16:45:41 CDT	<device>	alarm	on
10/18/2022 16:43:19 CDT	<device>	alarm	on
10/18/2022 16:37:50 CDT	<device>	alarm	on
10/18/2022 16:36:46 CDT	<device>	alarm	on
10/18/2022 16:35:39 CDT	<device>	alarm	on
10/18/2022 16:34:13 CDT	<device>	alarm	on
10/18/2022 16:32:40 CDT	<device>	alarm	on

Figure 62. Example of TraffiCalm® Alert Log.

Closed-course testing at the RELLIS campus began the week of August 15, 2022, and ended the week of October 24, 2022. Equipment installation, testing, and equipment removal typically occurred Tuesday through Thursday of each week. On the first day, manufacturers installed and calibrated equipment to ensure it was functioning properly. Researchers also met with the manufacturer representatives to learn about the system, including details about the detection technology, setup of the WW zones, and the tool(s) used to configure the technology and/or monitor events. Each manufacturer had as much time as needed to install and pre-test their system. Testing began once researchers received verbal confirmation from the manufacturer representatives that their device/system was functioning properly. Some manufacturers installed equipment quickly, allowing researchers to complete some or all the daytime data collection on the first day. Other manufacturers took longer to install equipment such that researchers begin data collection at night. Nighttime testing was typically completed on the first night. Researchers used the second day of testing for completing the daytime runs and removal of the equipment from the runways. On occasion, weather or equipment installation issues pushed testing to the second night or third day.

Figure 63 is a collective image of the manufacturers' equipment locations. The most popular area to install equipment was between the representative freeway and frontage road lanes to the south of the exit ramp. Two manufacturers installed devices to the west of the representative freeway lane due to the short length of the exit ramp. Three manufacturers installed devices to the east of the representative frontage road lane.

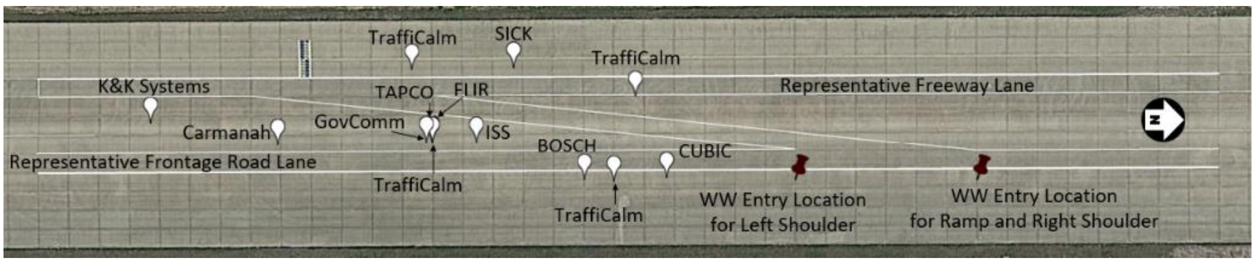


Figure 63. Location of All Tested Devices.

Researchers allowed manufacturers to perform some minor troubleshooting including restarting their systems during testing if researchers identified a change in behavior from the system. Major changes, such as moving equipment or altering detection zones, were not allowed after researchers started testing. Table 2 and Table 3 show the dates and weather conditions for daytime and nighttime testing for each detection technology, respectively. Table 4 shows the MOEs collected for each WWD detection technology.

Table 2. Date and Weather Conditions for Daytime Closed-Course Testing.

Detection Technology	Day Testing Date	Average Wind Speed (mph)	Max Wind Speed (mph)	Average Temperature (°F)	Average Humidity (%)
BOSCH & MH Corbin	9/14/22	4	10	83	61
Carmanah®	9/28/22	4	11	78	40
CUBIC™	8/31/22	4	6	85	75
FLIR	10/6/22	2	4	68	70
GovComm	9/7/22	2	5	91	52
ISS	8/24–25/22	8	12	87	62
K&K	8/16–17/22	5	12	92	56
SICK	10/12/22	9	13	85	63
TAPCO®	10/5/22	2	5	73	59
TraffiCalm®	10/18–19/22	10	23	59	38

Table 3. Date and Weather Conditions for Nighttime Closed-Course Testing.

Detection Technology	Night Testing Date	Average Wind Speed (mph)	Max Wind Speed (mph)	Average Temperature (°F)	Average Humidity (%)
BOSCH & MH Corbin	10/25/22	1	1	57	69
Carmanah®	9/27/22	3	4	79	33
CUBIC™	8/31/22	3	6	80	77
FLIR	10/5/22	2	2	74	48
GovComm	9/6/22	4	4	82	76
ISS	8/24/22	5	6	82	69
K&K	8/16–17/22	9	11	89	57
SICK	10/12/22	3	4	84	55
TAPCO®	10/4/22	2	3	75	41
TraffiCalm®	10/18/22	6	6	59	39

Table 4. Measures of Effectiveness Collected for Each WWD Detection Technology.

Detection Technology	Detection Accuracy	Sign Activation	Email Alert	SMS Alert
BOSCH & MH Corbin	Yes	Yes	Yes	Yes
Carmanah®	Yes	Yes	Yes	No
CUBIC™	Yes	No	Yes	No
FLIR	Yes	No	Yes	No
GovComm	Yes	Yes	Yes	No
ISS	Yes	No	Yes	No
K&K	Yes	Yes	No	No
SICK	Yes	No	No	Yes
TAPCO®	Yes	Yes	Yes	Yes
TraffiCalm®	Yes	Yes	Yes	No

The BOSCH daytime and nighttime testing took place in different months since the built-in infrared transmitter in the BOSCH optical camera (used for daytime testing) could not classify objects with the AI engine in the low-light nighttime conditions. The BOSCH team returned in October 2022, reinstalled, and configured their system similar to the daytime testing, but used a BOSCH thermal camera that could classify vehicles in nighttime conditions to detect WW vehicles.

RESULTS

This section documents the closed-course test results for the 10 WWD detection technologies evaluated. The testing included 84 WW vehicle runs and 36 RW vehicle runs. Thus, researchers expected 84 WW vehicle detections, sign (or surrogate device) actuations, and corresponding alerts via email and/or SMS, if tested.

Researchers initially reviewed all MOEs by time of day, vehicle type, vehicle speed, and driving path. None of these test parameters appeared to consistently impact WW vehicle detection accuracy, sign activation accuracy, email notification accuracy, and SMS notification accuracy. Instead, accuracy appeared to be dependent upon internal system parameters. Researchers did find that vehicle speed and driving path routinely impacted WW vehicle detection latency across all technologies tested.

Figure 64 shows the correct and missed detections for the WW vehicle runs for each system tested. The BOSCH, GovComm, ISS, TAPCO®, and TraffiCalm® systems detected all 84 WW vehicle runs (i.e., 100 percent WW vehicle detection accuracy). These systems represent a range of detection technologies including thermal cameras, optical cameras, radars, and combinations thereof. None of these systems produced false detections during the 36 RW vehicle runs.

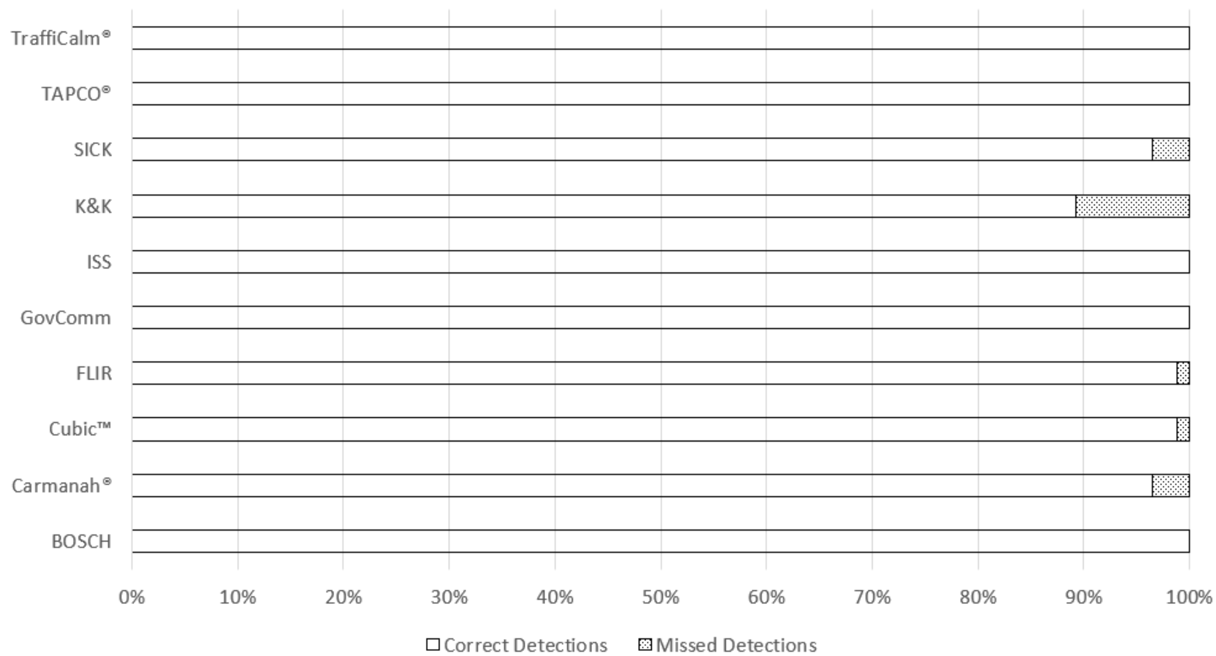


Figure 64. WW Vehicle Detection Accuracy for All Systems.

The CUBIC™ (optical camera) and FLIR (thermal camera) systems missed one WW vehicle detection (1 percent), resulting in 99 percent WW vehicle detection accuracy. The Carmanah® (radar and optical cameras) and SICK (radar) systems missed three WW vehicle detections (4 percent), resulting in 96 percent WW vehicle detection accuracy. The SICK radar must capture an adequate number of vehicle readings before it can classify the detection as a WW or RW object and declare the trajectory “valid.” Researchers noticed that the TEMS software reported “incomplete trajectory” or “incomplete trajectory, few objects” several times before reporting a “valid” detection. This behavior most often occurred during high-speed runs. The SICK system also occasionally generated multiple alerts that were labeled as “valid” for the same WW vehicle run. The K&K system (thermal and optical cameras) missed nine WW vehicle detections (11 percent), resulting in 89 percent WW vehicle detection accuracy. In addition, four test runs generated duplicate detections in the K&K software alert log. None of these systems produced false detections during the 36 RW vehicle runs.

Six systems tested sign activation accuracy. For the BOSCH, Carmanah™, GovComm, TAPCO®, and TraffiCalm® systems the sign activation accuracy was 100 percent. For the K&K system, the sign activation accuracy was 89 percent since the sign did not activate when the system missed detections.

Eight systems tested email notification accuracy (see Figure 65). The BOSCH, GovComm, ISS, TAPCO®, and TraffiCalm® systems sent at least one email for each WW vehicle run (100 percent). However, for three WW vehicle runs the TraffiCalm® system sent duplicate emails back-to-back, which are not reflected in Figure 65. The first run with multiple emails had two emails, the second had three emails, and the third had four emails sent for a single run. This totaled to six extra emails generated during testing.

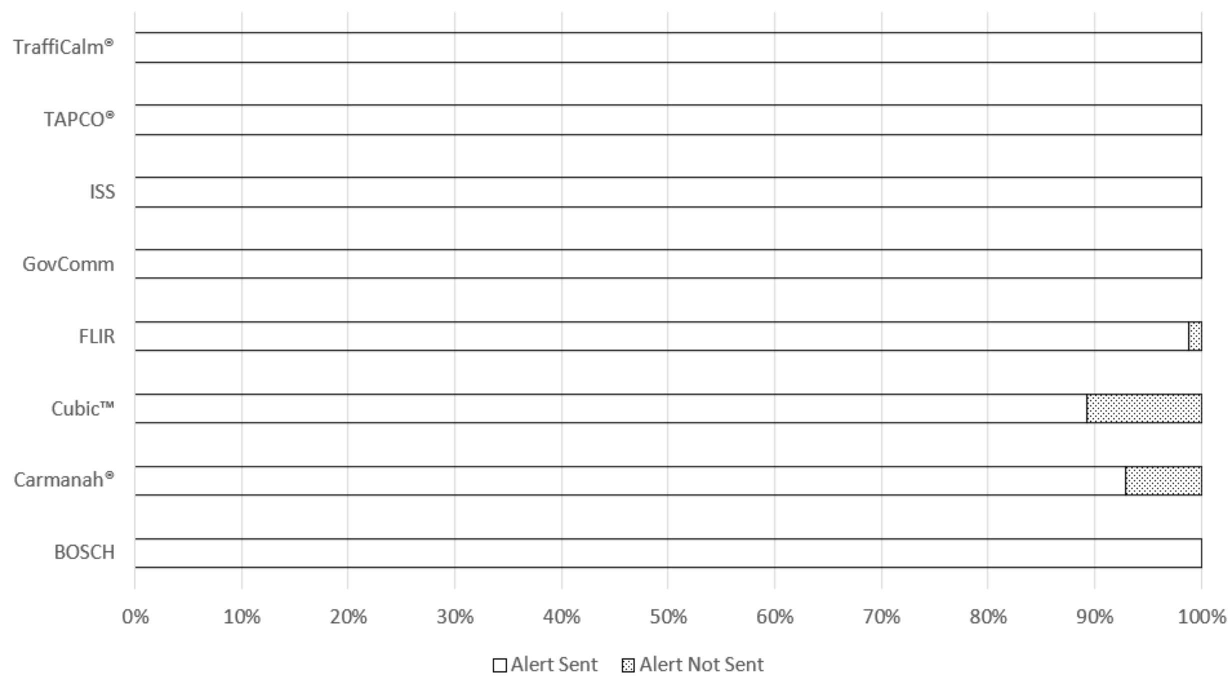


Figure 65. Email Notification Accuracy for All Systems.

Recall that researchers conducted most of the ISS closed-course testing without the third-party reviewing alerts due to the quick repetitive nature of the tests and the use of the ISS software to obtain the detection timestamps. However, for the daytime left shoulder runs, ISS helped the researchers configure the system to include the third-party review. Researchers compared the time difference between the email alerts sent automatically from the ISS system on the closed-course and the email alerts from the third-party review. Nine emails were received less than a minute apart. The time delay for the three remaining emails ranged from 1.3 to 6.7 minutes.

However, it is unknown whether these delays were caused by the third-party review or the TTI email server.

For the FLIR system, the email notification accuracy was 99 percent due to a missed WW vehicle detection. However, researchers observed three different types of unusual email behavior from the FLIR system that are not reflected in Figure 65. Recall that the FLIR system sends two emails for each WW vehicle detection: one with a still photo immediately after the WW vehicle detection and another with the same still photo plus a 30 second video of the WW vehicle. For nine runs, researchers received both emails, but the second email did not have any attachments (i.e., only the event description in the body of the email). For 10 runs, a third email with only the event description was received. For a single run, the second email was never received.

For the Carmanah® system, the email notification accuracy was 93 percent due to missed WW vehicle detections (three) and errors associated with sending emails for accurate detections (three). Upon further investigation, Carmanah® team members discovered that their new email notification feature created an issue that did not allow the system to send the email alert.

For the CUBIC™ system, the email notification accuracy was 89 percent. The system did not send nine emails due to either a missed detection (one) or the hard coded limit on the number of emails that can be sent per hour (eight). The CUBIC™ system also sent a duplicate email for one run. While testing the CUBIC™ system, researchers reached the hard coded limit on the number of email alerts per hour multiple times. The first time the system reached the limit, researchers waited for the time limit to expire and reran the WW vehicle tests for which an email was not received. The next time the limit was reached, researchers chose to continue the tests.

Three systems tested SMS notification accuracy (i.e., BOSCH, TAPCO®, and SICK). BOSCH and TAPCO® sent 100 percent of the SMS alerts during testing. SICK successfully sent seven SMS alerts (8 percent) before the system malfunctioned. Researchers allowed the SICK team to attempt to restore the SMS alert ability, but they could not restore the function. Hence, the high number of non-actuations for the SMS alert.

The WW vehicle detection latency for all systems for all runs is shown in Figure 66. This figure contains a box and whisker plot for each system that shows the upper and lower extremes, median detection latency (bolded line inside each box), and upper and lower quartiles. The median detection latencies across all WW vehicle runs ranged from 2 to 16 seconds. The highest detection latency was 28 seconds and the lowest was −9 seconds. Negative latencies were caused by how the detection zones were established relative to the WW entry locations. For some systems, the processor could search for the WW vehicle prior to the vehicle entering the ramp.

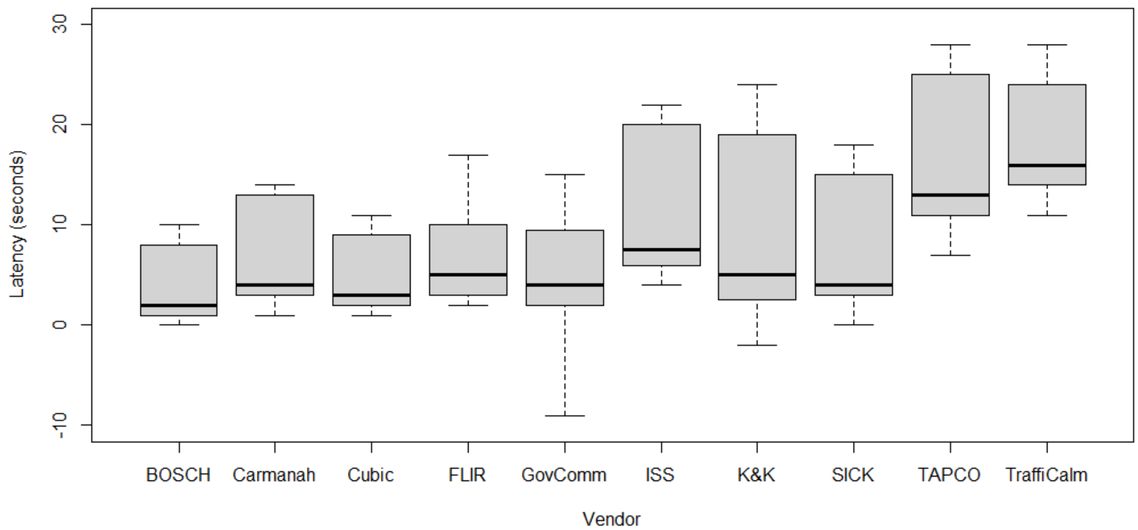


Figure 66. WW Vehicle Detection Latency for All Systems for All Runs.

As previously mentioned, researchers did find that vehicle speed and driving path routinely impacted WW vehicle detection latency across all technologies tested. Figure 67, Figure 68, and Figure 69 contain box and whisker plots for each system's WW vehicle detection latency by vehicle speed (i.e., 10 mph, 40 mph, and 60 mph, respectively). In general, researchers observed longer and more varied latencies for slower vehicle speeds (i.e., 10 mph) since it took the test vehicle longer to traverse up the ramp and enter the defined detection and confirmation zones. For example, the median detection latencies for the 10 mph runs ranged from 8 to 25 seconds compared to 2 to 15 seconds for the 40 mph runs, and 1 to 14 seconds for the 60 mph runs.

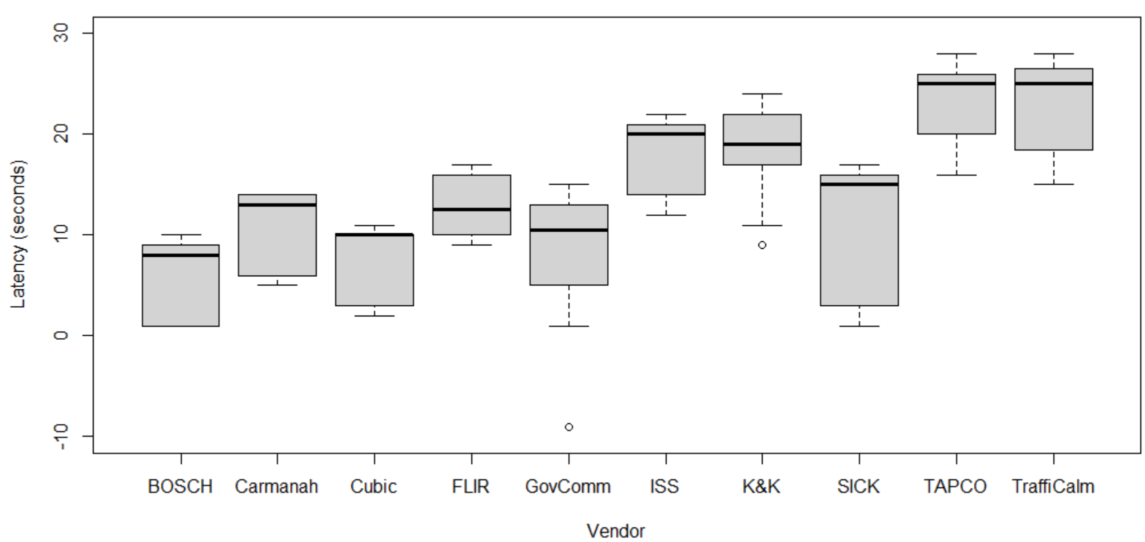


Figure 67. Latency Boxplots for All Systems for Runs at 10 mph.

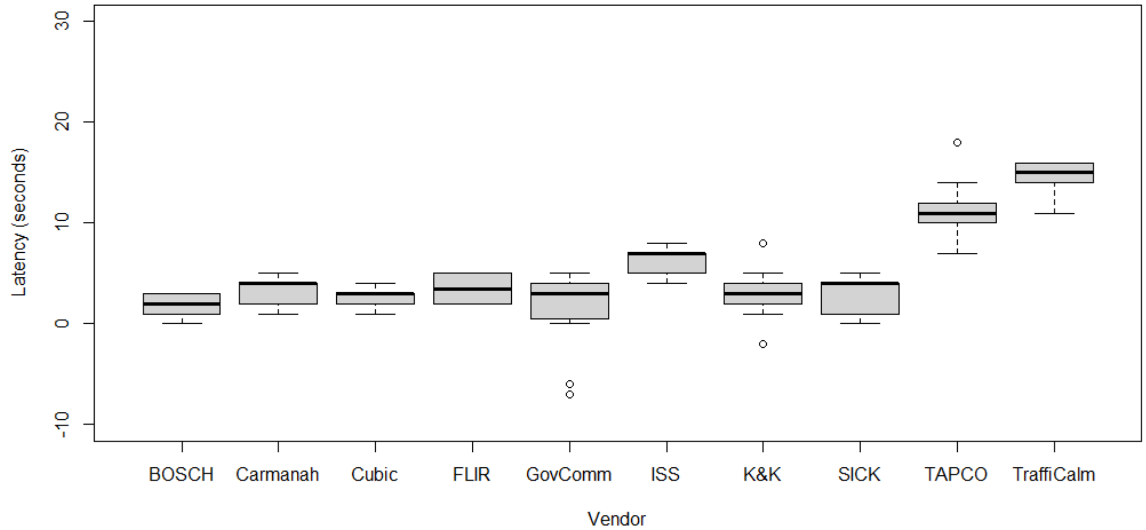


Figure 68. Latency Boxplots for All Systems for Runs at 40 mph.

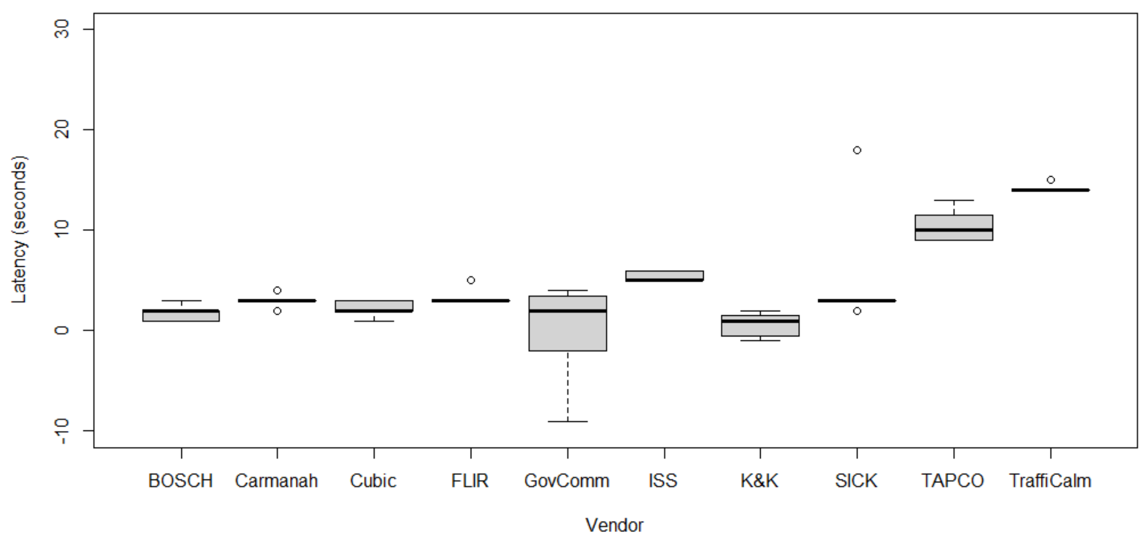


Figure 69. Latency Boxplots for All Systems for Runs at 60 mph.

Researchers also noticed that the left shoulder driving path typically resulted in shorter latencies compared to the ramp and right shoulder driving paths (see Figure 70, Figure 71, and Figure 72). Researchers believe the difference in latency between driving paths was due to the location of the detection zones relative to the entry locations.

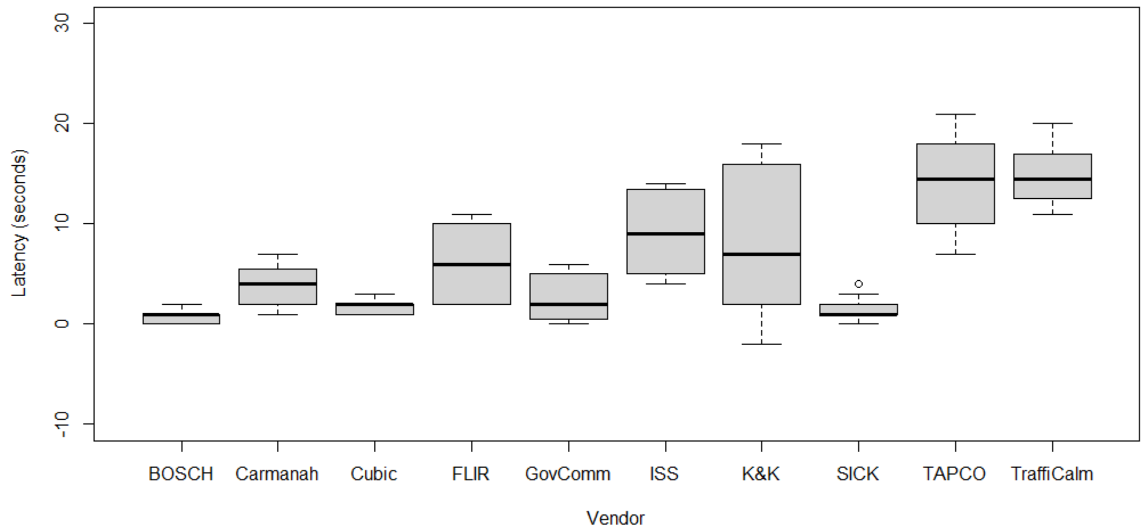


Figure 70. Latency Boxplots for All Systems for Runs on Left Shoulder.

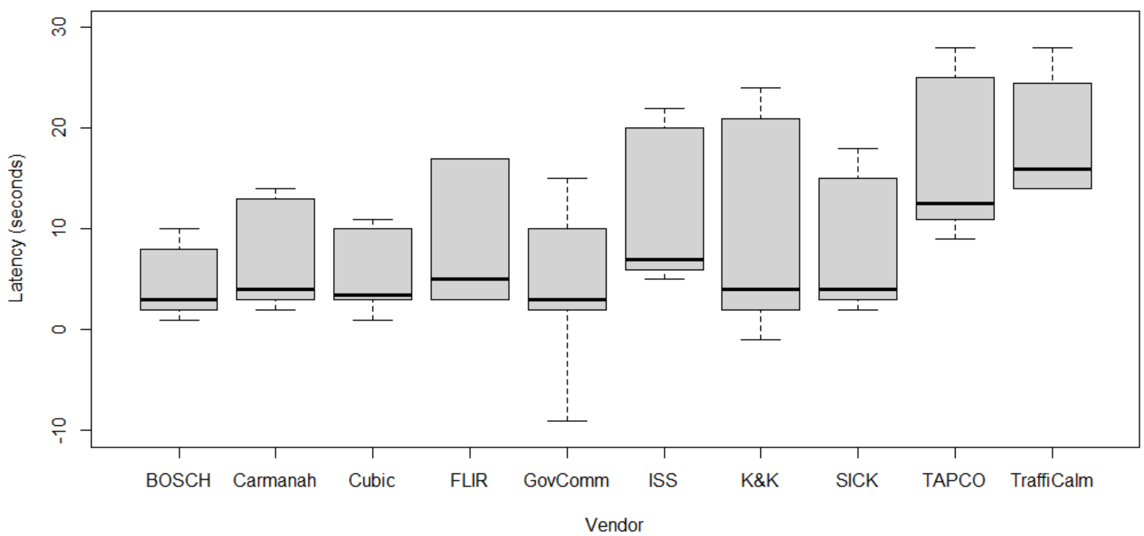


Figure 71. Latency Boxplots for All Systems for Runs on Ramp.

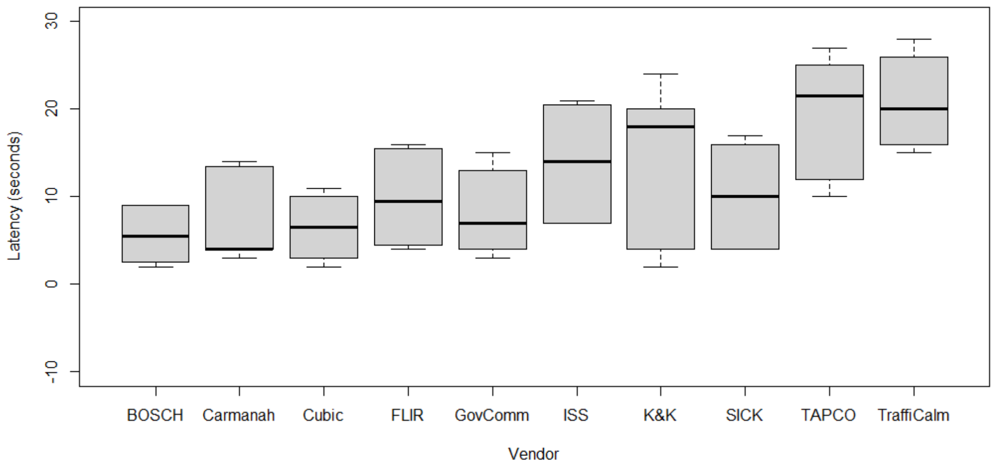


Figure 72. Latency Boxplots for All Systems for Runs on Right Shoulder.

Summary

TTI researchers tested 10 commercially available off-the-shelf WWD detection technologies between August and October 2022 in a closed-course environment at the RELLIS campus in Bryan, Texas. Each manufacturer was responsible for selecting the location for their equipment at the mock exit ramp, installing and configuring their equipment, and removing their equipment. Table 5 provides a summary of the closed-course testing results.

Table 5. Summary of Closed-Course Testing Results.

Detection Technology	WW Detection Accuracy	Sign Activation Accuracy	Email Alert Accuracy	SMS Alert Accuracy
BOSCH & MH Corbin	100%	100%	100%	100%
Carmanah®	96%	100%	93%	NA
CUBIC™	99%	NA	89%[b]	NA
FLIR	99%	NA	99%[b]	NA
GovComm	100%	100%	100%	NA
ISS	100%	NA	100%	NA
K&K	89%[a]	89%	NA	NA
SICK	96%[a]	NA	NA	8%[c]
TAPCO®	100%	100%	100%	100%
TraffiCalm®	100%	100%	100%[b]	NA

NA = Not Applicable.
[a] Generated duplicate detections for the same WW vehicle for some runs.
[b] Generated duplicate and/or incomplete emails.
[c] Malfunctioned.

Researchers also summarized information about the 10 WWD detection technologies tested into two-page documents (front and back) as an easy reference for practitioners. These two-page documents are in the appendix. Each of these two-page documents includes a table on the first page describing features offed by the WWD detection system when tested. Each of these features are defined as follows:

- WRONG WAY sign integration: The system was able to activate lights on a WRONG WAY sign (or surrogate device) after detecting a WW vehicle.
- Still photos: The system could capture, save, and send photographs of the WW vehicle upon detection.
- Video: The system could record and save video of the WW vehicle upon detection. The video may be sent with the alert, streamed, and/or stored on the local WWD system for upload.
- Email alert: The system was able to send alerts to an email address about a WW vehicle detected.
- SMS alert: The system could send SMS alerts to a phone via either cellular network or via email address that includes a phone number and cell provider (e.g., 1234567890@cellprovider.net)
- Active Traffic Management System (ATMS) alert: The system was able to raise an alert through an ATMS either provided by the manufacturer or a third party.
- Remote access: The system offered the user the ability to remotely access and configure system settings.
- Monitoring GUI: The system could provide a dashboard with information on the record of WW vehicles detected.
- System heartbeat: The system could provide information that remotely confirms the system is active and functioning.
- API offered: The system offered an API that provides the user with the ability to develop applications to interface with the system and integrate the system with the agency's central system.

CHAPTER 4:
FIELD TESTING

TTI researchers conducted three independent field tests to evaluate the real-world performance of three separate WWD detection technologies. Two of the sites and technologies were in-situ assessments of WWD detection technologies recently deployed by TxDOT. One additional site used technology made available by the manufacturer for a limited-duration field evaluation at a test site arranged by TxDOT San Antonio District staff. For each field evaluation, TTI researchers coordinated with TxDOT staff to obtain the WWD alerts received by TxDOT and analyze each event using the data and video available via the alert.

WWD TECHNOLOGIES AND FIELD SITES

WWD detection technologies have been used by the TxDOT San Antonio and Houston Districts for over a decade to detect WW drivers, send alerts to agency staff, and initiate multi-agency response to unfolding WWD events. Recently deployed technologies in San Antonio include radar sensors from TraffiCalm® (in-situ/existing) and optical cameras from ISS (field testing only). The Houston sites involved in the field testing were both in-situ/existing deployments of thermal camera systems from TAPCO®.

Radar Sensing Technology

Several generations of radar WWD detection systems have been used in the TxDOT San Antonio District over the past decade. The systems used along the Interstate 35 (I35) corridor in the northeastern part of the city were the subject of the in-situ field test. These devices were manufactured by TraffiCalm® and installed in the fall of 2019. An overview map of these installations is provided in Figure 73.

The WWD countermeasure system design of each site (see Figure 74) includes the primary radar sensor, camera, solar panel, batteries, housing—which includes cellular modem communications equipment to send alert messages and video to the cloud and, ultimately, the TransGuide TMC—and roadside LED-border illuminated WRONG WAY signs whose lighting is activated upon a WW vehicle detection. Satellite radar sensing equipment and solar panels for power are located at DO NOT ENTER and WRONG WAY signs, with the most advance sensors on DO NOT ENTER signs initially detecting the WW vehicle and sending this information to the primary control and communications unit (mounted further downstream in the direction of WW travel on a freeway overhead sign bridge [OSB]).

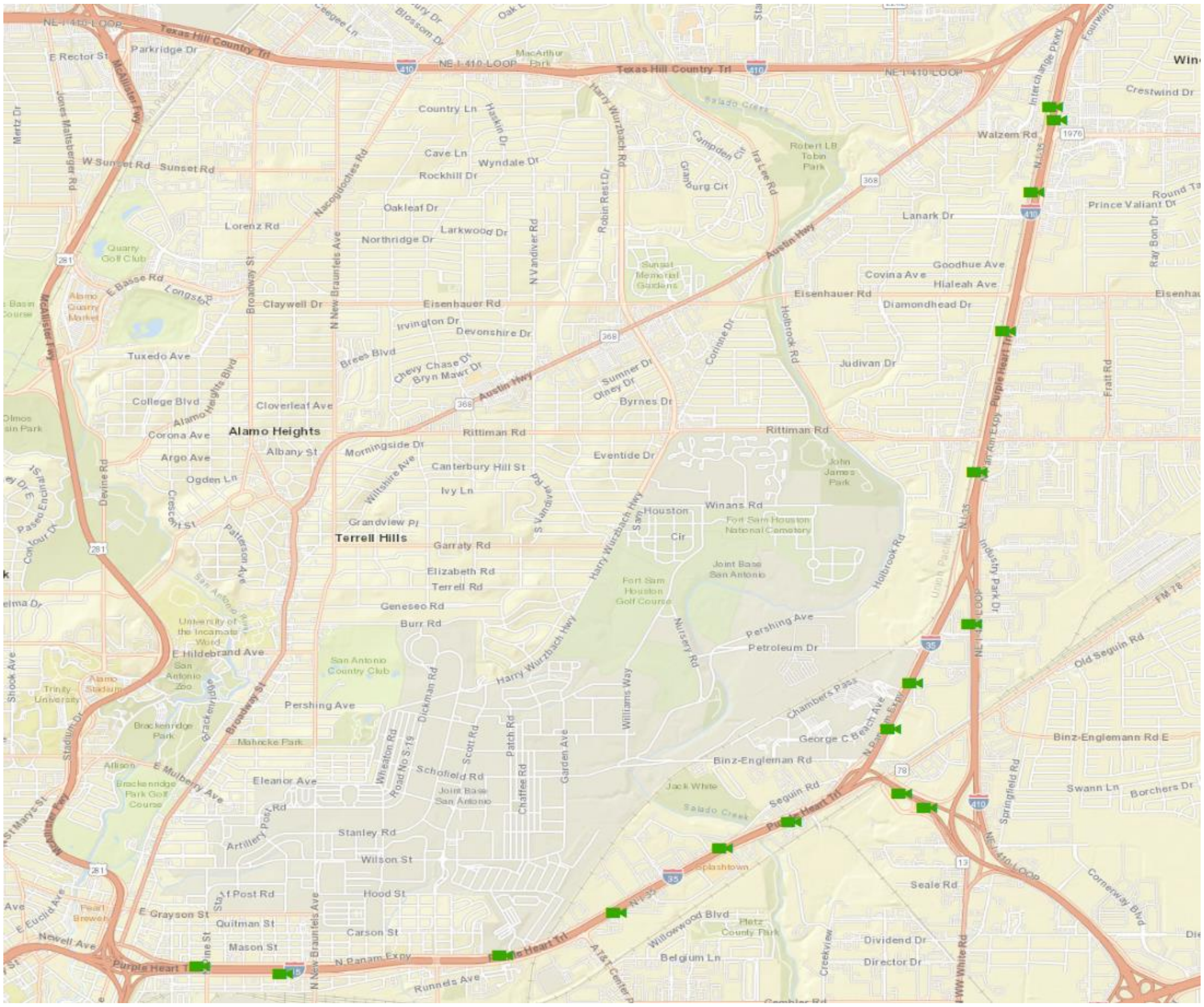
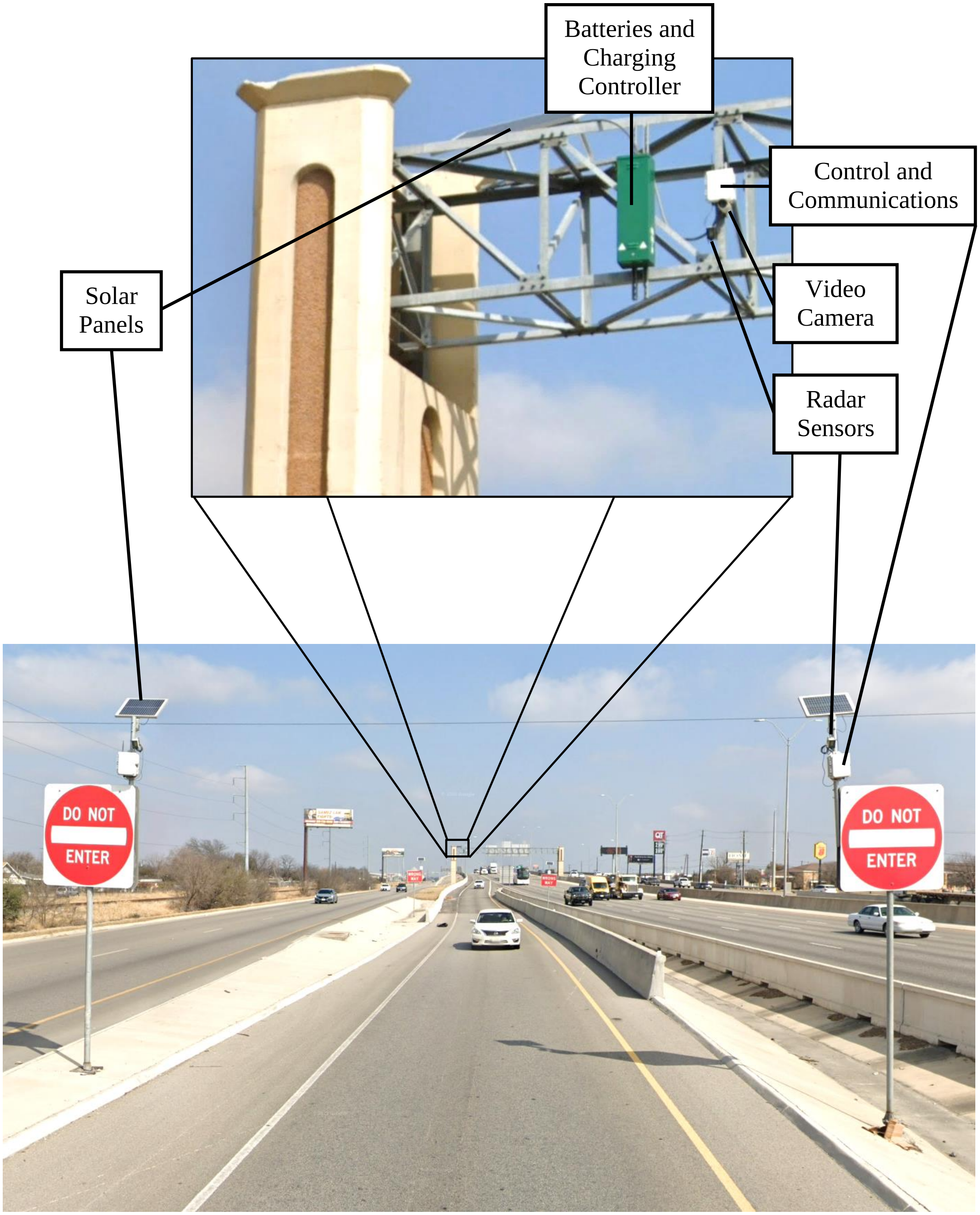


Figure 73. I35 Radar WWD Sensors (San Antonio, Texas).

A WW vehicle is first detected by the advance radar sensors, which are usually located on the exit ramp's DO NOT ENTER signs (i.e., the ramp signs typically located nearest to the frontage road and first to be encountered by a WW driver). The detection is communicated to the primary control unit on the OSB, which sends a signal to the WRONG WAY signs' controllers and activates the border LEDs on these signs. If the WW driver continues in the wrong direction on the ramp/frontage road and is detected by the primary radar sensor on the OSB, the details and video of the event are packaged into a WWD alert and communicated via cellular modem to TraffiCalm® servers via cloud communications (see Figure 75). TraffiCalm®'s servers process the event and send a WWD alert email to the TransGuide TMC, which is then read by the TMC operator who initiates staff response. Operators can attempt to verify the WWD event with freeway traffic surveillance cameras, can post DMS messages about the event to right-way motorists on the freeway, and can engage with co-located San Antonio Police Department dispatch to begin law enforcement in-field response to find and stop the WW driver.



(Source: © 2022 Google Maps)

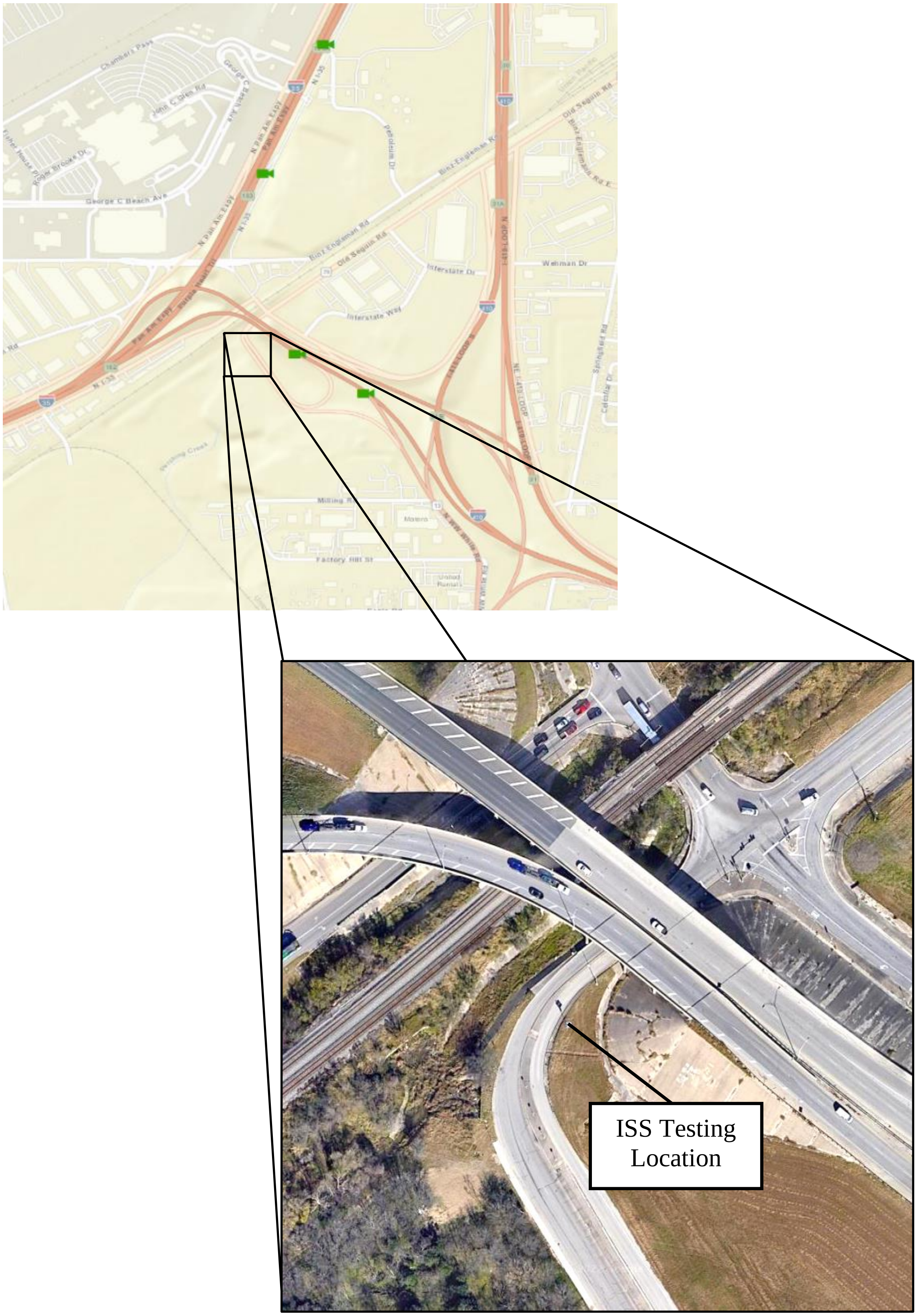
Figure 74. TraffiCalm® WWD Detection and Alert System—I35 Southbound Exit to Rittiman Rd. (San Antonio, Texas).

Figure 75. WW Vehicle (upper right) on I35 Northbound Exit to FM 78, June 25, 2022.

Optical Camera Sensing Technology

From April 2021 to January 2022, ISS and the TxDOT San Antonio District cooperated in a field test of ISS's optical camera-based WWD detection and warning system. The equipment was a solar-powered application along the I35 exit ramp to Farm-to-Market (FM) 78.

Figure 76 shows the location of the ISS test in northeastern San Antonio. The equipment consisted of a four-camera head unit, WWD processing module, communications module, and power supply system (see Figure 77). A solar panel and charging unit with batteries was provided to power the test system. Upon detection (using optical sensing zones from the detection camera) the system begins recording video from all four of its cameras, allowing confirmation of the WW vehicle in a verification zone, observation of the WW vehicle approaching warning devices (if present), and observation of the WW driver as they proceed along the ramp and/or reach the freeway mainlanes. A WWD detection event results in photo, video, and details of the event being sent via cellular radio and cloud communications to ISS servers. A third-party verification process reviews the photo and videos and determines if the event is a true WW driver. If so, an email alert is sent to TransGuide TMC operators. Video images from a San Antonio WWD event are provided in Figure 78 (image in the yellow rectangle is sent in the WWD alert email).



(Image Source: © 2022 Google Maps)

Figure 76. I35/I410 Interchange at FM 78, Northeast San Antonio, Texas.

Figure 77. ISS WWD Detection and Warning System Equipment, I35 Exit to FM 78 (San Antonio, Texas).

Figure 78. ISS WWD Event Images, I35 at FM 78, January 22, 2022.

Thermal Camera Sensing Technology

In the summer of 2020, installation was completed on TAPCO® thermal camera (infrared) WWD sensor and warning systems at two exit ramps in Houston, Texas. One system was located on the westbound Interstate 69 (I69) exit ramp to Kirby Drive, and the other was located on the eastbound Interstate 610 (I610) exit to Broadway Street (see Figure 79).

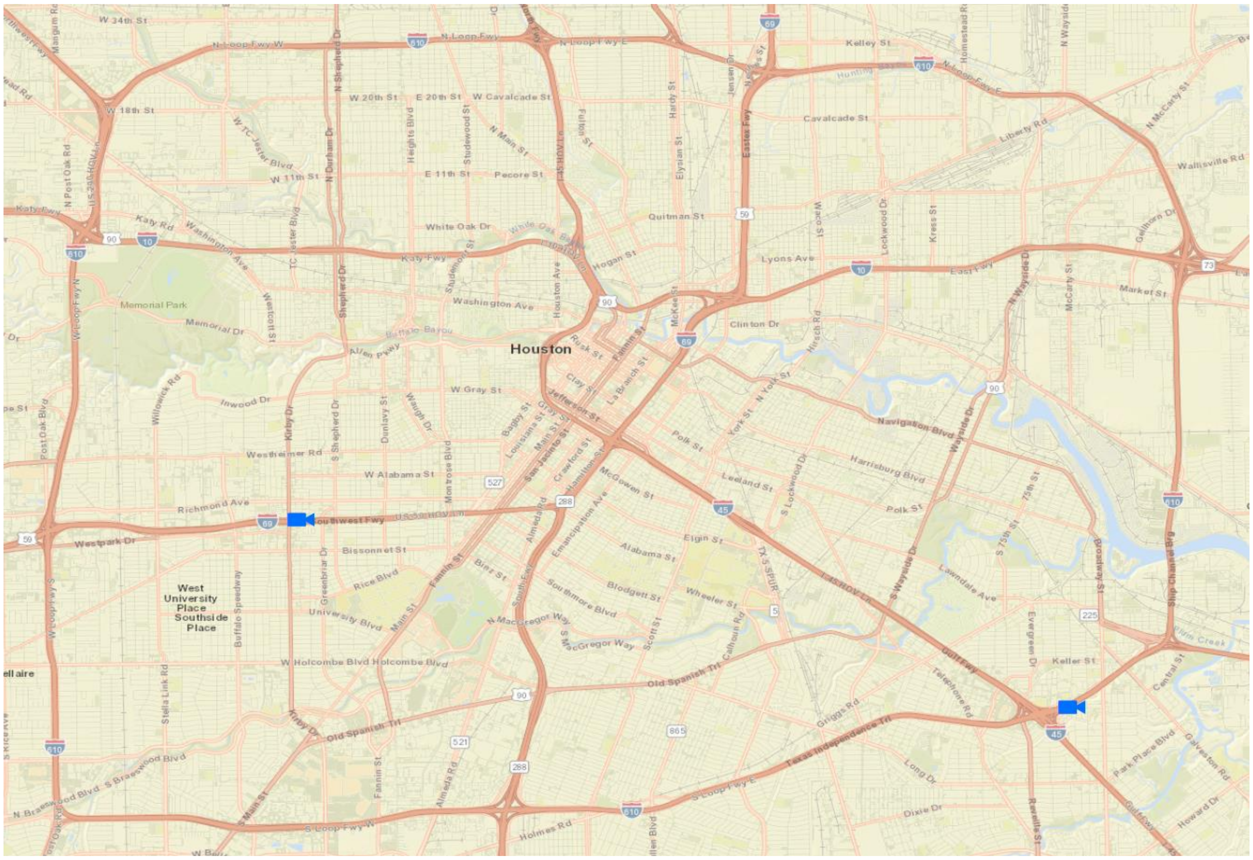
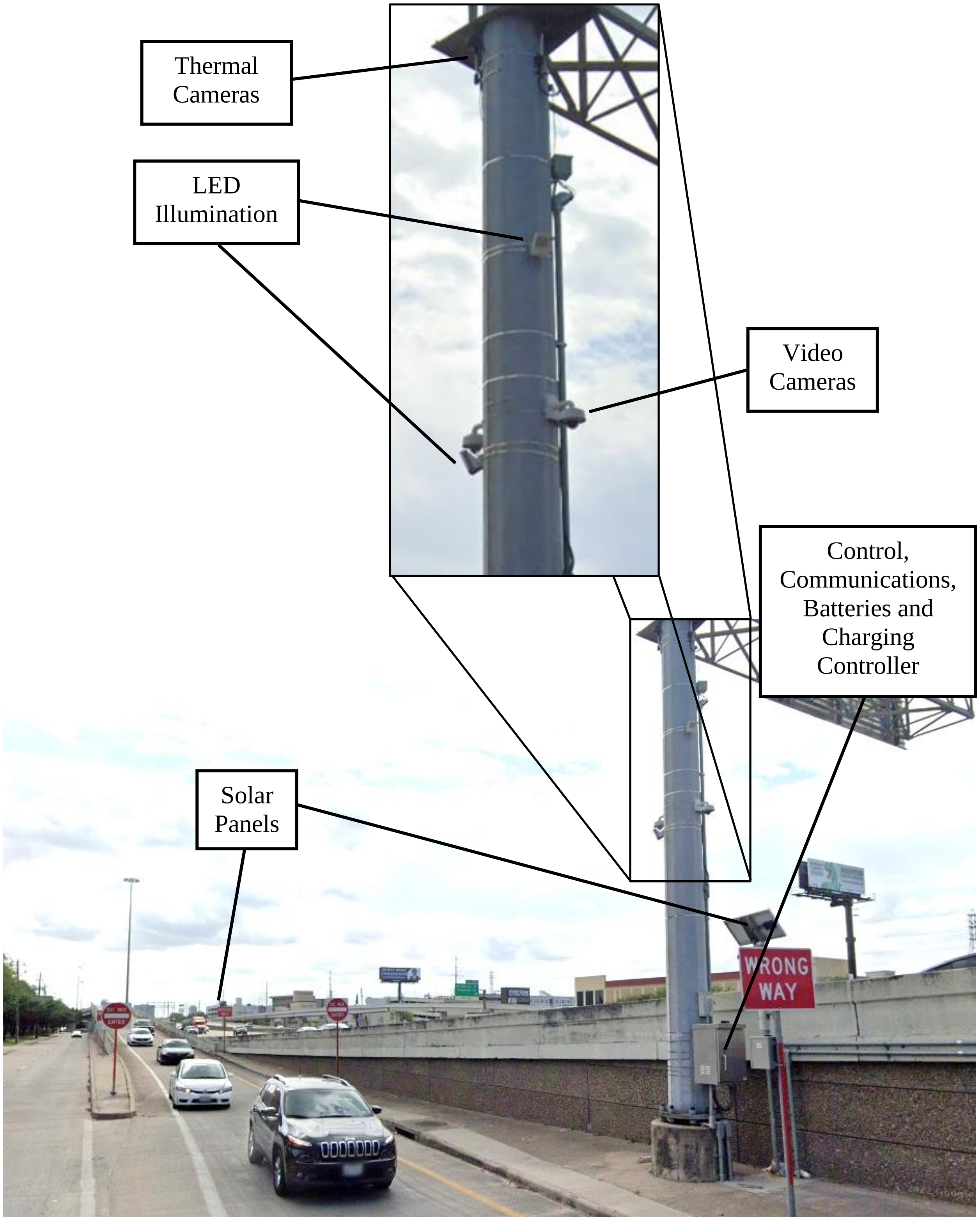


Figure 79. Thermal Camera WWD System Installation Sites (Houston, Texas).

The main thermal camera system includes thermal detection cameras, picture/video recording cameras, a cabinet for housing the system controller, communications equipment (cellular radio), batteries and charging controller (if solar powered), and LED lighting for improved image capture at night (see Figure 80). Solar panels, batteries, charge controllers, communications equipment, and pairs (left and right side of the road) of LED border-illuminated WRONG WAY signs are located on both the frontage road upstream of the primary system pole for initial driver warning and along the ramp.



(Source: © 2022 Google Maps)

Figure 80. TAPCO® WWD Detection and Alert System—I69 Westbound Exit to Kirby Dr. (Houston, Texas).

In everyday operations, the thermal camera first detects a WW vehicle, and the primary controller signals the downstream (in the direction of WW movement) LED border-illuminated WRONG WAY signs to begin flashing. If the vehicle continues travel in the wrong direction, it is picked up in the sensor's alert zone and details about the WWD event, including pictures of the vehicle progressing down the ramp or frontage road the wrong direction, are sent from the primary controller to the cloud via the system's cellular radio. TAPCO® servers process the alert and send a warning email to TxDOT TranStar TMC operations staff and, at the same time, log event details and imagery on servers that can be accessed by TxDOT staff via TAPCO®'s BlinkLink® event management software and/or website. Figure 81 contains an image of a WWD event processed by the TAPCO® WWD detection and warning system.

Figure 81. TAPCO® WWD Event Image, I69 at Kirby Dr., June 30, 2022.

FIELD TESTING RESULTS

With this research effort documenting in-field WWD detection performance for several manufacturers and varying detection technologies, each with a unique method of classifying detection events from their equipment, researchers developed a taxonomy for WWD detection events that could be universally applied. Broader categories group alerts by whether they accurately detected something approaching their equipment along the roadway, while more detailed categories provide information about the nature of the object (or person) being detected. The complete taxonomy used is provide in Table 6. The first category indicates that no wrong-way object (WWO) was observed approaching the WW sensor. This category is effectively labeled "false calls" (i.e., instances when the sensor activated for a WW alert and no visual verification was available of something traveling more or less directly toward the WWD activation sensor). The subcategories show that shadows or equipment disruption from the wind may have had a role in sensor activation, or there was no discernable cause for the detection. The second category indicates that something non-motorized (i.e., an animal, person, or bicycle) activated the WWD sensor. Since an object of some kind was approaching the sensor, it is not considered a false call. A third category indicates that a vehicle of some kind (i.e., in reverse, providing emergency services, maintenance, or even a train) was on a path roughly approaching the WW sensor equipment. Again, these are legitimate activations of the WWD sensing equipment but are not considered WWD events. The final category is genuine WWD events (i.e., drivers who are approaching the sensor traveling in the wrong direction on the ramp or frontage road and are not emergency or maintenance vehicles). Whether these WW drivers corrected their path because of response to on-road warning devices within the field of view of the WWD detection and monitoring equipment was recorded by analysts via subcategorization.

Table 6. Taxonomy of WW Detection Events.

Category	Subcategory
noWWO (false call)	noWWO (false call); lighting/shadow
	noWWO (false call); wind
	noWWO (false call); unknown
WWO—non-vehicle	WWO—non-vehicle; animal
	WWO—non-vehicle; bike
	WWO—non-vehicle; pedestrian
WWO—vehicle (not WWD)	WWO—vehicle (not WWD); backing
	WWO—vehicle (not WWD); emergency response
	WWO—vehicle (not WWD); maintenance
	WWO—vehicle (not WWD); train
WWD	WWD; corrected
	WWD; not corrected
	WWD; unknown

Additional descriptive details for each WW detection and alert were documented by researchers, including:

- Date.
- Time.
- Ramp/location.
- Ramp direction of regular traffic flow.
- Lighting (i.e., day, night, or dawn/dusk).
- Weather as observed in event photos/video (i.e., clear, rain, fog, wet, or snow).
- Email alert time as received by TxDOT TMC staff.
- Notes (optional; one to six word summary of event activity).

These data were used to support the analysis of the WW detection data and provide an overview of WWD behavior at each site.

Radar Sensing Technology

WW event data from March 2021 through June 2022 were available for 16 I35 exit ramps with radar detection equipment (see Figure 73). The researchers' initial review of the events detected by these devices revealed that multiple ramps had a high proportion of false calls with an unknown origin (see Figure 82).

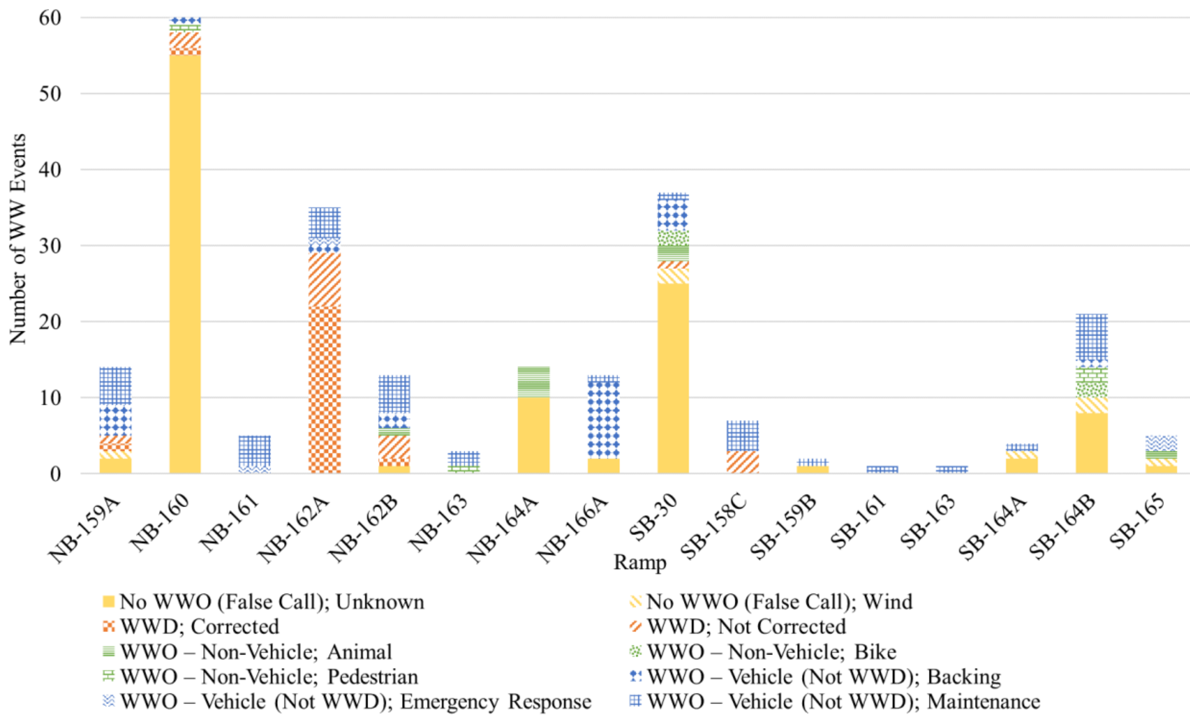


Figure 82. I35 Radar Sites by Type of WW Detection.

Subsequent review of ramps with greater than 25 percent of total site event calls classified as false calls of unknown origin revealed that the false calls were usually associated with heavy vehicle traffic on the frontage road (traveling in the correct direction), vehicular movement within parking lots along the frontage road (but not necessarily toward the radar sensing equipment), and vehicles exiting parking lots or side streets (whose motion was typically perpendicular to the frontage road and/or sensor). To prevent high false call sites (that could be addressed through sensor recalibration) from biasing the overall dataset, sites with greater than 25 percent false calls due to unknown causes were removed from the analysis. The removed sites are listed in Table 7.

Table 7. I35 Radar Sites Removed from Analysis Due to High False Call Rate.

Northbound I35 Ramps	Southbound I35/I410 Ramps
NB-160; I35 Exit to Splashtown Dr. NB-164A; I35 Exit to Rittiman Rd.	SB-30; I410 Exit to Binz-Engleman Rd. SB-159B; I35 Exit to Walters St. SB-164A; I35 Exit to Rittiman Rd. SB-164B; I35 Exit to Eisenhauer Rd.

NB = Northbound; SB = Southbound.

With high false call rate sites filtered/removed from the dataset, researchers re-examined the I35 sites/ramps for event causation. The results are contained in Figure 83 and reveal that the ramp with the highest number of WW detection events—by far—is ramp NB-162A, the northbound exit ramp to FM 78. Also noteworthy is that maintenance activity was detected at most ramps, indicating that such activities could be integrated into routine WWD detection equipment testing.

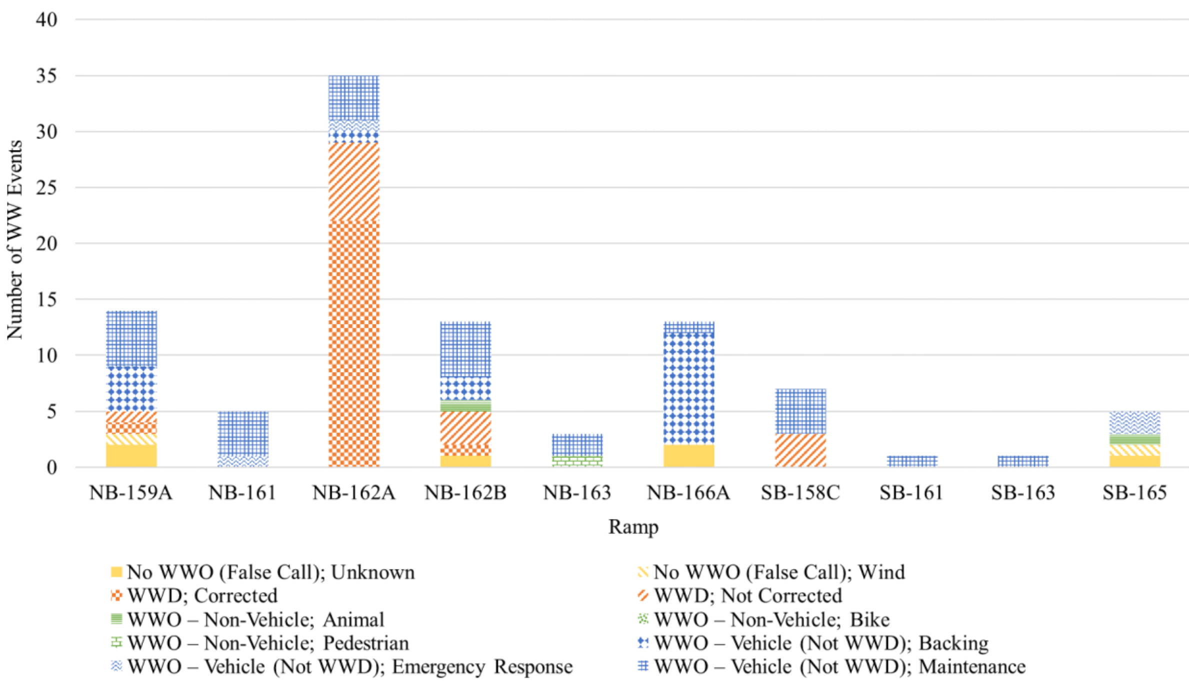


Figure 83. I35 Radar Sites by Type of WW Detection (Filtered).

In total, the WWD radar sensing technology at the 10 I35 ramps represented in the final dataset detected 97 WW events between March 2021 and June 2022. The frequency of each major category of WW events is provided in Figure 84, and the frequency of the more detailed subcategories of these events is provided in Figure 85. As revealed in the figures, 50 percent of all WW detections were vehicles moving toward the detection system (opposite the regular flow direction of traffic) that were not actually WW drivers. This group included maintenance vehicles (mainly street sweepers), vehicles reversing on the ramp or on the mainlanes near the ramp, and emergency vehicles. True WWD events constituted 39 percent of all detections, with the majority performing some form of corrective action such as turning around, reversing, crossing over a median to travel in the correct direction on a ramp, or stopping on the shoulder of the ramp. The false call rate for the radar warning WWD detection and warning system was 8 percent, with most of the false calls caused by unknown sources and a couple by wind. Three percent of the WW detections were non-vehicular, a category that includes pedestrians, bicyclists, and even animals (mainly birds).

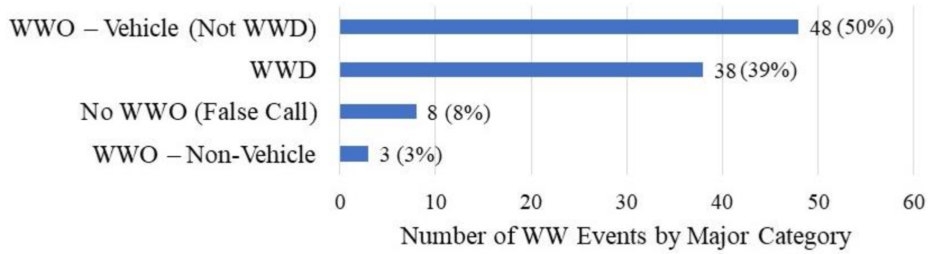


Figure 84. I35 Radar Site WW Events by Major Category/Type (Filtered).

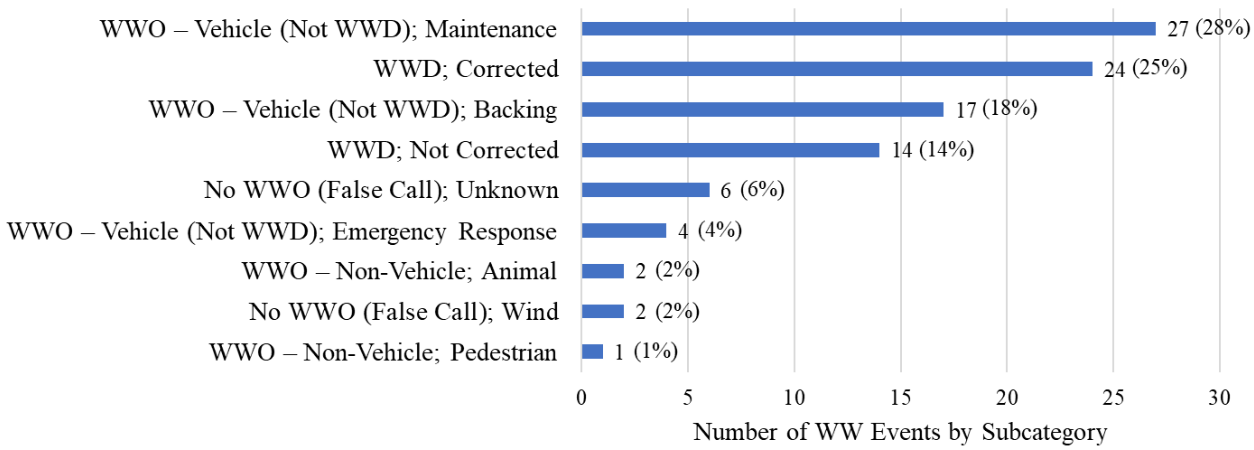


Figure 85. I35 Radar Site WW Events by Subcategory/Type (Filtered).

A final aspect of the evaluation of WWD detection system performance was the time delay (i.e., latency) between the time the WW object/driver was detected in the field and the receipt of the alert/warning email by TxDOT TMC operations staff. Swift notification of these events is essential so that operators can post DMS alerts to right-way motorists, monitor cameras to locate the WW driver in the field (for true WWD events), and engage with law enforcement to initiate in-field response for officers to find and stop any WW drivers. Figure 86 contains the results of the WW alert email latency for the 97 alerts received from the 10 I35 sites included in the analysis. The average latency was 36.34 seconds with a median of 36 seconds and a standard deviation of 17.67 seconds. Ninety percent of emails were received within one minute of WW detection in the field.

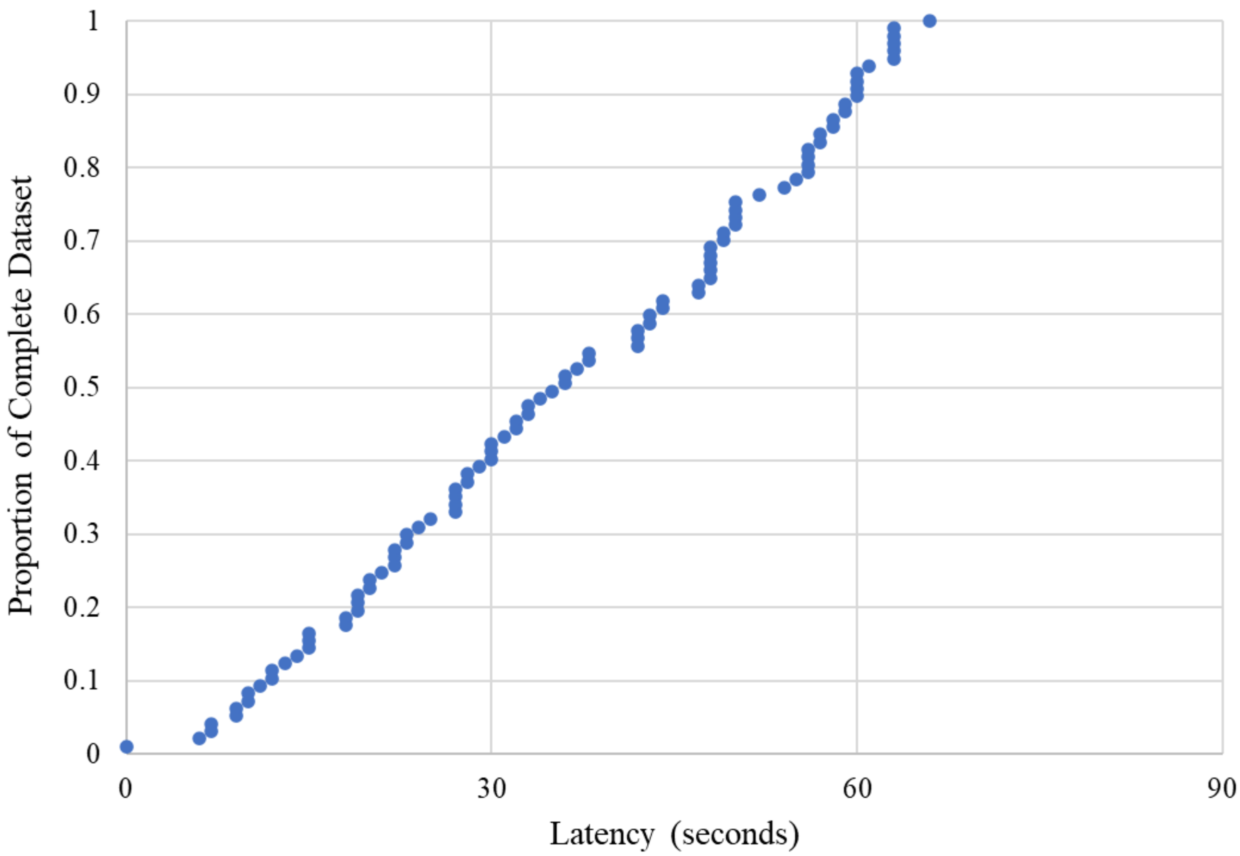


Figure 86. I35 Radar Sites WW Email Alert Latency (Filtered).

Optical Camera Sensing Technology

The field test of ISS optical sensing WWD detection technology at the I35 northbound exit ramp to FM 78 resulted in 183 WW alerts between April 2021 and January 2022. A categorical breakdown of the types of detection events is provided in Figure 87, while more detailed event information is provided in a subcategory summary in Figure 88. Along the I35/FM 78 exit ramp at the testing location—which was within 300 ft of the intersection where most WWDs on the ramp make a turn along an incorrect path—97 percent of the detected WW events were WW drivers. Four vehicular WWOs were maintenance vehicles (totaling 2 percent of WW events), and there were two false calls due to shadows from right-way vehicles interpreted by the optical sensing equipment as WW vehicles. The two false calls accounted for the 1 percent false call rate observed for the optical sensing equipment.

The I35 northbound ramp to FM 78 also features a permanent installation of radar WWD sensing equipment where the ramp meets the connector between the northbound I35 mainlanes and southbound I410. A WW driver along the ramp would first encounter the ISS detection equipment and then travel over 1300 ft along the looping ramp before reaching the radar equipment. Therefore, any WW drivers correcting their path in the observation range of the ISS sensing and monitoring equipment would not be picked up by the radar sensors further along the ramp (in the wrong direction of travel).

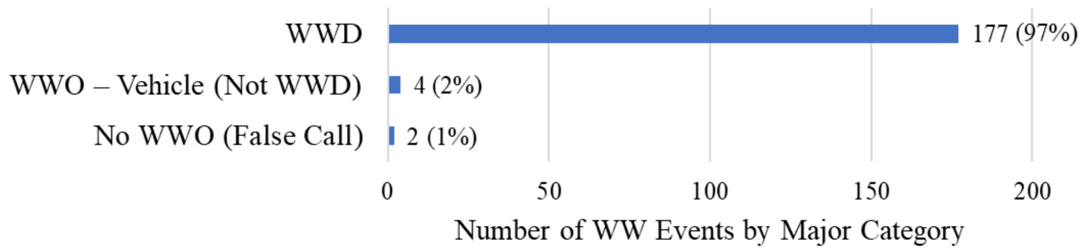


Figure 87. I35 NB/FM 78 Ramp Optical Sensing Site WW Events by Major Category/Type.

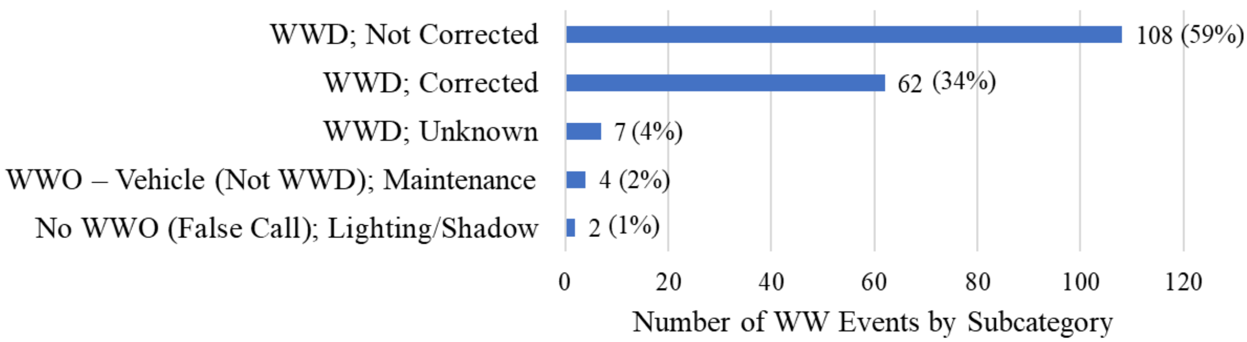


Figure 88. I35 NB/FM 78 Ramp Optical Sensing Site WW Events by Subcategory/Type.

Of the total 183 alerts from the ISS optical sensing system, an email receipt time at the TMC could be determined for 134 alerts (73 percent). The email receipt time for the remaining 49 alerts could not be determined since the actual emails themselves could not be retrieved from TxDOT archives. Instead, records for these alerts could only be pulled from ISS online archives. The average latency for TxDOT TMC staff to receive WW alerts/warning emails from the ISS optical sensing system was 82.89 seconds (see Figure 89). The median latency was 70 seconds, and the standard deviation of warning latency was 75.38 seconds. The 90th percentile latency was 140.5 seconds, showing that 90 percent of the time TMC operators received a WWD warning within two minutes and twenty seconds of the event occurring in the field. It is probable that the third-party review of ISS WWD alert events to filter out non-WWD events contributes to the observed latencies between field detection time and the time the email alert was received by TxDOT TMC staff.

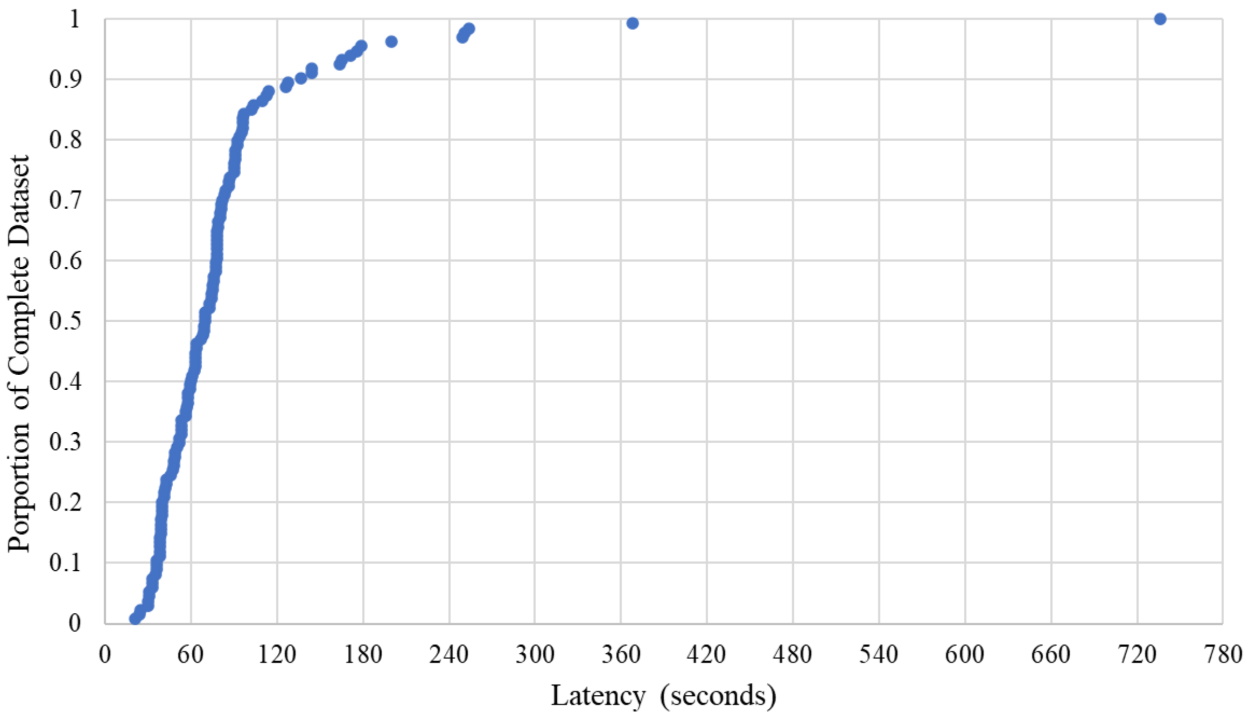


Figure 89. I35 NB/FM 78 Ramp Optical Sensing Site WW Email Alert Latency.

Thermal Camera Sensing Technology

Researchers obtained data for 761 WW events detected using Houston thermal camera equipment between March 2020 and July 2022. Of these alerts, 197 came from the I69 westbound/Kirby exit ramp site, and the remaining 564 came from the I610 eastbound/Broadway exit ramp site (see Figure 79 for site locations in Houston).

Figure 90 contains a breakdown of the thermal camera WW detections by ramp/site and subcategorical type. Researchers' first review of these site data revealed very high numbers of uncorrected WWD events and vehicle backing activity at ramp EB-31 (I610 exit to Broadway) and high bicyclist activity at ramp WB-126A (I69 exit to Kirby). A more detailed review of the photo documentation of each WW event at the EB-31 site showed that a small handful of vehicles accounted for most of the uncorrected WWD events and vehicle reversing activity on the frontage road. Motorists were not responsive to the activated border-illuminated WRONG WAY sign and event-related illumination (for improved nightime photo of WW vehicles) since they were deliberately driving the WW or reversing on the frontage road as a "short cut" from a minor cross street to an upstream residential complex driveway. To prevent this dangerous activity from biasing the dataset for the research effort, especially when it comes to documenting driver response to WW warning equipment, all data from site EB-31 were not analyzed further.

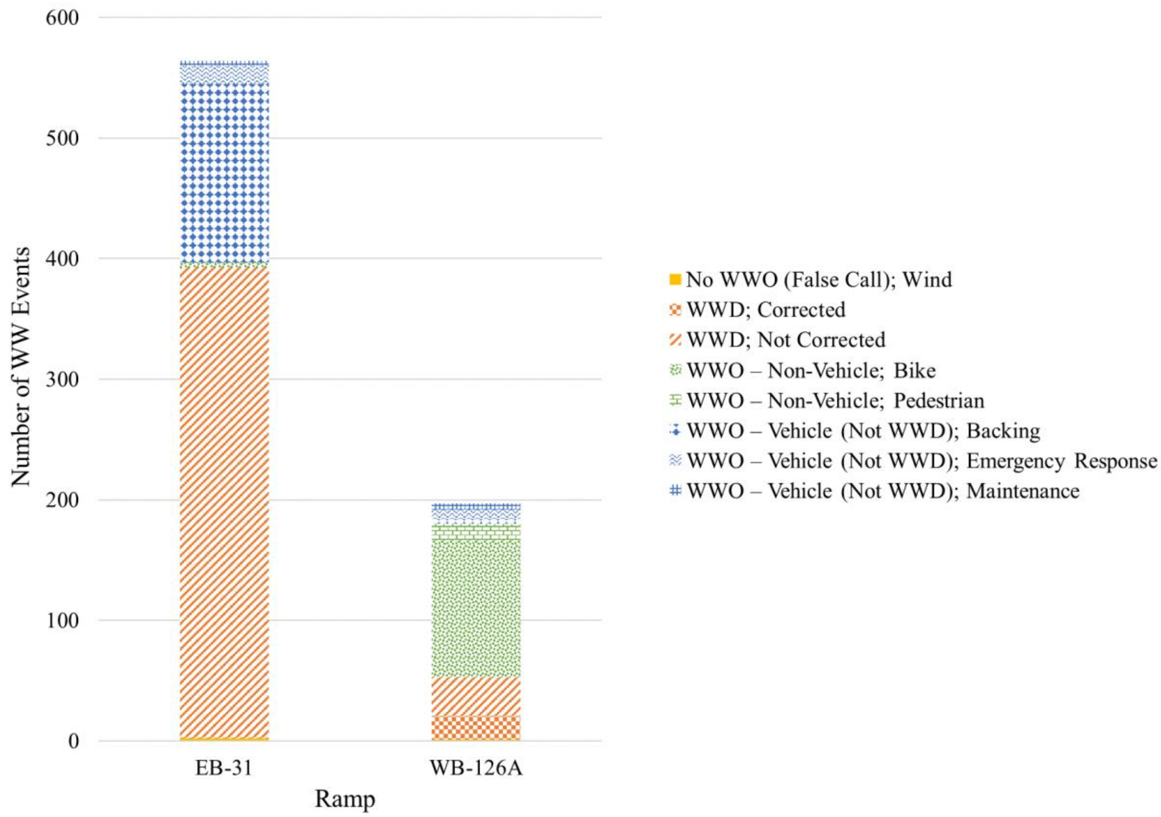


Figure 90. Houston Thermal Camera Sites by Type of WW Detection.

With data for site EB-31 (564 WW alerts) removed from the dataset, the remaining 197 WW detections occurred at the WB-126A ramp. A more detailed review of these thermal camera site data by major category (see Figure 91) showed that 64 percent of WW detections were bicyclists or pedestrians mostly using the frontage road sidewalk. These are not considered false calls since a WWO was genuinely approaching the sensing equipment. Twenty-six percent of detections were WWD events, with more WW drivers not correcting (32) than correcting (20) their behavior (details in Figure 92). Nine percent of WW detections were maintenance or enforcement vehicles (not considered WW drivers), and 1 percent were false calls.

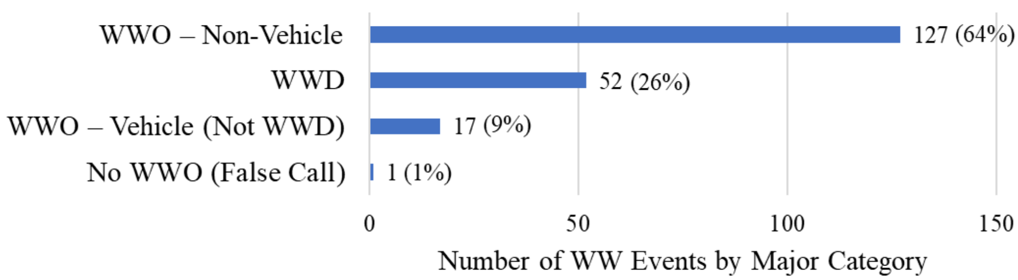


Figure 91. I-69 WB-126A Ramp Thermal Camera Site WW Events by Major Category/Type (Filtered).

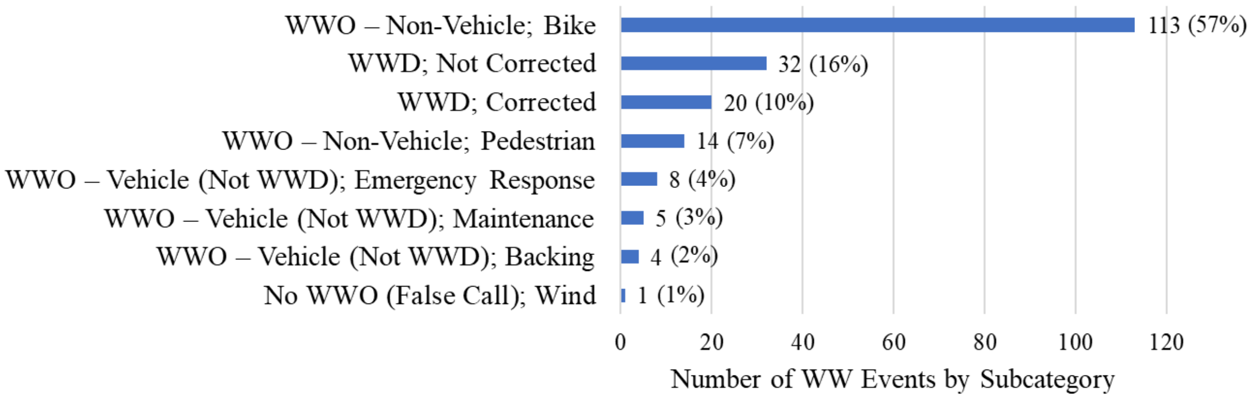


Figure 92. I69 WB-126A Ramp Thermal Camera Site WW Events by Subcategory/Type (Filtered).

The WW alert email latency for the thermal camera system is documented in Figure 93. Sixty-one email alerts were available from TxDOT staff archives. No email information for the remaining 136 alerts was available (i.e., records for these alerts could only be pulled from TAPCO®'s BlinkLink® event management software). The average email latency was 30.25 seconds, while the median value was 29 seconds. The standard deviation was 17.54 seconds. The 90th percentile latency was 53.8 seconds, indicating that the time elapsed between the occurrence of the WW event along the ramp/frontage road and the receipt of the email warning alert by TMC operators was less than a minute over 90 percent of the time.

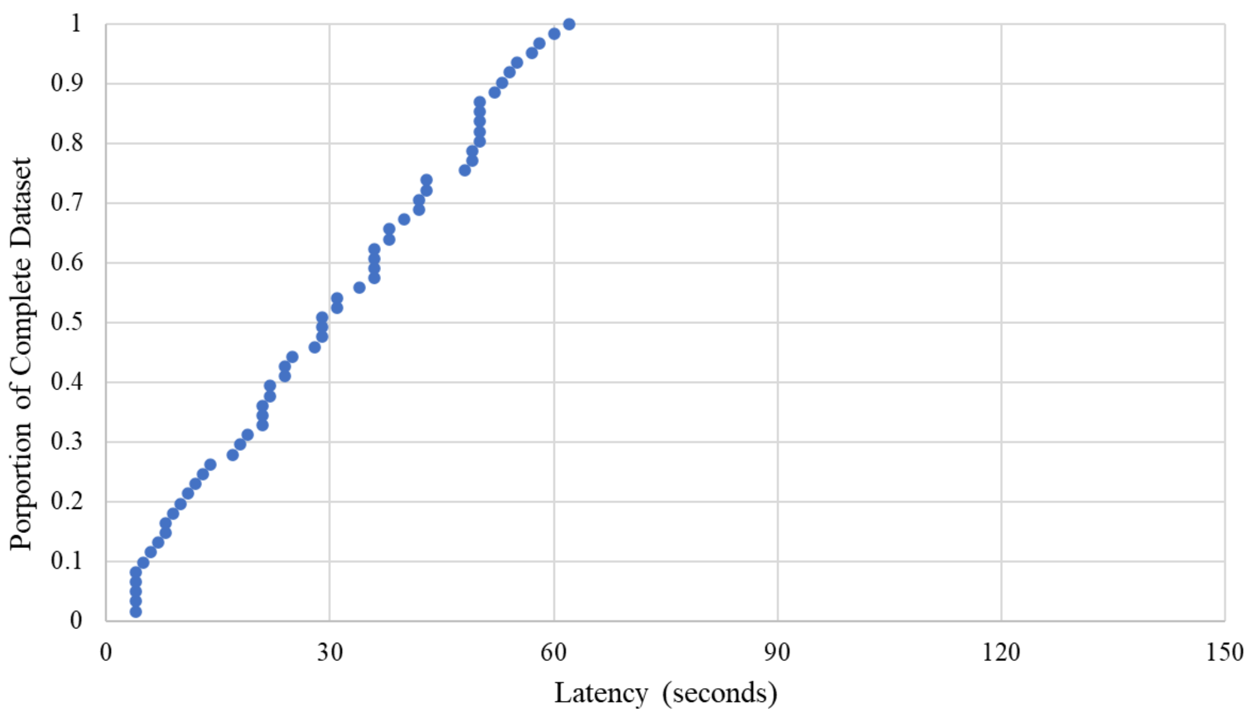


Figure 93. I69 WB-126A Ramp Thermal Camera Site WW Email Alert Latency.

WWD DRIVER BEHAVIOR AND CHARACTERISTICS

To better document and characterize WWD activity in Texas, researchers extracted the genuine WWD event data from the three successful tests used in the field evaluation and categorically summarized the events. The number of WWD events by technology are provided in Figure 94 and indicate that the highest count of events occurred during the ISS field test on the I35 northbound exit to FM 78 in San Antonio.

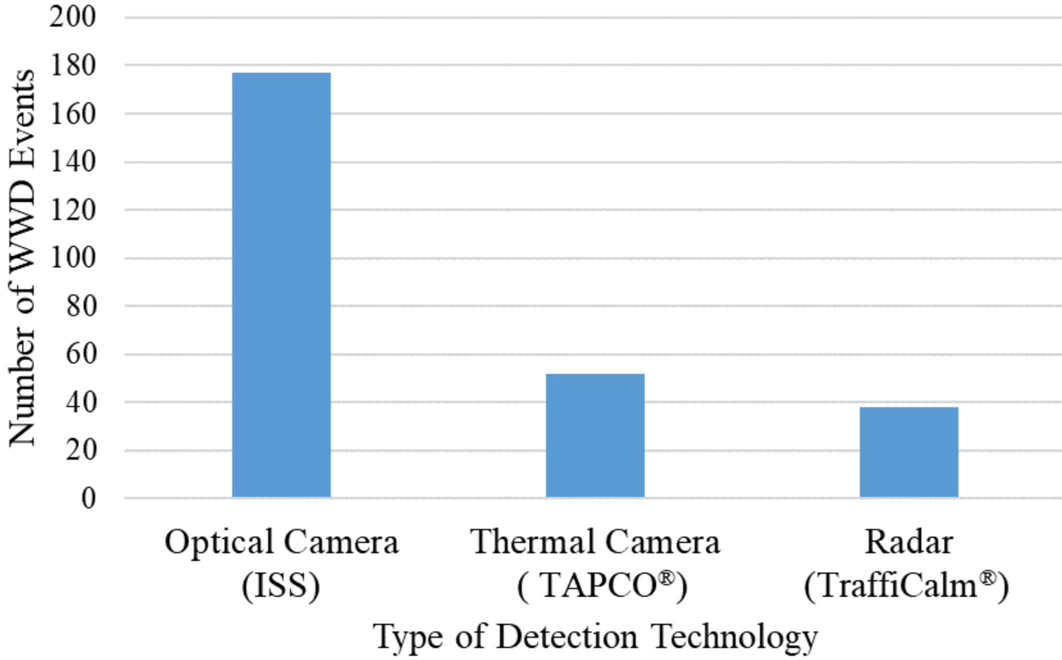


Figure 94. Texas Field Test WWD Events by Detection Technology.

Temporal characteristics of WWD events by day of week and hour of day are provided in Figure 95 and Figure 96, respectively. The figures reveal consistent findings with WWD behavior observations in Texas over the past decade. WWD activity tends to be higher on weekends compared with weekdays, and WWD events are much more common at night, with peaks between 8:00 p.m. and 10:00 p.m. and again when businesses that serve alcohol in Texas close at 2:00 a.m. The relatively high number of Monday WWD events includes situations where drinking likely began on Sunday night and continued into early Monday morning. The time lag introduced into the data set caused by the WWD event occurring after the associated drinking takes place is also noted for mid-week drinking on Wednesday night–Thursday morning, where the WWD activity occurs early on Thursday within several hours after midnight. Distribution of WWD events by month was not analyzed because the number of active WWD sensing sites was not consistent across each month of the year.

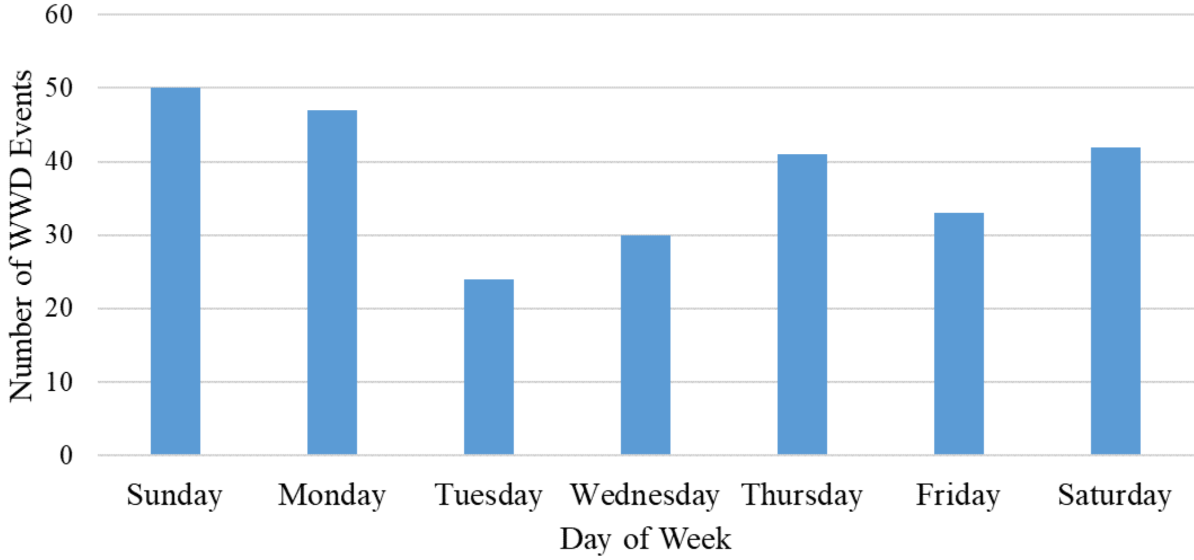


Figure 95. Texas Field Test WWD Events by Day of Week.

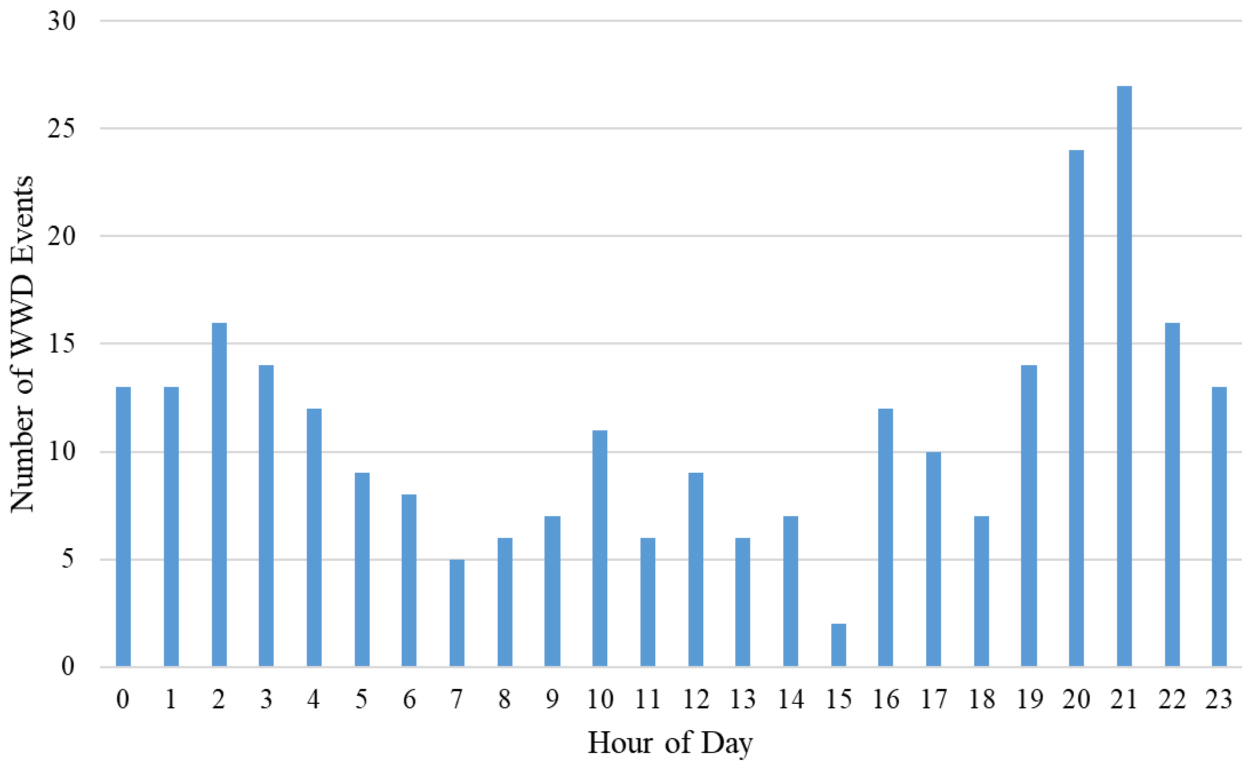


Figure 96. Texas Field Test WWD Events by Hour of Day.

WW driver behavior in response to active WW warning (i.e., 10 TraffiCalm® sites on I35 in northeast San Antonio and one TAPCO® site in Houston) is provided in Figure 97. Slightly more than half of WW drivers (51 percent) did not correct their WWD activity along the ramp or frontage road. Forty-nine percent of WW drivers corrected their behavior either by making some form of U-turn maneuver or stopping. For this subset of the data, there were no WW drivers' response actions that could not be determined using the video or photos available from the in-field WWD monitoring equipment.

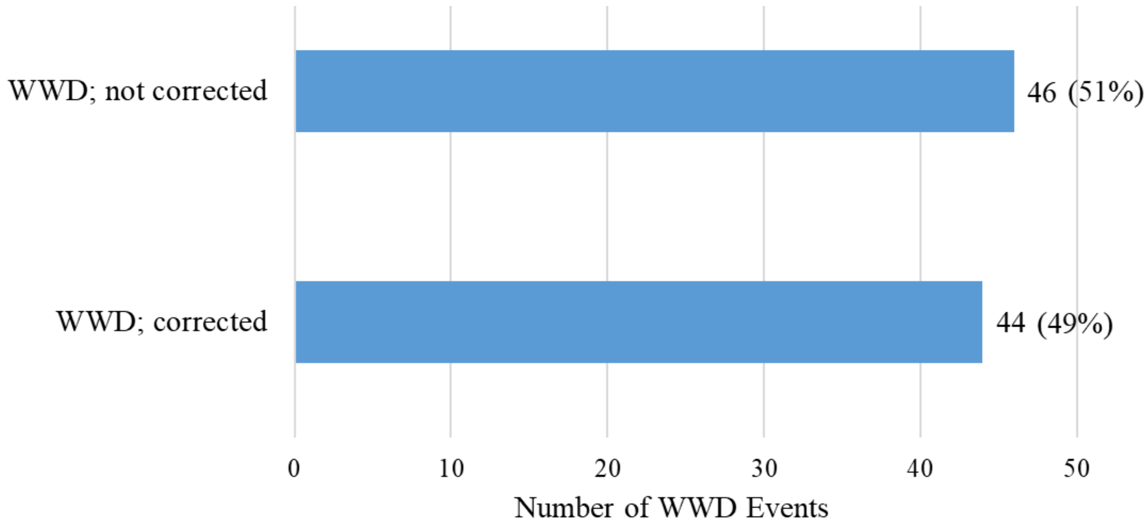


Figure 97. Texas Field Test WWD Events by Driver Response.

SUMMARY

The WWD detection equipment field tests conducted as part of this research investigation, while not definitive due to their limited scope, do provide meaningful insight into the practical application of the technologies. Situations where WWD sensing equipment must be deployed along a ramp or frontage road where parking lot or significant driveway activity occurs in close proximity to the road may result in a higher detection rate of vehicles that are not related to WWD with radar equipment due to the broadcast nature of its technology. However, at sites where shadows could confound optical detection equipment along east/west roadways in the morning or evening, radar technologies may be preferred.

All three technologies tested in the field (i.e., radar, optical camera, and thermal camera) proved that they can reliably sense a WW vehicle and that their control systems are capable of quickly providing an alert to TxDOT TMC staff. In one of the field systems tested, the manufacturer provided a third-party filtering service to review detection events and determine if a genuine WWD event was taking place. This resulted in a slight delay in transmittal of the WW alert email but a higher confidence rate on the receiving end at the TMC that a true WW driver was detected. However, the system that used a third-party filtering service still produced false calls. As accurate and reliable as the detection technology itself may be, each event must ultimately be reviewed by TMC/responsible agency staff before a response can be initiated. Whether this is done in part by the device provider/manufacturer, a third-party reviewer, and/or TMC staff—and where the time is invested to validate WW events—is up to system designers from the responsible agency.

The WWD detection equipment field tests revealed the need for ongoing maintenance of WWD detection technology. Since maintenance vehicles are routinely detected by WWD equipment such activities could be integrated into routine equipment testing to ensure systems are detecting WW drivers. In addition, high false call rates at some sites could possibly be addressed through sensor recalibration or equipment re-positioning. Field tests also exposed the issue of repeat drivers deliberately driving the WW or reversing down the road as a “short cut.”

Genuine WWD events documented at the field tests occurred mostly at night between 8:00 p.m. and 10:00 p.m. or around the 2:00 a.m. hour when businesses that serve alcohol in Texas close. The relationship between impaired driving and WWD is well established in the literature and is effectively reinforced with the findings from these real-world tests. At field sites where LED border-illuminated WRONG WAY signs were deployed in an active mode, 49 percent of WW drivers performed some form of corrective action. These findings provide support for a general WWD detection system design that includes an active signing element to immediately warn drivers of their WWD behavior in the hope that risks to the WW drivers and downstream right-way motorists can be mitigated with this relatively low-cost detection system feature/enhancement.

CHAPTER 5: GUIDANCE AND DRAFT SPECIFICATION

Based on information obtained from the literature review and state of the practice, as well as lessons learned from closed-course and field testing, TTI researchers prepared guidance material for practitioners to use when selecting and installing WWD detection technologies. Researchers also recommended language for future technical specifications for WWD detection systems that can be used by TxDOT to develop or revise applicable specifications, standards, and department policies.

GUIDANCE

The guidance provided in the following sections includes information about specific WWD detection system components, installation and initial testing, training, operations and maintenance, and site-specific and cost considerations that practitioners should take into account when determining the most appropriate system for a particular location.

System Components

The following sections contain guidance about detection technologies and algorithms, communication, notification to agencies, warning to drivers, software, mounting structures, and power sources.

Detection Technologies and Algorithms

Detection technologies and algorithms are inexorably linked in WWD detection systems. Any given detection technology may operate at different levels of accuracy and reliability depending on the algorithm—or how the information from the sensor is processed and interpreted. Most manufacturers consider their algorithms to be trade secrets and the key to surpassing the competition. However, understanding the basics of different detection technologies may help implementors choose more appropriate systems depending on the physical and geometric characteristics of the site. In simple terms, the detection technology is the sensing component of the system that searches for and identifies objects and their path. Algorithms then determine the direction of the object's path, verify that the object is of interest and going the WW, and trigger a WW alert based on the information.

There are many types of sensors and cameras currently used in WWD detection systems. The most common are radar, thermal cameras, optical cameras, and IR cameras.

Radar technology has been used in WWD detection systems since the early 2000s. These sensors emit long wavelength electromagnetic waves and measure the time and frequency of the waves reflected back to the sensor by objects. The processors on these devices can determine the distance and velocity of the object based on the reflected waves. Thus, radar detection technology can locate vehicles and determine if the object is traveling the WW. Early applications of single-unit radar systems produced high false call rates since objects close to radar sensors were detected (e.g., wildlife or noise in the reflected waves to the sensor). Most current systems that rely on radar for WW vehicle detection use multiple radar units or radar in combination with thermal and/or optical cameras. Even so, radar technology accuracy can be impacted by nearby traffic (e.g., adjacent ramps, parking lots, and driveways) and wind.

Thermal cameras detect infrared energy (heat) and convert it into a visual image. Since thermal cameras do not use visible light, they can identify objects in dark conditions. While a thermal camera can be used by itself to detect WW vehicles, thermal cameras are unable to provide color photographs/video of the vehicle. Thus, many WWD detection systems use thermal cameras in combination with optical cameras for monitoring. Thermal camera accuracy can be impacted by vibrations caused by wind.

Optical cameras capture frames using the visible light spectrum and are generally referred to as a “camera.” The most common use for optical cameras is for monitoring the WW vehicle and capturing photographs/video of the WW vehicle once detected. Optional illuminators (visible or infrared light) may be needed at night to illuminate the WW vehicle such that vehicle details can be identified. Optical cameras by themselves are not commonly used for WWD detection because they are prone to headlight flaring and reduced visibility in low light conditions. Several WWD detection systems combine optical and IR cameras so that WW vehicles can be detected during the day and at night.

IR cameras visualize shorter wavelength infrared light than thermal cameras and rely on reflected infrared light from the camera’s corresponding infrared emitter. Therefore, the clarity of the IR camera image is dependent on the strength of the emitter and short wavelength ambient infrared light. Since IR cameras rely on reflected light and short wavelength ambient light, these cameras may experience headlight flaring and reduced vision from weather effects. IR cameras are typically combined with optical cameras to provide improved detection under low light conditions.

Most of the systems tested as part of this research project included either multiple detection technologies or more than one of the same type of detection technology and at least one optical camera for capturing an image of the WW vehicle. Agencies should consider systems that use redundant detection capabilities to minimize false calls.

While not tested due to manufacturer/provider availability, some additional detection technologies are being developed by manufacturers, including lidar. These sensors utilize reflections from laser pulses emitted by the device to determine the location of objects and compare the location between pulses. These devices can identify objects as vehicles and the path of vehicles but cannot determine color photographs/videos of a vehicle. As with any type of system, there are generally continued development efforts to improve the capabilities, accuracy, and reliability. System improvements can include advances in detection technologies or overlap of technologies. As indicated previously, technologies are married to algorithms, and the two aspects of the system are difficult to separate. System improvements may also include enhancements to the perception and use of information seen by the detection technologies.

The proper setup of a WWD detection system at any given site requires much more than just the physical installation of the equipment. Both methodical physical installation and software configuration of the system via manufacturer specific proprietary software is critical. Perhaps the most important part of system configuration are the zones, or areas of detection, that are being actively examined by the detection technologies for the presence of vehicles moving in the wrong direction.

Most WWD detection systems rely on an expert user to configure the detection zones via proprietary Windows software or web-based interface. The number of zones and associated algorithms vary but in general the zones are used to detect WW vehicles, activate warning devices, confirm a WW vehicle detection, and trigger alerts to the transportation agency. Redundant detection zones can improve the reliability and accuracy of the WWD detection system. Most WWD systems tested can be configured locally or remotely using proprietary software and use edge computing to process the information received from the detection hardware to detect WW drivers.

Communication

WWD systems consist of several components and must establish and maintain communication between these components for proper system operations. Therefore, a critical component of WWD detection systems are the communications capabilities. There are two communication aspects, both of which are equally important to the overall operations. The first aspect, local communications, is the mechanism used for the exchange of information between system components at the site. The second, external communications, is the mechanism used to convey the results of the local system intelligence (the algorithm and its interpretation of detection technologies) to a remote location for review and action by system operators.

There are two types of local communication that are used by WWD systems to link the various components and enable local communications between the system components, either hard-wired or wireless. Hard-wired requires physical wire connections between the various components at the site, while wireless communications require installing secure wireless communication mediums, such as transceivers, to link the various components at site and enable communications between them.

Most WWD systems also support wired and wireless options for external communications. One of the wired options for external communications can be a transportation agency's fiber optic network if the fiber extends to the location where the system is installed. However, most transportation agencies use the wireless option, which in most cases utilizes the cellular network to provide external communications to the WWD system. Cellular communications typically require the addition of a cellular modem and router to link the various components of the WWD detection system to the internet, send alerts to the transportation agency, and provide remote access to system components to enable remote configuration and monitoring of the system.

Notification to Agencies

At a minimum, WWD systems should send email alerts to transportation agencies. The email should contain the date, time, location, and any malfunction codes for all detections. The email should also provide video and/or a sequence of still photos necessary to determine whether the wrong-way driver self-corrected or continued onto the facility. Some agencies prefer videos over still photos since it can be difficult to assess whether multiple vehicles are going the WW, if the vehicle self-corrects, and/or the cause of a false call from still photos. Optional illuminators (visible or infrared light) may be needed to illuminate the WW vehicle so that photos/video can uniquely identify the vehicle (e.g., color, type, and size). This information can then be shared with law enforcement to aid them in identifying and stopping the WW driver. The transportation agency should retain a full archive of all WWD email alerts (including photos and video) that can be analyzed for reliability and false call rates. Other communication methods for notifications include SMS, phone calls, advance traffic management system software, and proprietary software.

Warning to Drivers

WWD systems should be capable of activating traffic control devices that warn WW drivers (e.g., flashing beacons or flashing lights around the border of WRONG WAY and/or DO NOT ENTER signs). The system needs to be able to flexibly manage border-illuminated signing, including active and passive sign illumination and combinations thereof.

Some WWD systems provide the ability to communicate directly with DMSs. However, due to the number of non-genuine WWD events and false calls, researchers recommend that the transportation agency receive and verify the alert first before posting to a DMS. Some systems also transmit alerts via connected vehicle technology to warn right-way drivers in their vehicle. However, it is unknown how many vehicles currently receive and display such information.

Software

As discussed previously, each manufacturer and/or system is likely to have its own proprietary software. It is often challenging to compare two or more software products head-to-head. While one software application may have more capabilities, others might have a better user interface or experience, more refined analytics, or integration capabilities with other systems. For this reason, software comparisons will typically focus on the fulfillment of core requirements. This makes the identification of these core requirements an important consideration in the overall specifications released for system acquisition. Areas of core requirements that should be considered include configuration of devices and zones, the overall user interface, data acquisition, logging, and storage as well as performance metrics for system operations and communications. There are numerous additional areas of software that could be identified and inserted into requirement as necessary to support the specific needs of the agency or site.

The other aspect of software that is important to consider is its longevity and cost structure. Given the continued evolution of both computer hardware and software, it is unreasonable to expect any manufacturer's software to run forever. In most cases, manufacturers do not control the base operating system on the computer hardware executing the WWD applications. However, operating system changes made to these computers can impact the performance of the WWD application software. Agencies should expect a reasonable timeframe for supported software from the manufacturer/provider, which should be explicitly stated in the system requirements (specifications).

The other aspect of software that must be considered is cost—specifically recurring costs. Many manufacturers are now placing their software in the cloud, using third party-hosted systems, which incurs fees to the manufacturer/provider. While it is entirely reasonable to expect a provider to build in the costs of this cloud hosting into their pricing, they cannot do this in perpetuity. It is therefore unreasonable for an agency to expect manufacturer software in the cloud to be available and upgraded with no support timeframe identified. Detailing these explicit expectations of timeframes in the requirements is the only mechanism to avoid future issues and unidentified costs.

One other software item to be aware of is the developing "subscription model" for software services. Many commercial products in the office space environment now use this model, which leads to recurring costs, typically on a yearly timeframe. Non-payment of the recurring costs leads to suspension of access to the software, and in some cases to the data contained in, or developed by, the software application. System requirements must state that providers disclose any software subscription model so that operating costs for a reasonable timeframe can be either paid up-front or identified in the agency for reservation to protect the operations of the field sites.

Mounting Structures

WWD detection technology needs to be mounted to a sturdy structure to reduce false positives due to movement of the detection equipment (e.g., pole movement caused by wind). Thus, each deployment site will require a sturdy mounting structure on which equipment can be placed and expected to operate in the roadside environment. Several possibilities exist for mounting structures, including but not limited to steel or aluminum poles, traffic signal poles, overhead sign bridges, and cantilever sign bridges. Depending on the location of permanent infrastructure, existing mounting structures may not be available at the desired locations. In this case, new permanent infrastructure may be required. Staff should consult the TxDOT standards and manufacturer requirements to determine an appropriate local solution based on the system components (number of sensors/cameras, cabinets, solar panels, etc.), pole height, and wind loading. Foundation requirements, such as placement depth, will change based on the system components.

The use of luminaire poles as a mounting structure is discouraged. Most luminaire installations operate on either photometric sensors or timers and do so in chains or gangs, meaning that power is not constantly available. The arrangement of the sensors and timers typically relegates the site to solar power, which is problematic due to the additional weight and wind load placed on the structure. Additionally, equipment such as cameras or other detectors that require a firm structure will be operationally compromised on a luminaire.

Power Sources

Provisioning a field site for a sustainable and future-proofed power solution requires careful analysis of equipment, locations, and power generation and storage. All sites, regardless of the structural and cabinet solutions, must be powered by either permanent (also known as utility power) or solar power. While utility power can cut down on the equipment necessary at each site and removes a significant maintenance item in battery upkeep and replacement, the cost of utility power interconnects is highly variable depending on the difficulty of accessing existing utility infrastructure. Utility interconnects are also time-consuming to accomplish and can significantly delay implementations.

Site installations utilizing solar power are much quicker to deploy than utility-powered sites, but they require careful planning from several different considerations. The battery storage solution must account for the total amount of power draw for all equipment at the site, both at initiation and constant operation. Additionally, the provision for the number of batteries must handle not only the constant load, but a fair amount of reserve power. This is typically referred to as site autonomy or site power autonomy. Solar-powered sites cannot count on quality solar energy every day and must often run for several days on battery reserves. Many areas of Texas have significant cloud cover for months at a time during the fall and winter months and the need for sufficient reserve power can be significant. The question of how many days of reserve power to provide is a balance between cost and the reliability need of the equipment at a site. Incremental time running on batteries can be achieved through additional battery banks, but that reserve costs money in terms of cabinets, batteries, potentially additional panels, and increased complexity at the site. Given typical cloud cover in many parts of the state, a typical reserve battery life expectancy might be chosen at 7–10 days for a site with a small equipment load. A fully loaded site that includes more equipment may only be reasonably equipped to provide 3–5 days of reserve power. It is expected that manufacturers/providers should be able to supply different levels of site autonomy based on the configuration of the type and number of batteries. System specifications should explicitly detail the requirements for autonomy and should consider agency implication such as asset uptime reporting when determining those requirements.

Once autonomy needs have been established, a careful analysis of the entirety of the solar power solution must occur for the proper operation of these types of field sites. Larger cabinets may become necessary if upgrading site locations by adding additional batteries or adding or replacing the solar panels. Additionally, more power infrastructure will likely lead to a significant increase in project and labor costs. Staff must carefully consider the placement of the solar panels to account for different sun positions and avoid shadowing from the surrounding environment, which will limit the solar energy available.

Solar power is also a resource that benefits from careful monitoring. Sites should consider implementing solar power monitoring equipment, which can remotely detail voltages throughout the power system and the current battery loads. Installers can use these data to monitor site performance more accurately and to proactively recognize and address situations such as troubleshooting and battery replacement forecasting.

Finally, installers must plan for the proper current and voltage from the installed power source to the equipment. Most ITS equipment now operates on POE, which requires different solutions and wiring than non-POE sites. The detection and edge computing equipment typically requires Direct Current (DC) for power. Some sites may benefit from other power options, such as a 120V AC duplex outlet for temporary maintenance equipment usage.

Installation and Initial Testing

Transportation agencies should require the WWD detection technology/system manufacturer/provider to be onsite during installation (not just the agency's installation contractors). This will help ensure that the system is installed, configured, and calibrated properly.

Once the equipment has been installed, calibrated, and activated, the system should be tested during the day and at night. This will require the exit ramp to be closed. Proper approvals and temporary traffic control should be obtained and followed. Testing procedures vary around the state but usually include having the WWD test vehicle traveling at different speeds (e.g., 10 mph and 60 mph [or as a high speed as can be accommodated on the ramp safely]) and using several different paths (e.g., left side of ramp, right side of ramp, and centered in ramp) in combinations to ensure WW vehicles can be accurately detected under varying operational scenarios. Dependent upon the paved shoulder width, some test runs should include driving partially or completely on the paved shoulder. Staff should ensure that the WWD detection system is functioning properly, including detecting WW vehicles, activating signs that warn WW drivers, and sending notifications with still images and/or videos to the transportation agency.

A test vehicle should drive the WW up the ramp a minimum of 10 times in each lighting condition, with only a minimal number of false or missed detections (one or two) before repositioning/recalibrating the detection equipment and restarting the testing procedure. Once a minimum of 10 successful detections and notifications of the WW vehicle is received by the transportation agency during the day and at night (with the last five successful tests being consecutive), the equipment is considered accepted and ready for operations. As part of the testing, staff should also verify that the system is appropriately ignoring vehicles traveling in the correct direction. If the system passed one lighting condition and failed the next (e.g., passed daytime testing and failed nighttime testing), the testing team should talk with the manufacturer/provider on site to determine if the adjustment made to pass the different lighting condition will impact the alternative lighting conditions. Agency staff should use their engineering judgement to determine if the other lighting condition requires retesting.

Agencies may need to consider an extended evaluation period prior to final acceptance to ensure the system experiences a wide variety of operating conditions and responds appropriately.

Training

The manufacturer/provider of the WWD system should provide manufacturer-approved end-user training to the transportation agency and its representatives. The training should include instructions in the operation and maintenance procedures of the system and should cover the following training material at a minimum:

- Hands-on operation and monitoring of the system remotely.
- Explanation of the system functionality and usage.
- Required preventive maintenance and equipment servicing procedures.
- Usage of diagnostic software, system reporting, and operational logs to identify problems and troubleshooting procedures.
- Detailed documentation manuals of the various components of the system and training course materials (hard copy or electronic).

Operations and Maintenance

WWD detection technology from several manufacturers has been in use in Texas for up to 10 years, and lessons learned from this operating experience, the literature review, and the state-of-the-practice are summarized in the list below:

- For every 10 detection systems in the field, at least one knock-down or vandalism event will occur per year for pole- or sign-mounted WWD detection systems. Having a reserve set of equipment in the district’s signal shop can help ensure limited downtime for sites with damaged or missing equipment.
- Solar power system storage batteries will degrade slowly over time, and allowance should be made for battery replacement at least every 2 to 5 years to ensure adequate power.
- False calls can be caused by a variety of factors, including but not limited to equipment vibrations due to wind, dark shadows, headlight reflection on wet pavement, queued traffic on ramp, commercial vehicle traffic on the frontage road

(traveling in the correct direction), vehicular movement within parking lots along the frontage road, vehicles exiting parking lots or side streets (whose motion was typically perpendicular to the frontage road and/or sensor), and insufficient minimum tracking distances. False call rates increase over time as the technology ages and/or the surrounding environment changes. Transportation agency staff should either be trained in repositioning and calibrating the WWD detection systems so that this service can be performed every 3 to 5 years, or allowances should be made with a contractor or the system manufacturer to have this service performed.

- WWD detection systems will detect WW objects that are not genuine WWD events. Examples include pedestrians, animals, bicycles, maintenance vehicles, and emergency services. Since these objects are approaching the sensor in the wrong direction of travel, they are not considered a false call.
- Routine ramp maintenance activities, especially street sweeping and mowing, present a unique opportunity to test WWD detection system operation. Street sweeping and mowing usually involves travel in both directions on a ramp (or in the vicinity of the ramp) to ensure maintenance covers the width of the ramp and, by its nature, involves a temporary ramp closure. Street sweeping activities, in particular, are typically performed at night to minimize traffic impacts, and nighttime is also the low-light condition under which detection system accuracy should be assured (i.e., WWD frequency is usually at its greatest at night). If TMC staff are aware of street sweeping or mowing on ramps, they can anticipate the upcoming WWD detection system calls, record if ramp maintenance did not result in WWD calls (as expected), and schedule WWD detection system maintenance to identify and resolve any issues. Other types of maintenance vehicles and emergency response vehicles can be used to verify whether the WWD detection technology is functioning properly.
- WWD detection systems should be designed and installed with the understanding that long-term maintenance will incur costs that are necessary and recurring. An issue is whether TxDOT staff will be trained to perform these tasks or if the responsible district will establish a maintenance agreement with a contractor or the provider to maintain the WWD detection equipment and ensure proper everyday functionality. If maintenance is a contracted service, it will be necessary to identify a funding source that will cover this expense on an annual basis, understanding that these costs will increase with the age of each system, the number of systems installed, and if the district's WWD countermeasure program includes systems from multiple manufacturers.
- At some point legacy systems will need to be replaced. This typically occurs when the various suppliers of the system components quit manufacturing parts and the provider can no longer acquire parts for continued repairs. The timeframe for this inevitable need is unknown and may be largely out of the provider's control. However, agencies can, and likely should, specify a minimum expected operating

timeframe for the system such that a lengthy field shelf life is readily achievable. These timeframes also relate to cost considerations for the agency from both an operational and maintenance perspective.

Site-Specific Considerations

Operating experience from TxDOT districts around the state has contributed to a body of knowledge that can be considered useful lessons learned to guide future implementations of WWD detection and warning systems. Guidance related to site-specific concerns regarding exit ramp (and potential WWD countermeasure) operating environment and design are below.

Proximity to Other Ramps and Intersections

Ramp design and proximity to other ramps affected several field sites' propensity/probability of higher WWD activity and complications with WWD sensor calibration and operation. At one field site, the exit ramp from a freeway was located side by side with an entrance ramp, and both joined into an at-grade interchange where a traffic signal was located. Several WWDs per month historically turned left off a one-way frontage road and into/onto the exit ramp on the near side of the intersection rather than tracking farther into the signalized intersection before making their left turn onto the entrance ramp (the exit ramp intersection approach and the entrance ramp departure were side by side). Intersection turning movement lane markings (also known as "cat tracks") were used to help reduce this activity (in addition to already present DO NOT ENTER and WRONG WAY signing), but a design geometrically separating the exit and entrance ramps terminals would eliminate a turning path error from becoming a WWD.

At this same location, the side-by-side nature of the exit and entrance ramps lead to an unexpected situation where shadows from right-way traffic on the entrance ramp cast shadows in the late afternoon across the exit ramp. To optical camera WWD detection systems, this shadow could appear as a WW vehicle along the exit ramp. If such a situation does exist in the field at a future WWD countermeasure deployment site, caution should be exercised in the selection of WWD detection technologies. If the detection technology at a location becomes subject to such issues, careful attention should be paid to sensor zone setup, filtering logic, and sensor calibration to prevent false calls caused by right-way traffic.

Intersections are a concern for WWD detection systems that have broadcast and reflection sensing rather than prescribed sensing zones. Fringe parking lot activity along frontage roads, activity along minor streets, and driveways intersecting frontage roads have caused false calls with radar WWD detection systems, though repositioning and recalibration of said field equipment has helped reduce false calls. In cases where an exit ramp is located along the frontage road near a downstream interchange, there is also the possibility that arterial traffic through the interchange could be picked up by broadcast sensing systems. Sensor positioning, sensitivity adjustment, and detection algorithm logic programming can also reduce false call rates in these conditions.

A final observation on site considerations is that despite public agencies' best efforts in roadway design and law enforcement, some deliberate WWD activity occurs in certain situations. On one Texas facility, WWDs traveled along the frontage road (with WWD detection equipment) because traveling the WW was perceived as more convenient than routing the correct way along the roadway network even though right-way travel requires a path no longer than a mile more to reach an apartment complex. This extremely risky driving behavior contributes to routine WWD alerts for the affected district's TMC staff, who cooperate with local law enforcement but have very limited resources and time in which to stop and cite the WWD. Public information campaigns and even focused materials for this area may have some benefit in reducing this type of WWD movement, but to date the WWD continues despite the active warning and alert systems in place.

Mix of Technologies

An agency may choose to install WWD detection systems on all ramps within a freeway corridor if the entire corridor is being widened or rehabilitated. In this case, roadway improvement project funding is used, and it is likely all exit ramps in the improved corridor will have WWD detection systems installed. However, if safety project funding is used, only one, or perhaps just a couple, ramps may have systems installed. This raises the possibility of having equipment of different detection system types and from different manufacturers, present on a single freeway corridor. Testing during this project has revealed that there are some field situations where one type of WWD detection system may be favored over another to minimize the potential for false calls. As a result, a mixture of WWD detection technology types can be reasonably expected within a corridor and, in turn, across corridors managed by the same agency.

What is less desirable from an agency and TMC operations standpoint is having systems from different manufacturers present in a single corridor. As there are no existing industry standards for TMC communications (i.e., WWD alerts, system power and maintenance alerts, etc.) with WWD detections systems, manufacturers typically have their own/independent software applications for communicating with field devices. This means that TMC operations staff must learn to use system management software from multiple manufacturers to be able to manage alerts (i.e., WWD and system status alerts) from their full WWD detection and alert management system. This circumstance is logically unavoidable with a long-term WWD countermeasure program, where different manufactures can introduce new and improved technologies for WWD detection over time (and each manufacturer has their own device interface software/platform).

However, if different ramps within a given corridor have different interfaces—a possibility if a manufacturer's devices are mixed for ramps in a corridor—an operator having to manage an active WWD event would face the potential challenge of having to figure out which manufacturer's application to use in a very short period of time (and recall extremely quickly how to use it) with competing communication needs with staff from other agencies (e.g., law enforcement dispatchers). This potential for delay and confusion is minimized if one manufacturer's interface is used within a given freeway corridor. Similarly for maintenance staff, having to allow for multiple manufacturers' equipment when maintaining WWD detection systems in the field would necessitate allowing for and carrying replacement parts from multiple manufacturers when performing field visits to a corridor.

Cost Considerations

As is evident from the discussions preceding this section, WWD detection systems have numerous areas of cost. Initial costs include the physical system complete with sensors and installation. Due to the specific engineering needs associated with each individual site, providers should not be expected to provide quotes without a detailed needs assessment and ensuring that their systems are a good match for the specific site requirements.

Maintenance costs are obviously a well-known item but can vary significantly by the type of technologies in use and the field site. Agencies should plan for reasonable maintenance costs based on experience and/or provider input.

Software costs were also discussed previously. The software landscape continues to change, and more cloud-based and subscription-based models are consistent with broader trends in the industry. This is a wholesale change for many operating agencies of WWD deployments. While operating agencies are not likely to be able to change the costs models, agencies should establish an explicit understanding of these new models and how they affect initial and long-term recurring costs so that WWD detection systems remain viable for public safety.

Finally, an often-overlooked cost component is training and/or retraining of agency personnel. While job movement and progression are standard and typically a good thing for operating agencies, that can lead to knowledge gaps in the acquisition, configuration, operation, and upkeep of WWD detection systems. These costs are not typically included in any specification requirements to providers, but they do need to be considered by the operating agency. Some specifications may allow for optional line items of provider retraining of agency personnel on an as-needed basis.

TECHNICAL SPECIFICATIONS

Researchers reviewed existing technical specifications to identify common elements that should be included in future specifications, tracing the history and assessing the portability of language from one specification to another. Table 8 provides recommended language for future technical specifications for WWD detection systems. The language is written to provide requirements and guidelines for performance-based descriptions and does not define specific system components;

this allows flexibility for multiple providers to develop systems with different components that can achieve the desired performance, and it allows flexibility for changes and innovations in future technologies.

Table 8. Recommendations for Technical Specifications for Future WWD Detection Systems.

GENERAL REQUIREMENTS	
Description	
	Furnish, install, relocate, or remove Wrong-Way Driver System (WWDS) at locations shown on the plans, or as directed.
Functional Requirements	
	Furnish a WWDS that provides a highly visible, enhanced warning for the purpose of alerting the wrong-way (WW) driver and proper authorities. Upon detection by system sensors/technologies of a WW driver, the system shall activate and flash all red lights and other local alert signs on separate pedestal poles simultaneously. The lights will flash synchronously and then cease operation after a programmable timeout. When shown on the plans or as directed, the WWDS equipment must also send alerts including visual confirmation to an application as well as e-mail and Short Message Service (SMS) alerts for all configured users. Ensure equipment is designed to protect personnel from exposure to high voltage during installation, operation, and maintenance. If 120 V AC /60 Hz power is not available and solar power must be used, ensure all components can operate on DC power so a power inverter is not needed.
Equipment	
General	
	Except as allowed for relocation of WWDS equipment, ensure all equipment and component parts are new and in an operable condition at time of delivery and installation. Ensure all WWDS within the project are from the same manufacturer. WWDS equipment is further classified by the type of functions they can perform. Provide WWDS that is compatible with existing infrastructure and software located in the Department's Traffic Management Centers (TMCs) across the state or as directed. Provide materials that comply with the details shown on the plans, the requirements of this Item, and the pertinent requirements of the following Items: • Item 618, "Conduit," • Item 620, "Electrical Conductors," • Item 622, "Duct Cable," • Item 624, "Ground Boxes," • Item 628, "Electrical Services," • Item 636, "Signs,"

	• Item 643, "Sign Identification Decals," • Item 644, "Small Roadside Sign Supports and Assemblies," • Item 656, "Foundations for Traffic Control Devices," • Item 687, "Pedestal Pole Assemblies," • Item 6006, "Electronic Components," • Item 6062, "Intelligent Transportation System (ITS) Radio," • Item 6063, "Intelligent Transportation System (ITS) Solar Power System," • Item 6064, "Intelligent Transportation System (ITS) Pole with Cabinet," and • Item 6304, "Intelligent Transportation System (ITS) Radar Vehicle Sensing Device."
Main Components	
	The WWDS should be provided as a system from the same manufacturer. The WWDS is composed of the principal items as shown on the plans, or as directed. Additional components as detailed for site-specific needs may be provided as detailed in plan. Standard components include: • WRONG WAY sign (R5-1a). • LED strips for flashing red lights when a wrong-way driver is detected. • Detector(s) for detecting wrong-way drivers. • Flash controller. • Power source for powering any lights and equipment. • Sign support and foundation. • Monitoring application for WWDS status configuration and wrong-way driver alerts. • Communication (local) between pedestal poles with LED Warning Alert Lights and the central pedestal pole containing the sensors, illuminator, and camera. • Communications (external) for system status, configuration, and alerts. • High-resolution camera with video capture capability for visual confirmation of wrong-way driver event. • White LED Illuminator for providing visibility during image capture at night. Ensure all equipment and components listed are new and in operable condition without defect at time of delivery and installation.
WRONG WAY Sign	
	• Provide WRONG WAY signs (R5-1a) and DO NOT ENTER signs (R5-1) with high-powered LEDs mounted to a pole assembly that must comply with Item 636 "Signs" and Item 644 "Small Roadside Signs and Assemblies" at locations shown on the plans or as directed. • The DO NOT ENTER and WRONG WAY signs must be of appropriate size in accordance with Standard Highway Sign Designs for Texas (SHSD) and Texas Manual of Uniform Traffic Control Devices (TMUTCD). • Sign must be standard 0.080-inch grade aluminum with reflective sheeting and meet the Texas Manual on Uniform Traffic Control Devices (MUTCD). The sign must be composed of a minimum of eight environmentally sealed, high-powered LEDs.

LED Warning Alert Lights	
	Provide high-powered LED Warning Lights in accordance with the following: • Consist of the minimum specified quantity of high-power, 1-W LEDs of the specified color. • High-powered LEDs must be visible at more than 1,000 ft during the daytime and more than 1 mi. during the nighttime. • All LEDs must be red and must be rated for 100,000-hr. life expectancy, have an operating temperature range of −40°F to 165°F (−40°C to +74°C), and be powered by a flash controller. • Ensure wiring on backside of sign is environmentally sealed for protection against weather and tampering. • Ensure the sign's LEDs are dimmable by a photocell sensor input or 6V solar panel to reduce night glare. • LEDs must be wired in strings to activate simultaneously according to TMUTCD standards. • LEDs must be wired in parallel electrically so that remaining LEDs continue to flash if any individual LED fails. • Wiring between LEDs must be encapsulated inside 1 inch × 3/8 inch aluminum extrusions secured to the back of each sign assembly to provide weather resistance, protection, and sign face rigidity.
LED Illuminator	
	Provide LED illuminator in accordance with the following: • Shall be triggered by the programmable wrong-way logic controller under specific adjustable conditions. • Shall be mounted to the WWDS detector pole/structure assembly. • Shall include a photodiode capable of determining ambient light levels. • Shall offer adjustable lenses to disperse light based on site-specific requirements. • Shall operate from 10 to 42 VDC. • Shall be constructed of polycarbonate and aluminum. • Shall be rated for outdoor use. • Shall operate from −40°F to 165°F (−40°C to +74°C). • Shall include IP67-rated connectors for power and trigger inputs.
Programmable Wrong-Way Logic Controller	
	Provide Programmable Advanced Communication Controller in accordance with the following: • Shall operate from −40°F to 165°F (−40°C to +74°C) • Shall operate from 10 to 42 VDC. • Shall analyze discrete inputs from multiple sensors. • Shall provide discrete relay outputs for each event, including sign activation and wrong-way alert event generation. • Shall indicate signal input and relay output status via LED indicators on controller, visible from cabinet for on-site testing and troubleshooting. • Shall indicate input/output status, device status including voltage and temperature, and any wrong-way application configurable. parameters via on-

	board web page, accessible from web browser when connected locally or remotely over network. • Shall allow manual activation of relay outputs to trigger events, including sign activation and wrong-way alert events, from on-board web page when accessed locally or remotely over network. • Shall allow updating of controller settings, firmware, and wrong-way application programmable logic from on-board web page, accessible locally or remotely over network. • Shall include a minimum of one (1) integrated RS-232 communications port. • Shall include a minimum of two (2) 10/100 Base Ethernet ports, capable of independent operation on isolated networks. • Shall support common communication protocols, including TCP, hypertext transfer protocol (HTTP), and simple network management protocol (SNMP).
Sign Support and Foundation	
	If mounting the WWDS on an existing sign support, ensure the system is sized appropriately and is able to withstand the maximum wind load defined in the Department's basic wind velocity zone map standard without any damage or loosening from structure.
Primary Enclosure	
	The primary enclosure shall meet the following: • Be aluminum NEMA 3R type vented enclosure. • Be able to be pole-mounted. • Be constructed of 0.125-inch aluminum. • Be sufficiently vented. • Be designed with screening to prevent insects and other debris from entering. • Be installed with Number 2 Corbin lock and tamper-resistant hinges.
Detectors	
	General: Program detectors to provide trigger outputs only when a wrong-way driver is detected traveling between 2–3 mph to 100 mph. Radar Detector: Unless otherwise shown on the plans, or as directed, provide Radar Vehicle Sensing Device (RVSD) in accordance with Intelligent Transportation System (ITS) Radar Vehicle Sensing Device Statewide Special Specification. • Ensure RVSD does not require tuning or recalibration to maintain performance once initial calibration and configuration is complete. • RVSD must not require cleaning or adjustment to maintain performance. • RVSD must self-recover from power failure once power is restored. Thermal Detector: Unless otherwise shown on the plans or as directed, provide thermal imaging cameras and sensors for detection. The thermal detector shall be capable of detecting and distinguishing a variety of moving targets including vehicles, motorcycles, and bicycles without headlights in operation. The detector:

- Shall be able to visualize zones and fields of detection.
- Shall be protected from reverse polarity power connections and power surges and comply with part 15 class A of FCC rules.
- Shall have a IP68 housing that is weatherproof, Ultra-Violet (UV)-resistant, and protected from water intrusion.
- Shall detect vehicles up to 300 ft.
- Shall be long-wave infrared (7 to 14 mm).
- Shall have a focal distance between 7.5 mm and 19 mm.
- Shall have a horizontal field of view between 25 and 90 degrees.
- Shall have a vertical field of view between 19 and 69 degrees.
- Shall be able to program at least eight zones.
- Shall be able to be programmed via an Ethernet communication using a Windows-based software.
- Shall be able to push visual confirmation of configured detection zone(s) to user interface software.
- Shall meet NEMA TS2 shock and vibration.
- Shall operate from 10 to 42 VDC.

<u>Lidar Detector:</u>
Unless otherwise shown on the plans or as directed, provide lidar sensors for detection. Provide a lidar detector as specified:

- Shall have a 360° horizontal by 45° vertical Field of View (FOV) with a max detection range of 360 ft at 80 percent reflectivity and a maximum angular resolution of 0.18 inch horizontal and 0.35 inch in the vertical.
- Shall provide detector compatible with the management alert system.
- Shall provide minimum frame rate of 10 frames per sec.
- Shall provide enclosure that meets a minimum of IP67 and meet a minimum operating temperature range of −40°F to 165°F (−40°C to +74°C).
- Shall operate within a minimum range of ± 2 V of its nominal voltage.
- Shall meet requirements of International Electrotechnical Commission IEC 60825 Class-1.

Verification Technology

Provide a tracking camera that is compatible with the management alert system at the location specified on the plans or as directed. This tracking camera must have built-in machine-learning logic to recognize specified target criteria and the unusual direction of motion such as a wrong-way vehicle. Upon detecting motion contrary to the usual direction of motion, the camera’s intelligent video analytics must be capable of triggering an alarm if object enters a preprogrammed alarm field. Once an alarm is triggered, using its tilt, pan, and zoom capabilities, the camera’s visual imager must be able to track the vehicle keeping it focused and within view as it approaches, passes, or departs from the camera’s point of view.

- The camera shall use noise suppression or comparable technology for color clarity in low levels of ambient light.
- For further clarity in low levels of ambient light the camera must have the ability to combine with a compatible IR detector to enhance image contrast.

<table>
<tr><td></td><td>

In situations where the camera’s view contains bright and dark areas, the camera must have technology to combine multiple images at varying shutter positions and exposure times to produce a single image removing over and under exposed areas.
The tracking camera must comply to Impact Protection (1K) 10 rating for impact resistance and to the IEC 60068 standards for vibration and shock. The camera must meet environmental protection IP68 for dust and immersion test.
The camera must comply with NEMA Type 6P enclosure rating and pass the American Society of Testing and Materials (ASTM) B117 salt spray test.

Additional specific camera requirements include:

Shall provide HDTV 1080P with WDR up to 60 fps.
Shall have an enclosure that is IP66 NEMA 4X-rated.
Shall comply with part 15 of the FCC rules.
Shall have a shutter time of 1/6 sec to 1/24 sec.
Shall have a minimum of one input and one output.
Shall be programmable from Windows-based software.
Shall be programmable remotely via application software.
Shall be adjustable for setting of color, image compression, white balance, brightness, contrast, sharpness, exposure control, low light, and rotation.
Shall have programmable, event-based logic that integrates with WWD controller.
Shall operate from 10 to 42 VDC.
Shall operate from −40°F to 165°F (−40°C to +74°C)
Shall be capable of storing recent images as a backup.
Shall be capable of transmitting images to application software as part of system requirements.

For camera’s tilt, pan, and zoom operations ensure the:

Use of closed-loop feedback control system,
Use of brushless motors; and
Ensure pan of 360° continuous rotation and meet a maximum speed of to 120° per sec.

</td></tr>
<tr><td colspan="2">Power Supply</td></tr>
<tr><td></td><td>
Refer to plans or as directed to determine if 120 V AC/60 Hz power or solar power is required.

If 120 V AC/60 Hz power is not available, provide a solar power system that must power the entire WWD System.
Unless otherwise shown on the plans or as directed, size solar power system with batteries for a 3-day autonomy in accordance with Item 6063 “Intelligent Transportation System (ITS) Solar Power System.”
Solar panel system should be installed with the panels positioned to get the maximum solar insolation during winter months.

</td></tr>
</table>

	• The solar panels must not be installed in a position which can be shaded by nearby objects or other system components. • If a post-top mounting system is used, provide 360° of rotational direction adjustment. • Include voltage regulator. • Include power inverter if required by the system. Batteries must be replaceable independently of other components. Battery storage requirements include: • Use tamper-resistant fasteners for mounting. • Conform to the IP-67 rating. • Use Pulse Width Modulation for battery charging. • Have the capability of using gel, sealed, or flooded batteries. • Provide protection against high voltage, reverse current, reverse polarity, short circuits, and overloads.
Communications	
Local Communications	
	If local communications are provided via hard-wired connectivity, refer to Cabling section in this standard. If local communications are provided via wireless connectivity, all WWDS pedestal poles must be equipped with a wireless transceiver. The wireless transceiver must: • Provide the ability to operate as a Gateway, Node, or Repeater. • Provide a means to verify signal strength between network devices. • Operate on the license Industrial, Scientific, and Medical (ISM) band. • Comply with Part 15 of Federal Communication Commission (FCC) rules. • Be housed in a NEMA 4X enclosure.
External Communication	
	If external communications to designated locations (such as a designated TMC) are to be provided via hard-wired connectivity, the WWDS must interface to the Department's fiber optic ITS network utilizing a provided Ethernet port on the management alert system unit. If external communications to designated locations (such as a designated TMC) are to be provided via wireless communications, provide TCP/IP options over a manufacturer-provided radio in accordance with Item 6062 "Intelligent Transportation System (ITS) Radio" or a device that is compatible with a department-furnished cell modem. Cellular modem communication must use a minimum of a 4G/LTE cellular gateway and: • Shall include LED indicators for Power, WAN, Signal, RS232, Ethernet Link and Activity. • Include an integrated five (5) port 10/100 ethernet switch. • Comply with Part 15 FCC rules.

	• Be capable of Over the Air (OTA) firmware updates and remote management. • Be programmable from Windows-based software. • Include 5 years of paid internet service. • Shall be capable of IPSEC VPN. • Operate from −40°F to 165°F (−40°C to +74°C). • Operate from 10 to 42 VDC.
Cloud-Based Monitoring System (also called Application)	
	• When a wrong-way driver is detected, the cloud-based monitoring system shall be capable of sending on-screen notifications to an online secure user interface using either an application or a standard browser. • Notifications may also be sent to emails and SMS text. The notifications shall come with color images identifying the vehicle by a direction and provide a time and date of detection. • Event video and offline site streaming shall be offered by the WWDS. System shall also offer diagnostic alerts about the system status, such as temperature, battery voltage and network connectivity. • The system shall also maintain historical data for later analysis and reporting. Communication Requirements: • WWDS shall be capable of sending alert data to and receiving control commands from a cloud-based management software using cellular modem or local fiber network. • System shall be capable of sending alert data to and receiving control commands from an external cloud-based management software using an agency's private communication network. • System shall be capable of sending alert data to and receiving control commands from an agency's Advanced Traffic Management Software using an agency's private communication network. • Cloud-based management software shall be accessible by users from a standard web browser with internet access. • Cloud-based management software shall have an Application Programming Interface (API) with sufficient documentation to allow for integrating into third party software platforms. • API shall allow alert images and data received by cloud-based management software from WWDS to be sent to other software platforms using industry-standard communication methods. API shall allow software platforms to send control requests and responses, such as received alert classification, to cloud-based management software for manipulation of its stored alerts and direct communication with WWDS
Mechanical	
	Mechanical connections within the WWDS must meet the following minimum requirements: • Ensure that all parts are fabricated from corrosion-resistant materials, such as plastic, stainless steel, aluminum, or brass.

	• Ensure that all screws, nuts, and locking washers are stainless steel. Do not use self-tapping screws. • Ensure equipment is clearly and permanently marked with manufacturer name or trademark and part number as well as date of manufacture or serial number. • Ensure WWDS is modular in design for ease of field replacement and maintenance. • All printed circuit boards (PCB) must have conformal coating. • Ensure that all fasteners, including bolts, nuts, and washers not already included with equipment and with a diameter less than 5/8 inch are Type 316 or 304 stainless steel and meet the requirements of ASTM F593 and ASTM F594 for corrosion resistance. • Ensure that all bolts and nuts not already included with the equipment and over 5/8 inch in diameter are galvanized and meet the requirements of ASTM A307. • Separate dissimilar metals with an inert dielectric material.
Cabling	
	Supply each WWDS installation with all cabling of the appropriate length and type for each component and need.
Connectors and Harness	
	Connectors and harnesses must meet the following minimum requirements: • External connections exposed to the outdoor environment must be made with weatherproof connectors. • Connectors must be keyed to ensure correct alignment and mating. • Ensure all conductors are properly color-coded and identified. • Ensure that every conductive contact surface or pin is gold-plated or made of a noncorrosive, nonrusting, conductive metal. • Ensure power and data cable connectors exposed to the elements are IP67 compliant. • Ensure all conductors that interface with the connectors are encased in one jacket.
Environmental	
	• All WWDS components must operate properly during and after being subjected to the environmental testing procedures described in NEMA TS2, Section 2. • Provide a WWDS with a design that will minimize weight and wind loading when mounted on a sign support. WWDS must be able to withstand the maximum wind load defined in the Department's basic wind velocity zone map standard without any damage or loosening from structure.
Documentation	
	Provide hardcopy operation and maintenance manuals, along with a copy of all product documentation on electronic media. Include the following documentation for all system devices and software: • Operator manuals. • Installation manuals with installation procedures.

	• Maintenance and troubleshooting procedures. • Manufacturer's specifications (functional, electrical, mechanical, and environmental).
Warranty	
	Manufacturer and/or provider must warranty the WWDS and components as follows: • Warrant the equipment against defects or failure in design, materials, and workmanship for a minimum of 3 years or in accordance with the manufacturer's standard warranty if that warranty period is greater. The start date of the manufacturer's standard warranty will begin after the equipment has successfully passed all tests contained in the final acceptance test plan. Any equipment with less than 90 percent of its warranty remaining after the final acceptance test is completed will not be accepted by the Department. • Guarantee that equipment furnished and installed for this project performs according to the manufacturer's published specifications. • Assign, to the Department, all manufacturer's normal warranties or guarantees on all electronic, electrical, and mechanical equipment, materials, technical data, and products furnished for and installed on the project. • Malfunctioning equipment must be repaired or replaced at the Contractor's expense prior to completion of the final acceptance test plan. Furnish replacement parts for all equipment within 10 days of notification of failure by the Department. • During the warranty period, technical support must be available via telephone within 4 hours of the time a call is made by a user, and this support must be available from factory-certified personnel. • The warranty must cover all defects in material, design, and workmanship, and must cover 100 percent of parts and labor for repair work, including diagnostics. • The provider must provide in writing the terms of warranty. • During the warranty period, the provider must be responsible for labor, materials, shipping, traffic control and other costs as outlined below for required warranty repair. It is the intent of this warranty that the provider performs warranty repair work. • At the Department's option, the Department may perform minor warranty repairs at the provider's expense without voiding the warranty. All diagnostics, testing, and replacements necessary to resolve any problems must be assumed by the provider at no cost to the Department.
Testing	
	Testing of the installed equipment locations is for the purpose of relieving the Contractor of maintenance of the equipment. Ensure that tests are performed on equipment and systems unless otherwise shown on the plans, or as directed. The Department may witness all the tests. • To ensure proper installation, configuration, and functionality, the WWDS must be tested and certified under the direct on-site supervision of the manufacturer.

	• Coordinate with the Department on scheduling a testing date at least 40 days before construction to allow manufacturer to provide a written test plan to the Department at least 30 days before the scheduled testing date.
Performance Test/Pre-Test	
	• Conduct a Performance Test for each unit after installation. Ensure the WWDS meets all functional performance requirements. • Once the equipment has been installed and activated, the exit ramp must be closed to traffic. • A test vehicle must then be driven the wrong way down the ramp a minimum of ten times. • If the system calls to be integrated to the TMC, then once a maximum of ten successful detections and notifications of the wrong-way vehicle are received at the TMC, as well as successful activation of LED flashing signs or beacons, the equipment must be accepted as fully tested and ready for operation. To be accepted the last five successful tests must be consecutive. • If the system does not call to be integrated to the TMC, then once a maximum of ten successful detections of the wrong-way vehicle and successful activation of LED flashing signs or beacons, the equipment must be accepted as fully tested and ready for operation. To be accepted the last five successful tests must be consecutive. • After each equipment location has been installed, the Department and the Contractor will conduct approved continuity, stand alone, and system tests on the installed field equipment with laptop equipment.
Final Acceptance Test/Post-Test	
	• A final acceptance test must be conducted to demonstrate all control, monitor, and communication requirements for 60 days. • The Engineer will furnish a letter acknowledging the final acceptance testing commencement date stating the first day of the final acceptance test. • The completion of the final acceptance test occurs when less than two (2) false calls have occurred from 100 vehicles passing through this detection zone; the system downtime due to mechanical, electrical, or other malfunctions to equipment furnished or installed does not exceed 72 hours; and any individual points of failure identified during the test period have operated free of defects.
Consequence of Test Failure	
	If a unit fails a test, submit a report describing the nature of the failure and the actions taken to remedy the situation prior to modification or replacement of the unit. • If a unit requires modification, correct the fault, and then repeat the test until successfully completed. • Correct minor discrepancies within 30 days of written notice to the Engineer. • If a unit requires replacement, provide a new unit, and then repeat the test until successfully completed. • Major discrepancies that will substantially delay receipt and acceptance of the unit will be sufficient cause for rejection of the unit.

	• If a failure pattern develops in similar units within the system, implement corrective measures, including modification or replacement of units, to all similar units within the system as directed. • Perform the corrective measures without additional cost or extension of the Contract period.
Relocation and Removal Testing	
Pre-Test	
	• Tests may include, but are not limited to, physical inspection of the unit and cable assemblies. • Include the sequence of the tests in the procedures along with acceptance thresholds. • Contractor to resubmit, if necessary, rejected test procedures for final approval within 10 days. • Review time is calendar days. • Conduct all tests in accordance with the approved test procedures. • Conduct basic functionality testing prior to removal of WWDS field equipment. • Test all functional operations of the equipment in the presence of representatives of the Contractor and the Department. • Ensure that both representatives sign the test report indicating that the equipment has passed or failed each function. • Once removed, the equipment becomes the responsibility of the Contractor until accepted by the Department. • Compare test data prior to removal and after installation. • The performance test results after relocation must be equal to or better than the test results prior to removal. • Repair or replace those components within the system that failed after relocation but passed prior to removal.
Post-Test	
	Testing of the WWDS field equipment is to relieve the Contractor of system maintenance. The Contractor will be relieved of the responsibility for system maintenance after a successful test period. The Department may also conduct system tests on the field equipment with the central equipment. The tests will, as a minimum, exercise remote control functions and confirm communication with field equipment. • The Contractor will not be required to pay for electrical energy consumed by the system. • After all existing WWDS field equipment has been installed, conduct approved continuity and performance tests. • Furnish test data forms containing the sequence of tests including all the data taken as well as quantitative results for all tests. • Submit the test data forms to the Engineer at least 30 days prior to the day the tests are to begin. • Obtain Engineer’s approval of test procedures prior to submission of equipment for tests. • Send at least one copy of the data forms to the Engineer.

	• Conduct an approved performance test of the equipment installation at the field sites. • At a minimum, exercise all stand-alone (non-network) functional operations of the field equipment installed per the plans as directed by the Engineer. • Complete the approved data forms with test results and turn over to the Engineer for review and either acceptance or rejection of equipment. • Give at least 30 working days' notice prior to all tests to permit the Engineer or his representative to observe each test. • If any unit fails to pass a test, prepare, and deliver a report to the Engineer. Describe the nature of the failure and the corrective action needed. If the failure is the result of improper installation or damage during reinstallation, reinstall or replace the unit and repeat the test until the unit passes successfully, at no additional cost to the Department or extension of the Contract period.
Construction/Installation	
	• Before installation of any equipment, perform a site survey of the proposed locations to determine the optimal positioning of the signs and thermal cameras and sensors to achieve proper operation based on the manufacturer's recommendations. • Test wireless links to assure they provide optimal communication between transmitters and receivers. • Adjust locations as approved by the Engineer if necessary. • If required, remove any existing WRONG WAY signs from their mounts to allow the installation of the new signs. • Mount WRONG WAY sign in accordance with Section 2B.41 Wrong-Way Traffic Control at Interchange Ramps of the TMUTCD or shown on the plans or as directed. • Install equipment in accordance with this Item and the lines, grades, details, and dimensions as shown on the plans or as directed. • Maintain safe construction practices. • Equipment must be installed in a neat and workmanlike manner. • Provide all mounting hardware and cabling necessary to install and make operational all equipment. • Provide only new and corrosion-resistant materials. • Consider all mounting hardware and cables as subsidiary to this item with no direct payment. • Adjustments and addition of sign attachment hardware, mounting components and hardware for thermal imaging cameras, sensors, solar panels, support brackets and appurtenances, such as conduit, etc., may be necessary for compatibility with specified positioning recommended by the manufacturer, as shown on the plans or as directed. • All adjustments and additional materials will not be paid for directly but will be subsidiary to this item. • Replace any portion of the equipment that is damaged or lost during transportation or installation.

	• Any unused or removed material deemed salvageable by the Engineer will remain on the property of the Department or be delivered to a designated site. • Accept ownership of unsalvageable materials and dispose of in accordance with federal, state, and local regulations. • The Contractor must complete manufacturer-provided training on the installation of all equipment before any work begins. • The Contractor will provide documentation that they have completed the required training from the equipment manufacturer before final testing of the equipment. • Once installation is complete, contractor will coordinate with equipment manufacturer to ensure all sensors and verification devices are properly positioned and the wrong-way driver detection zones are accurate. • Ensure that all equipment is functioning properly and communicating with manufacturer's application. • Testing will begin once proper system functionality is proven. • Stockpile all materials designated for reuse or to be retained by the Department within the project limits or at a designated location as directed.
Electric Service	
	When shown in the plans, the Contractor is responsible for checking the local electrical service (if available) to determine if a modification is needed for the equipment
Grounding	
	Ensure all WWDS devices, cabinets, and supports are grounded in accordance with the NEC and manufacturer recommendations.
Relocation of WWDS Field Equipment	
	• Perform the relocation in strict conformance with the requirements herein and as shown on the plans. Completion of the work must present a neat, workmanlike, and finished appearance. Maintain safe construction practices during relocation. • Inspect the existing WWDS field equipment with a representative from the Department and document any evidence of damage prior to removal. Conduct testing in accordance with the Relocation and Removal Testing section in this standard. Remove and deliver equipment that fails inspection to the Department. • Prior to removal of existing WWDS field equipment, disconnect and isolate the power cables from the electric power supply and disconnect all communication cabling from the equipment located inside the cabinet. • Coil and store power and communication cabling inside the cabinet until such time that it can be relocated. • Remove existing WWDS field equipment as shown on the plans only at such time as authorized by the Engineer. • Use care to prevent damage to any support structures. Any equipment or structure damaged or lost must be replaced by the Contractor (with items approved by the Engineer) at no cost to the Department.

	• Make all arrangements for connection to power and communications including any permits required for the work to be done under the Contract. • Provide wire for the power connection at least the minimum size and insulation indicated on the plans.
Removal of WWD Field Equipment	
	• Perform the removal in strict conformance with the requirements herein and as shown on the plans. Completion of the work must present a neat, workmanlike, and finished appearance. Maintain safe construction practices during removal. • Inspect the existing WWDS field equipment with a representative from the Department and document any evidence of damage prior to removal. Conduct testing in accordance with the Relocation and Removal Testing section in this standard. • Disconnect and isolate any existing electrical power supply prior to removal of existing field equipment. • Use care to prevent damage to any support structures. Any equipment or structure damaged or lost must be replaced by the Contractor (with items approved by the Engineer) at no cost to the Department. • All materials not designated for reuse or retention by the Department will become the property of the Contractor and be removed from the project site at the Contractor's expense. Deliver items to be retained by the Department to a location shown on the plans or general notes. The Contractor is fully responsible for any removed equipment until released by the Engineer.
Contractor Experience Requirements	
Minimum Experience	
	Provide proof of two (2) years of continuous existence offering services in the installation of WWDS. Experience must include equipment setup, testing, and troubleshooting.
Completed Projects)	
	Provide references to at least two (2) completed projects where personnel installed, tested, and integrated WWDS field equipment. The detectors and radios must have been installed outdoors and permanently mounted. The completed installations must have been in continuous satisfactory operation for a minimum of 1 year. Submit the names, addresses and telephone numbers of the references that can be contacted to verify the experience requirements given above.
Equipment Experience	
	Provide references to at least one (1) project in which the personnel worked in cooperation with technical representatives of the equipment supplier to perform installation, integration, or acceptance testing of the work. The Contractor will not be required to furnish equipment on this project from the same supplier who was referenced in the qualification documentation. Submit the names, addresses and telephone numbers of the references that can be contacted to verify the experience requirements given above.

Training	

	Provide manufacturer approved end user training to the Department and their representatives as follows:
	• Provide a minimum of two days of instruction in the operation and maintenance procedures.
	• Train a maximum of 10 Department designated personnel. Cover the following training material as a minimum:
	    o Hands-on operation of the sign,
	    o Explanation of any system commands, their function and usage,
	    o Required preventative maintenance procedures,
	    o Equipment servicing procedures,
	    o Sign troubleshooting and problem identification procedures, and
	    o Use of diagnostic software.
	• Furnish a manufacturer-approved training session agenda, and a complete set of manufacturer-approved training materials. Provide one copy of the course material for each person. Coordinate with the Department to provide a training room.

Measurement	
	This Item will be measured by each system furnished, installed, relocated, or removed of the types specified, to provide communication and functionality. This Item will be measured as each “WWDS” furnished, in accordance with this Specification. This Item will be measured as each unit furnished, installed, made fully operational and tested in accordance with these Special Specifications.
Payment	
	The work performed and materials furnished in accordance with this Item and measured as provided under “Measurement” will be paid for at the unit bid price for “LED Wrong Way Driver System.” This price is full compensation for furnishing, installing, configuring, integrating, and testing the completed installation including WWDS equipment, voltage converters or injectors, cables, connectors, associated equipment, and mounting hardware; and for all labor, tools, equipment, any required equipment modifications for electrical service, documentation, testing, software, warranty, and incidentals necessary to complete the work.

CHAPTER 6: VALUE OF RESEARCH ASSESSMENT

Researchers completed a Value of Research (VoR) assessment as part of the project. Researchers based the VoR assessment on the benefit areas in Table 9. Since the level of knowledge benefit area was qualitative in nature, it was not included in the economic benefit analysis.

Table 9. Selected Benefit Areas for VoR Assessment.

Benefit Area	Qualitative	Economic	Both	TxDOT	State	Both	Definition in Context to the Project Statement
Level of Knowledge	X			X			Research will provide a current summary of the state-of-the-practice, which will form a basis for developing implementation guidance and helping practitioners in TxDOT and its partners make more informed decisions on future WWD system installations.
Increased Service Life		X		X			Research will develop specification to make sure adopted technologies meet minimum requirements, which will improve compatibility with existing and future systems as well as functionality and minimizing the need for early replacement of non-functioning and incompatible systems.
Reduced Construction, Operations, and Maintenance Cost		X			X		Research will develop specification that should improve system performance and thus reduce operations (e.g., false calls) and maintenance costs (e.g., adjusting sensors).
Safety			X			X	Research will improve the ability to detect WWD incidents and respond to them, which will increase the potential for reduced crashes and resulting injuries/fatalities.

The economic benefit analysis focused on four variables: capital costs, personnel time cost savings, maintenance costs savings, and safety benefits. Table 10 shows the assignment of these variables to the appropriate economic benefit area and documents the assumptions used for one metropolitan region. Most of the assumptions are based on experiences from the TxDOT San Antonio District. Other resources used included *Crash Costs for Highway Safety Analysis* (*29*) and NCHRP Research Report 881 (*30*).

Table 10. Economic Benefit Analysis Assumptions for One Metropolitan Region.

Benefit Area	Capital Costs	Personnel Time Cost Savings	Maintenance Costs	Safety Benefits
Increased Service Life	• WWD detection systems cost on average $15,000/ramp. • Early replacement of one system per year. • Project results in early replacement of zero systems.	NA	NA	NA
Reduced Construction, Operations, and Maintenance Cost	NA	• 15 false calls/month. • Each false call takes a TMC operator 5 minutes to completely vet. • TMC operator makes $20/hour. • Engineer spends 2 hours a month reviewing false calls. • Engineer makes $50/hour. • Project results in 10 false calls/month (reduced by 1/3).	• Two-person maintenance crew spends 8 hours/year working on a system with false calls. • Four systems per year require false call maintenance. • Maintenance worker makes $26/hour. • Project results in 2.67 systems per year requiring false call maintenance (reduced by 1/3).	NA
Safety	• WWD detection systems cost on average $15,000/ramp. • Install 10 systems per year.	NA	NA	• Average of 172.8 WWD events/year. • Average of 18.8 WWD crashes/year. • Average of 4.2 WWD fatal crashes/year. • 32% reduction in WWD events/year. • 3.5% reduction in WWD crashes/year.

NA = Not Applicable.

Based on the documented assumptions, researchers initially calculated the monetary values for one metropolitan region for a year and then scaled them to represent the six major metropolitan regions in Texas (i.e., Austin, Dallas, El Paso, Fort Worth, Houston, and San Antonio) for a year. Table 11 contains the value of the variables for the VoR assessment for the state.

Table 11. Value of Variables for VoR Assessment.

Benefit Area	Capital Costs	Personnel Time Cost Savings	Maintenance Costs	Safety Benefits	Total
Increased Service Life	$90,000.00	NA	NA	NA	$90,000.00
Reduced Construction, Operations, and Maintenance Cost	NA	$3,120.00	$3,328.00	NA	$6,448.00
Safety	−$150,000.00	NA	NA	$7,530,586.95	$7,380,586.95

NA = Not Appliable.

Researchers entered the values shown in Table 11 into the TxDOT VoR Assessment spreadsheet to calculate the formal VoR measures. Those results are shown in Figure 98. The results show that, based on the assumptions provided previously, the research project is estimated to have a benefit-cost ratio of approximately 149:1 over a 10-year expected value duration, with over $66 million in savings.

Texas Department of Transportation®	Project #	0-7119		
	Project Name:	Develop Standardized Operational Evaluationof Wrong-Way Driving Detection Technologies		
	Agency:	TTI	Project Budget	$ 413,513
	Project Duration (Yrs)	2.0	Exp. Value (per Yr)	$ 7,477,035
Expected Value Duration (Yrs)		10	Discount Rate	3%
Economic Value				
Total Savings:	$ 66,879,801	Net Present Value (NPV):		$ 61,732,902
Payback Period (Yrs):	0.055304	Cost Benefit Ratio (CBR, $1 : $___):		$ 149

Figure 98. Results of VoR Assessment for Project.

REFERENCES

1. Tamburri, T.N., and D.J. Theobald. *Wrong Way Driving (Phase II)*. Traffic Department, Division of Highways, Department of Public Works, State of California, February 1965.

2. Tamburri, T. *Report on Wrong Way Automatic Sign, Light and Horn Device*. Traffic Department, Division of Highways, Department of Public Works, State of California, June 1965.

3. Rinde, E. *Off-Ramp Surveillance: Wrong Way Driving*. Report No. FHWA-CA-TE-78-1. California Department of Transportation, Office of Traffic, Sacramento, California, August 1978.

4. Knight, D. “Danger! Wrong Way Driver Ahead!” *Traffic Safety* (Chicago), Vol. 83, No. 5, 1983.

5. Cooner, S.A., A.S. Cothron, and S.E. Ranft. *Countermeasures for Wrong Way Movement on Freeways: Overview of Project Activities and Findings*. Report No. FHWA/TX 04/0 4128-1. Texas Transportation Institute, College Station, Texas, January 2004.

6. Moler, S. “Stop. You’re Going the Wrong Way!” *Public Roads*, Vol. 66, No. 2, September/October 2002.

7. Williams, C. District 3 ITS Project Update Presentation. Florida Department of Transportation, 2007.

8. Simpson, S.A. *Wrong-way Vehicle Detection: Proof of Concept*. Report No. FHWA-AZ-13-697. United Civil Group Corporation, Phoenix, Arizona, March 2013.

9. ITS International. “Wrong Way Detection System Prevents Accidents, Improves Safety.” *ITS International*, June 2010.

10. American Traffic Safety Services Association. *Emerging Safety Countermeasures for Wrong-Way Driving*. Fredericksburg, Virginia, 2014.

11. Kayes, M.I., H. Al-Deek, and A. Sandt. Comparison of Two Intelligent Transportation Systems Wrong-Way Driving Countermeasures Currently Deployed on Florida Toll Roads. *Journal of Intelligent Transportation Systems*, Vol. 24, No. 4, 2020, pp. 315–330.

12. Simpson, S., and D. Bruggeman. *Detection and Warning Systems for Wrong-Way Driving*. Report No. FHWA-AZ-15-741. United Civil Group Corporation and Lee Engineering, Phoenix, Arizona, November 2015.

13. Tappendorf, D. “Staying Alive.” *Roads & Bridges*, Vol. 57, No. 1, January 2019.

14. Arizona Department of Transportation. *Interstate 17 Wrong-Way Vehicle Detection Pilot Program*. Phoenix, Arizona, June 2020.

15. Athey Creek Consultants. *Countermeasures for Wrong-Way Driving on Freeways*. Project Summary Report. ENTERPRISE Transportation Pooled Fund Study TPF-5 (231), September 2016.

16. Bucko, T.R. *Wrong Way Pilot Projects for Prevention of Wrong Way Collisions on Freeways*. California Department of Transportation, Sacramento, California, May 2020.

17. Slonaker, J. *Wrong Way Driver Mitigation*. Presented at the 100th Transportation Research Board Annual Meeting, January 2021.

18. Lasky, T.A., K. Yen, S. Donecker, W. White, D. Bennett, T. Swanston, and B. Ravani. *Vision-Based Sensor System for Site Monitoring: Wrong-Way Driving, Phase 1*. Report No. CA20-2970. AHMCT Research Center, Davis, California, June 2020.

19. Lin, P. C. Chen, S. Ozkul, and M. Rajalingola. *Testing and Evaluation of Freeway Wrong-way Driving Detection Systems*. Center for Urban Transportation Research, University of South Florida, Tampa, Florida, November 2018.

20. Lin, P. C. Chen, and E. Bialkowska-Jelinska. *Testing and Evaluation of Thermal Camera-Based and Video-Analytic Systems on Wrong-Way Driving, Stopped Vehicle, and Pedestrians*. Center for Urban Transportation Research, University of South Florida, Tampa, Florida, October 2019.

21. Florida Department of Transportation. *Standard Specifications for Road and Bridge Construction*. Tallahassee, Florida, January 2022. Available at https://www.fdot.gov/programmanagement/implemented/specbooks/default.shtm. Accessed on January 31, 2022.

22. Florida Department of Transportation. *Supplemental Wrong Way Vehicle Detection System (WWVDS) SunGuide HTTP Protocol*. SR-995-2.7.2-01. Tallahassee, Florida, July 16, 2021. Available at https://www.fdot.gov/traffic/Traf-Sys/Product-Specifications.shtm. Accessed on January 31, 2022.

23. Florida Department of Transportation. *Design Manual*. Section 230.4. Tallahassee, Florida, January 2022. Available at https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/roadway/fdm/2022/2022fdm230spavtmarkings.pdf. Accessed on January 31, 2022.

24. Florida Department of Transportation. *FY 2022-23 Standard Plans Index 700-120 Enhanced Highway Signing Assemblies*. Sheet 9 of 11. Tallahassee, Florida, January 2022. Available https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/design/standardplans/2023/idx/700-120.pdf. Accessed on January 31, 2022.

25. Florida Department of Transportation. *Traffic Engineering Research Laboratory (TERL) Wrong Way Vehicle Detection System (WWVDS) Compliance Matrix*. CM-995-2.7-01 Revision 2.0. Tallahassee, Florida. Available at https://www.fdot.gov/traffic/Traf-Sys/Product-Specifications.shtm. Accessed on January 31, 2022.

26. Sabawat, V., S. Marlina, A. Stamp, and B.N. Janson. *Evaluation of Wrong-Way Driving (WWD) Detection Proof of Concept*. Presented at the 100th Transportation Research Board Annual Meeting, January 2021.

27. Marlina, S., and V. Sabawat. *Evaluation of Wrong-Way Driving (WWD) Detection Final Report*. Colorado Department of Transportation Region 1, Denver, Colorado, June 2020.

28. Golias, M., S. Mishra, and H. Ngo. *Investigation on Wrong Way Driving Prevention Systems*. University of Memphis, Memphis, Tennessee, May 2021.

29. Harmon, T., G. Bahar, and F. Gross. *Crash Costs for Highway Safety Analysis*. FHWA-SA-17-071. VHB, Vienna, Virginia, January 2018.

30. Finley, M.D., R.E. Avelar, S.P. Venglar, H.G. Hawkins, Jr., and H. Al-Deek. *Traffic Control Devices and Measures for Deterring Wrong-Way Movements*. NCHRP Research Report 881. National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 2018.

APPENDIX

BOSCH & MHCORBIN

Closed-Course Testing Overview

Wrong-Way Detection	False Positive Detection	Sign Activation	Email Alerts	SMS Alerts
★★★★★	★★★★★	★★★★★	★★★★★	★★★★★
84/84	0/36	84/84	84/84	84/84

Description

The BOSCH and MhCorbin wrong-way (WW) vehicle detection system tested used a BOSCH thermal camera for nighttime detection, a BOSCH optical camera with built-in infrared transmitter for daytime detection, a PTZ camera to capture color photos and monitor the WW vehicle, and a MhCorbin roadside controller. The cameras utilized video analytics with a deep learning artificial intelligence to produce vehicle tracking to analyze video and trigger WW alerts.

To search for WW vehicles, the user must configure detection zones in BOSCH-developed software. The configuration allows the user to define up to three detection zones and select one of three actuation methods. One method for WW vehicle detection requires the sequential actuation of zones (e.g., Zone 1 then Zone 2) to detect a vehicle traveling in the incorrect direction. A second option uses a single zone that can be set to activate only if a vehicle is traveling a certain direction. In both these options, zones can be any size. The third option allows the user to configure a line of detection with a direction of travel to trigger a WW vehicle detection. The first actuation method was tested.

Features Offered	Supported
WRONG WAY Sign Integration	✓
Still Photos	✓
Video	✓
Email Alert	✓
SMS Alert	✓*
ATMS Alert	✓*
Remote Access	✓
Monitoring GUI	✓*
System Heartbeat	✓*
API Offered	✓

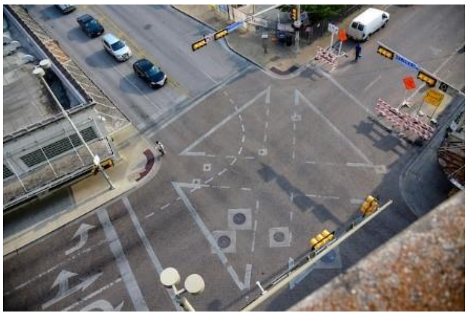
* MhCorbin component

The Bosch cameras can be configured to send emails about detected events, but the system tested used the MhCorbin roadside controller for all alerting. The email alert contained information about the location, device, alert reason, alert parameters, operation type, event timestamp, and two still photos (each with an embedded timestamp). The MhCorbin roadside controller also offers two web-based dashboards. The first dashboard connects to the controller via a web-browser and allows the user to configure alerts. The second web-based dashboard allows users to monitor alerts and system health. It also stores still photos and video files with each event.

Applications

Freeway Ramps

Freeway Mainlanes



Intersections

Specifications

Parameter	Specification
Maximum Range	722 ft
Mounting Height	> 25 ft (16 ft is acceptable)
Power Sources	AC
Environmental Specs	−29°F to 165°F; 0–95% humidity
Lifespan	5-year warranty; 12-year expected life

Additional Notes

BOSCH provides several different camera technologies that can support the same algorithm for detecting WW vehicles. The cameras can be equipped with different lenses to support a range of detection distances.

References

https://mhcorbin.com/Solutions/Wrong-Way-Detection

https://commerce.boschsecurity.com/jp/en/DINION-IP-thermal-8000/p/79153091851/

CARMANAH® TECHNOLOGIES CORP

Closed-Course Testing Overview

Wrong-Way Detection	False Positive Detection	Sign Activation	Email Alerts	SMS Alerts
★★★★☆	★★★★★	★★★★★	★★★☆☆	N/A
81/84	0/36	84/84	78/84	Not Tested

Description

The Carmanah® Technologies Corp wrong-way (WW) 400 system tested utilized one radar unit and two camera units (intersection and freeway that process both infrared and optical images) to detect and validate a wrong-way driving event. The system used the radar and cameras to perform a two-stage detection and validation process. The radar unit had three zones along the search area. If two zones were activated, the system triggered the lights on a WRONG WAY sign. After three zones were activated, the radar signalled the controller to begin recording the event with both cameras and logged an associated timestamp. The intersection camera captured photos and video of the vehicle as it traveled through the radar zones. The freeway camera searched for a vehicle that traveled the wrong way using image processing that looked for ray tracing of components of the vehicle. If the freeway camera did not detect a WW vehicle, the event was labeled as "Radar Detected," which indicated that the vehicle did not pass the freeway camera. If the freeway camera detected a WW vehicle, the event label was changed to "Camera Validated," which communicated that the vehicle proceeded through the WW detection area in view of the freeway camera. Email alerts were sent regardless of the event's label. The email contained an event timestamp and color and infrared photos from the intersection and freeway cameras with or without ray tracing visualized. The system was monitored through proprietary software that shows the history of events at a given site and a system heartbeat.

Features Offered	Supported
WRONG WAY Sign Integration	✓
Still Photos	✓
Video	✓
Email Alert	✓
SMS Alert	✓
ATMS Alert	✓
Remote Access	✓
Monitoring GUI	✓
System Heartbeat	✓
API Offered	✓

Applications

Freeway Ramps

Freeway Mainlanes

Specifications

Parameter	Specification
Maximum Range	600 ft
Mounting Height	> 18 ft for radar / > 14 ft for cameras
Power Sources	AC/Solar
Environmental Specs	−29°F to 165°F; 0–95% humidity
Lifespan	3-year warranty

Additional Notes

Photos and videos saved with WW events can be with either the optical or infrared images from the two cameras. Carmanah also offers SMS messages via email address that includes a phone number and cell provider (e.g., 1234567890@cellprovider.net), which could not be tested.

References

https://carmanah.com/product/ww400-wrong-way-vehicle-detection-warning-and-alert-system/

https://carmanah.com/product-category/wrong-way-driver-systems/

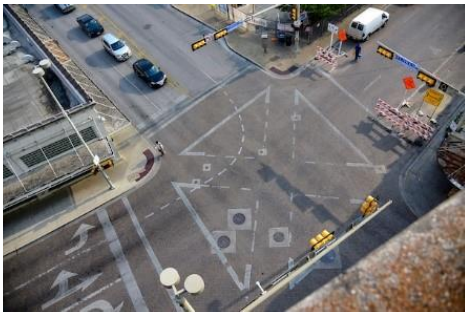
Wrong-Way Detection	False Positive Detection	Sign Activation	Email Alerts	SMS Alerts
★★★★☆	★★★★★	N/A	★☆☆☆☆	N/A
83/84	0/36	Not Tested	75/84	83/84

Description

The CUBIC™ Transportation Systems Gridsmart and GS2 Processor wrong-way (WW) vehicle detection system tested used a bell-shaped fisheye camera unit that had optical video processing on an edge computing device. For testing, CUBIC™ configured three zones to search for WW vehicles using the proprietary software. Zones drawn for WW detection must point in the incorrect direction of travel. Upon detecting a WW vehicle, the GS2 processor sends an email to the designated email addressed to alert users.

Features Offered	Supported
WRONG WAY Sign Integration	
Still Photos	✓
Video	
Email Alert	✓
SMS Alert	
ATMS Alert	
Remote Access	✓
Monitoring GUI	
System Heartbeat	✓
API Offered	✓

Applications



Intersections

Specifications

Parameter	Specification
Maximum Range	8 lanes—up to 300 ft
Mounting Height	> 35 ft
Power Sources	AC or solar with battery backup
Environmental Specs	−29 °F to 165 °F; 0–95% humidity
Lifespan	3-year warranty (1–3 year extensions available); 8-year expected life

References

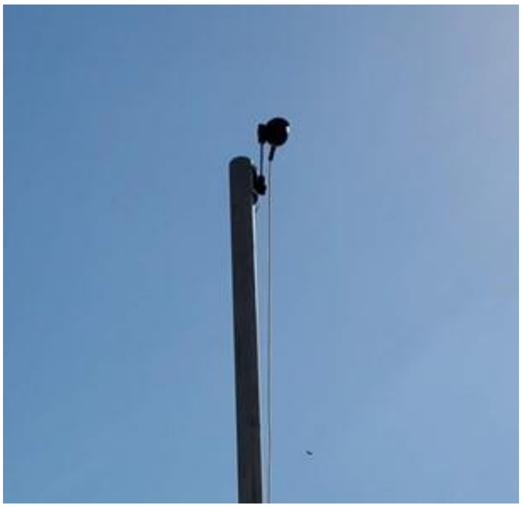
https://www.cubic.com/sites/default/files/2023-03/GS-Bell-Camera-Data-Sheet.pdf

https://www.cubic.com/sites/default/files/2019-05/GS2%20Data%20Sheet.pdf

TELEDYNE FLIR

Closed-Course Testing Overview

Wrong-Way Detection	False Positive Detection	Sign Activation	Email Alerts	SMS Alerts
★★★★☆	★★★★★	N/A	★★★★☆	N/A
83/84	0/36	Not Tested	83/84	Not Tested



Description

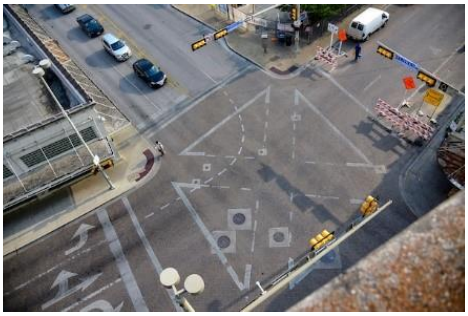
The FLIR system tested used a single thermal camera and proprietary software to configure and detect vehicle presence and direction of travel. To detect wrong-way (WW) vehicles, the camera must be configured with zones pointing in the correct direction of travel with an inverse direction of travel triggering an email plugin. For each alert, the system sent two emails. The first email contained a still photo, event timestamp, type of event, name of camera, and the zone activated. The second email contained the same information but also included an event video. The first email was sent immediately after an event was triggered, and the second email was sent after the video had finished recording. The system was monitored through proprietary software that allows a user to monitor a real-time event management screen. This screen also showed all other events for the device (e.g., user logins, communication losses, and user-triggered events). The proprietary software also stores logs of WW vehicle detections with the photos and videos.

Features Offered	Supported
WRONG WAY Sign Integration	✓
Still Photos	✓
Video	✓
Email Alert	✓
SMS Alert	✓
ATMS Alert	✓
Remote Access	✓
Monitoring GUI	✓
System Heartbeat	✓
API Offered	✓

Applications

Freeway Ramps

Freeway Mainlanes



Intersections

Specifications

Parameter	Specification
Maximum Range	5 lanes—up to 300 ft
Mounting Height	> 20 ft
Power Sources	AC or DC
Environmental Specs	−29 °F to 167 °F; 0–95% humidity
Lifespan	3-year warranty; 12-year expected life

Additional Notes

Each unit provides up to 24 zones of detection. Teledyne FLIR also offers SMS messages via email address that includes a phone number and cell provider (e.g., 1234567890@cellprovider.net), which could not be tested.

References

https://www.flir.com/

https://www.flir.com/products/flir-traficam-x-stream2/

GOVCOMM, INC.

Closed-Course Testing Overview

Wrong-Way Detection	False Positive Detection	Sign Activation	Email Alerts	SMS Alerts
★★★★★	★★★★★	★★★★★	★★★★★	N/A
84/84	0/36	84/84	84/84	Not Tested

Features Offered	Supported
WRONG WAY Sign Integration	✓
Still Photos	✓
Video	✓
Email Alert	✓
SMS Alert	✓
ATMS Alert	✓
Remote Access	✓
Monitoring GUI	✓
System Heartbeat	✓
API Offered	✓

Description

The GovComm, Inc. wrong-way driving (WWD) detection system tested utilized a dual optical and thermal camera housing and a computation module that uses artificial intelligence to analyze the two video streams to detect wrong-way (WW) vehicles. The installation also included a rear-facing camera to capture photos of the WW vehicle after entering the ramp. To search for WW vehicles, the processor used zone configurations from both the optical and thermal cameras. Users configure an outer zone (area of interest) and a detection zone. If the processor determined that both video streams identified a WW vehicle within the two zones at the same time, a WW vehicle detection was triggered and an alert was transmitted. The system sent emails that contained an event timestamp and a link to a proprietary web-based monitoring tool for access to the associated photos and videos. The proprietary web-based monitoring tool also stores WWD alert details and information about system health and operation. Videos and images of events are stored in the monitoring system for a week unless longer storage is requested.

Applications

Freeway Ramps

Freeway Mainlanes

Specifications

Parameter	Specification
Maximum Range	8 lanes—up to 300 ft
Mounting Height	> 20 ft
Power Sources	AC or solar with battery backup
Environmental Specs	−29 °F to 165 °F; 0–95% humidity
Lifespan	2-year warranty

References

https://govcomm.us/wrong-way-video-detection-systems/

IMAGE SENSING SYSTEMS INC.

Closed-Course Testing Overview

Wrong-Way Detection	False Positive Detection	Sign Activation	Email Alerts	SMS Alerts
★★★★★	★★★★★	N/A	★★★★★	N/A
84/84	0/36	Not Tested	84/84	Not Tested

Description

The Image Sensing Systems, Inc. (ISS) wrong-way (WW) alerting solution used for testing was comprised of a single camera with four independent lens housing that monitored various portions of the exit ramp and frontage road. All four cameras were optical cameras. The detection camera used a wide-angle lens. The other cameras used standard lenses for monitoring. The system processed the optical video for vehicles within a single detection zone traveling in the opposite direction of the defined correct travel direction. Email alerts contained a still photo (with an embedded timestamp), incident type, incident description, and device name. The still photo was from the camera used for detection. Images captured during daylight conditions included a color photo, a depiction of the detection zone, and a timestamp. Photos from nighttime conditions were black-and-white and included the timestamp, but not a representation of the detection zone.

The system also saved a video of the triggered events that contains 15 seconds before triggering the event and 15 seconds after the event detection. The video could be configured to use a single camera view or quad camera view. Videos are visible through proprietary software or may be retrieved from the system via an open API. To keep videos of events they must be downloaded from the software. Otherwise, the software only keeps the video for a seven-day period. The software keeps a log of the event timestamps and stores event data in the system for seven days before clearing the event from the history. The software also shows system health monitoring including system heartbeat and data streaming information.

Features Offered	Supported
WRONG WAY Sign Integration	✓
Still Photos	✓
Video	✓
Email Alert	✓
SMS Alert	✓
ATMS Alert	✓
Remote Access	✓
Monitoring GUI	✓
System Heartbeat	✓
API Offered	✓

Applications

Freeway Ramps

Specifications

Parameter	Specification
Maximum Range	4 lanes—up to 100 ft
Mounting Height	15–20 ft
Power Sources	AC/solar
Environmental Specs	−29 °F to 167 °F; 0–95% humidity
Lifespan	3-year warranty with sensor and up to 10-year warranty for thermal core

Additional Notes

ISS offers a third-party validation of the WW vehicle detections. This feature sends the WW alert to another entity to review the photo and decide if the event was a genuine WWD event prior to pushing the alert to a transportation agency. ISS also offers a phone call alert medium, if desired. Although not tested due to a I/O module error, ISS offers WRONG-WAY sign integration. ISS also offers SMS messages via email address that includes a phone number and cell provider (e.g., 1234567890@cellprovider.net), which could not be tested.

References

https://www.imagesensing.com/solutions/wrong-way.html

https://www.imagesensing.com/assets/documents/products/AID/wrong-way-brochure-ltr.pdf

K&K SYSTEMS INC.

Closed-Course Testing Overview

Wrong-Way Detection	False Positive Detection	Sign Activation	Email Alerts	SMS Alerts
★★★★☆	★★★★★	N/A	★★★★☆	N/A
83/84	0/36	Not Tested	83/84	Not Tested

Description

The K&K Systems, Inc. detection technology tested was a three-camera system (one thermal and two optical) in separate housings integrated with a WRONG WAY sign. The thermal camera was the detection device, and the optical cameras were for photo capture and wrong-way (WW) vehicle monitoring. On the thermal camera, the detection zone was drawn such that the arrows pointed in the incorrect direction of travel to detect WW vehicles and send alerts. K&K used a time threshold (1 second) before signaling an alert to prevent false detections. The system uses proprietary software for configuration of the cameras and monitoring events. The software logs and stores event details such as a timestamp for sign activations, a timestamp for WW vehicle warnings, event videos (typically 30 seconds after the onset of the warning), still photos, and system response logs. The video places a box around the object that triggered the detection so a user can identify what the system thought was the WW vehicle.

Features Offered	Supported
WRONG WAY Sign Integration	✓
Still Photos	✓
Video	✓
Email Alert	✓
SMS Alert	✓
ATMS Alert	
Remote Access	✓
Monitoring GUI	✓
System Heartbeat	✓
API Offered	✓

Applications

Freeway Ramps

Freeway Mainlanes

Specifications

Parameter	Specification
Maximum Range	1000 ft
Mounting Height	> 20 ft
Power Sources	AC/Solar/Mix
Environmental Specs	−29 °F to 165 °F; 0–95% humidity
Lifespan	5-year warranty

Additional Notes

Although not tested due to a server error, the K&K system can transmit alerts to email addresses and text messages via an email address.

References

https://www.k-ksystems.com/wrong-way-systems.html

https://www.k-ksystems.com/assets/wrong-way-brochure-online.pdf

https://drive.google.com/file/d/1tSUqhFkaC0rKRN8yrqK8sZ84mtzL1Nkd/view

SICK, INC.

Closed-Course Testing Overview

Wrong-Way Detection	False Positive Detection	Sign Activation	Email Alerts	SMS Alerts
★★★★☆	★★★★★	N/A	N/A	★☆☆☆☆
81/84	0/36	Not Tested	Not Tested	7/84

Description

The SICK, Inc.'s Advanced Object Detection System (AOS) wrong-way driving (WWD) detection system used a single radar unit in conjunction with a data processor to evaluate a vehicle's direction of travel and send alerts about WWD events. To generate a detection zone, a user entered coordinates of the region of interest into a proprietary web portal. In the region of interest, the device generated a log and an object trajectory of each detected vehicle. If the object trajectory was sufficient and in the "Wrong Way," the system sent a wrong- way (WW) alert. Text alerts were configured and generated through a plugin in the proprietary software. The radar communicated with a cellular SIM card–equipped modem to send SMS messages. The monitoring GUI is web-based and keeps tables for each object found by the radar. Each object was assigned either a "Normal Way" or "Wrong Way" label and the object trajectory data were logged based on the direction of travel in the z-axis. A "valid" status meant that the object trajectory was sufficient to trigger a WW alert. An "incomplete trajectory" or "incomplete trajectory, few objects" status meant that the object trajectory was not adequate to trigger an alert. The "incomplete trajectory" or "incomplete trajectory, few objects" status would apply to objects travelling in a perpendicular direction or not completely through the region of interest.

Features Offered	Supported
WRONG WAY Sign Integration	✓
Still Photos	
Video	
Email Alert	✓
SMS Alert	✓
ATMS Alert	
Remote Access	
Monitoring GUI	✓
System Heartbeat	
API Offered	✓

Applications

Freeway Ramps

Freeway Mainlanes

Specifications

Parameter	Specification
Maximum Range	492 ft
Mounting Height	8–16 ft
Power Sources	DC typical/Solar capable
Environmental Specs	−40°F to 149°F; 0–95% humidity
Lifespan	1-year warranty (can be extended)

Additional Notes

The SICK AOS WWD system tested was still under development. An email plugin allowed the system to send alerts to a designated email. However, the SICK system tested did not have a connection to a mail server. Therefore, researchers did not evaluate email alerts.

The SICK AOS WWD system is able to send email alerts; however, the system did not have an email address to send the alerts from at the time of testing, so this feature was not tested.

References

https://www.sick.com/ag/en/radar-sensors/c/g575803?q=:Def_Type:ProductFamily

https://www.sick.com/no/en/industries/mining/open-cut-surface-mining/vehicles-for-mining/wrong-way-detection/c/p661469

Wrong-Way Detection	False Positive Detection	Sign Activation	Email Alerts	SMS Alerts
★★★★★	★★★★★	★★★★★	★★★★★	★★★★★
84/84	0/36	84/84	84/84	84/84

Description

The TAPCO wrong-way driving (WWD) system tested was comprised of one thermal camera, two optical cameras, one radar unit, and two illuminators. The system utilized a combination of radar and thermal camera technology to identify wrong-way (WW) vehicles in two stages. The first stage (called sign activation zone) used the radar to search for a WW vehicle on the ramp. Once a WW vehicle was detected, the system activated LEDs on a WRONG WAY sign and LED illuminators. The first stage also triggered a detection alert to users through a proprietary web-based monitoring system and activated the optical cameras to capture upstream and downstream ramp views for alert still images and video. If the WW vehicle proceeded through the second zone monitored by the thermal camera (second stage called wrong-way alert zone), the system sent a confirmation alert. These notifications are configurable to a user's preference within TAPCO's cloud-based software. During testing, alerts were sent via email and SMS. Email alerts contained a series of 15 still photos, system details, asset name, event timestamp, and a link to the notification in the proprietary monitoring system. Detection and confirmation events are logged in the proprietary monitoring system such that users can review and manage the events. Users can resolve an event by selecting from a pre-defined list of 15 choices that allows the user to document the characteristics of the event. There is also a place to enter additional notes about the event. The alert event log notes a timestamp for when the alert was reported and the camera photo was processed. The log also documents when (timestamp) and to whom (name) the email and text notifications were sent. The proprietary monitoring system also offers health monitoring options including system heartbeat, voltage, temperature, camera status, and data usage.

Features Offered	Supported
WRONG WAY Sign Integration	✓
Still Photos	✓
Video	✓
Email Alert	✓
SMS Alert	✓
ATMS Alert	✓
Remote Access	✓
Monitoring GUI	✓
System Heartbeat	✓
API Offered	✓

Applications

Freeway Ramps

Freeway Mainlanes

Specifications

Parameter	Specification
Maximum Range	300 ft
Mounting Height	> 20 ft
Power Sources	AC/Solar/Mix
Environmental Specs	−40°F to 140°F; 0–95% humidity
Lifespan	5-year warrantee (extendable); 10-year expected life

Additional Notes

TAPCO offers a phone call alert medium, if desired. The proprietary monitoring system documents when (timestamp) and to whom (name) the phone notification was sent.

References

www.TAPCOnet.com

https://www.tapconet.com/product/wrong-way-alert-system

TRAFFICALM®

Closed-Course Testing Overview

Wrong-Way Detection	False Positive Detection	Sign Activation	Email Alerts	SMS Alerts
★★★★★	★★★★★	★★★★★	★★★★★	N/A
84/84	0/36	84/84	84/84	Not Tested

Description

The TraffiCalm® wrong-way driving (WWD) system tested used four radar units placed around the exit ramp and operated in pairs to detect a wrong-way (WW) vehicle. Each radar unit was pointed in the correct direction of travel, had a single detection zone, and determined the speed and direction of objects on the ramp. Within each pair, the system required the speeds from both radars to match to activate the corresponding zone. For the closed-course testing, the pair of radars near the WW entry locations activated flashing lights on the WRONG WAY signs and participated in the algorithm used for detection (called the pre-alert zone). The other pair of radars worked together to create an alert zone that is the primary zone for detection. The alert zone was used in conjunction with the pre-alert zone, such that both radar pairs (i.e., all four radars) had to agree that a WW vehicle was detected for the system to issue an alert email. The system used a zone length threshold (i.e., distance the vehicle must travel) between the radar detection zones to ensure that zones were activated consistent with a WW vehicle and were not noise detected by the radar units. When the system detected a WW vehicle, it sent an email that contained a video and link to a proprietary web-based monitoring interface, where a user can view additional details (e.g., timestamp) and deactivate the alarm. The monitoring interface keeps a log of WWD events but only stores the latest video. However, each email alert has the corresponding video attached.

Features Offered	Supported
WRONG WAY Sign Integration	✓
Still Photos	✓
Video	✓
Email Alert	✓
SMS Alert	✓
ATMS Alert	✓
Remote Access	
Monitoring GUI	✓
System Heartbeat	
API Offered	

Applications

Freeway Ramps

Specifications

Parameter	Specification
Maximum Range	600 ft
Mounting Height	10–14 ft
Power Sources	AC/Solar/Mix
Environmental Specs	−29°F to 122°F (batteries) or 165 °F (AC)
Lifespan	10-year expected life

Additional Notes

The TraffiCalm® system can include additional pairs of radars, other zone types (i.e., flasher activation and confirmation), and different alert configurations. The flasher activation zone only activates the sign lights. It does not participate in the detection logic. Confirmation zones are used after the alert zones to promote a low false positive rate. The system configuration can modify the conditions required from the radar units to trigger sending an alert. TraffiCalm® also offers SMS messages via email address that includes a phone number and cell provider (e.g., 1234567890@cellprovider.net), which could not be tested.

References

https://trafficalm.com/wwa/

https://trafficalm.com/wp-content/uploads/2020/10/Wrong-Way-Combined.pdf