Final Report

Testing and Evaluation of Freeway Wrong-way Driving Detection Systems

Project Number

FDOT BDV25-977-40

Prepared For

Florida Department of Transportation

November 2018

CUTR CENTER FOR URBAN TRANSPORTATION RESEARCH
USF UNIVERSITY OF SOUTH FLORIDA
CUTR.USF.EDU

Testing and Evaluation of Freeway Wrong-way Driving Detection Systems

BDV25-977-40

Final Report

Submitted to:

Dr. Raj Ponnaluri, P.E., PTOE, PMP
Connected Vehicles and Arterial Management Engineer
Florida Department of Transportation
605 Suwannee Street, MS 36
Tallahassee FL 32399-0450
Email: raj.ponnaluri@dot.state.fl.us
Phone: (850) 410-5616

Prepared by:

Dr. Pei-Sung Lin, P.E., PTOE, FITE
Principal Investigator (PI)
Program Director – ITS, Traffic Operations and Safety
Center for Urban Transportation Research (CUTR)
University of South Florida
4202 E. Fowler Avenue, CUT100
Tampa, FL 33620
E-mail: lin@cutr.usf.edu
Phone: (813) 974-4910

Dr. Cong Chen, EI
Research Associate Faculty
Center for Urban Transportation Research (CUTR)
University of South Florida
4202 E. Fowler Avenue, CUT100
Tampa, FL 33620
Email: congchen1@cutr.usf.edu
Phone: (813) 974-2344

Dr. Seckin Ozkul, P.E.
Research Associate Faculty
Center for Urban Transportation Research (CUTR)
University of South Florida
4202 E. Fowler Avenue, CUT100
Tampa, FL 33620
Email: sozkul@cutr.usf.edu
Phone: (813) 974-0445

November 2018

DISCLAIMER

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

UNIT CONVERSION TABLE

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
in^2	squareinches	645.2	square millimeters	mm^2
ft^2	squarefeet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	**2. Government Accession No.**	**3. Recipient's Catalog No.**

4. Title and Subtitle Testing and Evaluation of Freeway Wrong-way Driving Detection Systems	**5. Report Date** November 2018
	6. Performing Organization Code
7. Author(s) Pei-Sung Lin, Cong Chen, Seckin Ozkul, Manvitha Rajalingola	**8. Performing Organization Report No.**
9. Performing Organization Name and Address Center for Urban Transportation Research (CUTR) University of South Florida 4202 E. Fowler Avenue, CUT100 Tampa FL 33620	**10. Work Unit No. (TRAIS)**
	11. Contract or Grant No. BDV25-977-40
12. Sponsoring Agency Name and Address Florida Department of Transportation (FDOT) 605 Suwannee St., MS 53 Tallahassee, FL 32399-0450	**13. Type of Report and Period Covered** Final Report, 4/1/17–11/30/18
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Although wrong-way driving (WWD) crashes account for a relatively small portion of total crashes, the impact between two cars crashing into each other at high speeds in opposite directions causes a tremendous amount of damage compared to any other types of crashes, especially on freeways or other limited access facilities. Therefore, there is a continuing need to expand opportunities to reduce crashes by applying new technologies. Sponsored by Florida Department of Transportation (FDOT), this project successfully evaluated video-analytic freeway WWD detection systems currently on the market from three vendors, regarding their capabilities for real-time WWD vehicle detection and Traffic Management Center (TMC) notification. In this project, in addition to actual WWD vehicles, traffic of inside-lane driving in the opposite direction (IDOD) was treated as WWD traffic under certain data collection scenarios for WWD detection to ensure sufficient data size. Six testing locations were selected on I-275 segment between I-4 and I-75 in the Tampa Bay area, and these testing locations were assigned to one of four testing scenarios: (1) testing with normal daily traffic conditions; (2) testing consecutive WWD in both directions; (3) testing under normal light nighttime traffic conditions; and (4) testing under low light nighttime traffic conditions. Real-time WWD incident detection and data collection were conducted through fixed camera videos streams at these locations. A series of performance measures was defined to evaluate the performance of the WWD detection systems from three vendors, including (1) WWD detection system accuracy; (2) percentage of false calls; (3) actual WWD detection accuracy; and (4) percentage of missed calls. In addition, the capabilities of candidate systems on TMC notification were tested by collecting email notification data. The data review and analysis results revealed that (1) WWD is a very rare traffic incident, as there were no actual WWD vehicles detected in real traffic during the one-week data collection period; (2) in all three testing scenarios, including testing of consecutive WWD vehicles in both directions, testing under normal light nighttime traffic conditions, and testing under low light nighttime traffic conditions, researchers found that the system from Vendor 1 showed the best performance at an overall 95% detection system accuracy and 94% actual detection accuracy, followed by the systems from Vendor 2 and Vendor 3; (3) system performance from the three vendors on WWD detection varied significantly, indicating that performance of real-time video-analytic freeway WWD detection systems highly depends on the individual vendor's system; (4) analysis of TMC notification data revealed that all three candidate systems were able to send an email notification if a WWD was detected. The evaluation results and findings from this research project are informative and can be used to support FDOT and other state DOTs in future implementations of WWD detection systems on freeways and limited-access facilities.

17. Key Words	**18. Distribution Statement**
Wrong-way driving (WWD), freeway, limited access facility, video content analytics, WWD detection, Traffic Management Center (TMC) notification, system performance.	

19. Security Classif. (of this report)	**20. Security Classif. (of this page)**	**21. No. of Pages**	**22. Price**
	Unclassified	54	

ACKNOWLEDGEMENTS

The research team is grateful for the excellent guidance and support provided by Project Manager Dr. Raj Ponnaluri of the Florida Department of Transportation (FDOT) Traffic Engineering and Operations Office. We appreciate the support and encouragement of FDOT Research Center Manager Darryll Dockstader and Research Performance Coordinator David Sherman and sincerely thank Chester Chandler, Daniel Buidens, Vincenzo Corazza, Jared Roso, Peter Hsu, and Ron Chin of FDOT District 7 for their full support and assistance in setting up vendor freeway wrong-way detection systems and field data collection. We would like to recognize the three vendors participating in this important research: Telegra, Inc. (Matej Krpan, Branko Glad, Toni Žgaljić), MetroTech Net, Inc. (Paul Valcheff, Dan Harris), and Citilog, Inc. (Tad Carter, Irv Rosenblum). We also would like to acknowledge FDOT District 7 consultants Andrew Young and Scott Teal of TransCore and Matthew Mileto of Lucent Group, Inc., for their support and assistance in camera setup, system testing and calibration, data collection, validation, and analysis. Finally, the research team would like to thank our affiliated faculty Dr. Rui Guo, staff member Kristin Larsson, and student assistants at CUTR who supported our efforts in this project.

EXECUTIVE SUMMARY

Wrong-way driving (WWD) is a major safety concern along freeways and limited-access facilities in Florida. Although WWD crashes account for a relatively small portion of total crashes, the impact between two cars crashing into each other at high speeds in opposite directions causes a tremendous amount of damage compared to any other type of crash, especially on freeways or other limited access facilities. Therefore, it is essential to implement real-time and accurate WWD detection systems on limited-access facilities to instantly detect WWD vehicles and inform regional Traffic Management Center (TMC) personnel and responsible law enforcement officers to take immediate action to prevent the occurrence of a potential wrong-way crash. Sponsored by the Florida Department of Transportation (FDOT), this project successfully evaluated real-time video-analytic freeway WWD detection systems currently on the market from three vendors regarding their capabilities for real-time WWD vehicle detection and TMC notification.

Six testing locations were selected on an I-275 segment between I-4 and I-75 in the Tampa Bay area, including Mile Post (MP) 45.7 Southbound, MP46.7 Southbound, MP47.6 Northbound, MP51.6 Northbound, MP57.0 Northbound, and MP58.9 Southbound, at which the research team conducted WWD incident detection data collection through fixed camera video streams. Since a WWD incident is a very rare event, it is not possible to collect enough actual WWD data within the project timeframe and budget for a solid data analysis to evaluate vendor WWD detection systems. To overcome this challenge, the research team developed an innovative approach to collect sufficient WWD data to evaluate vendor video-analytic freeway WWD detection systems. This innovative approach included collecting actual WWD incident data only at the first location and collecting simulated WWD incident data at five locations. At the second location, the research team treated all right-way traffic as wrong-way traffic for both directions of I-275. For the remaining four locations, traffic of inside-lane driving in the opposite direction (IDOD) was treated as WWD traffic.

The six testing locations were assigned to one of four testing scenarios based on WWD definitions, lighting conditions and testing time: (1) testing with normal daily traffic conditions, (2) testing consecutive WWD in both directions, (3) testing under normal light nighttime traffic conditions, and (4) testing under low light nighttime traffic conditions. Appropriate region of interest (ROI) was defined on the fixed camera video image at each testing location.

A series of performance measures was defined to evaluate the real-time video-analytic freeway WWD detection systems from three vendors, including:

- **Performance Measure #1: WWD Detection System Accuracy** – percentage of true calls on a WWD detection system over total number of WWD calls placed by the system.
- **Performance Measure #2: Percentage of False Calls** – percentage of false calls on a WWD detection system over total number of WWD calls placed by the system.

- **Performance Measure #3: Actual WWD Detection Accuracy** – percentage of true calls on a WWD detection system over total number of true WWD vehicles present in the collected data.
- **Performance Measure #4: Percentage of Missed Calls** – percentage of missed calls on a WWD detection system over total number of true WWD vehicles present in the collected data.

The research team worked and coordinated closely with all involved parties to set up and test three vendors' WWD detection systems regarding system configuration, camera views, camera angles, and system communication. WWD detection data were collected for a full week, including five weekdays and two weekend days. Each system reported the number of WWD incidents detected during the data collection period at each of six study locations during the defined data collection period as well as the detailed date, time (HH:MM:SS), and location information for each WWD incident detected.

To test the capabilities of the three vendors' WWD detection systems to notify the TMC of WWD incidents detected, a project-related email account was created. All three vendors were asked to report related WWD incident information during the defined data collection period to this email account, including WWD occurrence date, time (HH:MM:SS), and location information (site milepost and lane number).

A sufficient-size data sample was reviewed by fully-trained research assistants and researchers for data analysis. Video data during all data collection periods also were collected and reviewed as ground truth data for performance comparison purposes. The results of the data analysis regarding the performance measures of the vendors' WWD detection systems are summarized as follows:

- WWD is a very rare traffic incident. This was confirmed in this study, as there were no actual WWD vehicles detected under normal traffic conditions during the week-long data collection period.
- In tests of vendor systems to detect consecutive WWD vehicles in both directions using one camera, the system from Vendor 1 showed the best performance regarding both detection system accuracy (94%) and actual detection accuracy (98%). The system from Vendor 2 ranked second, and the system from Vendor 3 ranked third. The differences for detection system accuracy between Vendors 1 and 2 and Vendors 1 and 3 were significant at 5% significance level; the differences for actual detection accuracy for each pair of vendor systems were significant at 5% significance level.
- In tests under normal light nighttime traffic conditions, the system from Vendor 1 showed the best performance regarding both detection system accuracy (98%) and actual detection accuracy (90%). The system from Vendor 2 ranked second, and the system from Vendor 3 ranked third. For both detection system accuracy and actual detection

accuracy, the differences between each pair of vendor systems were significant at 5% significance level.

- In tests under low light nighttime traffic conditions, the system from Vendor 1 showed the best performance regarding both detection system accuracy (96%) and actual detection accuracy (90%). The system from Vendor 2 ranked second, and the system from Vendor 3 ranked third. Regarding both detection system accuracy and actual detection accuracy, the differences between each pair of vendor systems were significant at 5% significance level.
- No conclusion could be reached from this project regarding the performance for actual detection accuracy under nighttime traffic with normal light conditions and nighttime traffic with low light conditions. Normal light conditions provided better illumination, but low light conditions seemed to provide better contrast. Both had their own advantages. Further research on this subject is recommended.
- Overall, the results from freeway WWD detection data, TMC notification data, and statistical analysis illustrated that the system from Vendor 1 showed the best performance regarding the proposed measures of effectiveness; the system from Vendor 2 ranked second, and the system from Vendor 3 ranked third. For both detection system accuracy and actual detection accuracy, the difference between each pair of vendor systems was significant at 5% significance level.
- The system performance for all three vendors on WWD detection based on this study varied significantly, indicating that system performance of real-time video-analytic freeway WWD detection systems depends significantly on the individual vendor system. The best system performance was from Vendor 1, at an overall 95% detection system accuracy and 93% actual detection accuracy. The least system performance was from Vendor 3, with an overall 28% detection system accuracy and 12% actual detection accuracy. Vendor 2 had an overall 73% detection system accuracy and 50% actual detection accuracy. The Vendor 1 system potentially could achieve even higher accuracy with proper improvement and enhancement.
- Analysis of TMC notification data revealed that all three candidate systems were able to send an email notification if a WWD was detected; there were no issues with TMC notification connections.
- During testing, issues during system setup revealed that pan–tilt–zoom (PTZ) cameras could not always return to the exact pre-set position to resume WWD detection data collection after contingent operations by FDOT District 7 TMC operators for their needed traffic monitoring activities. To overcome these issues, fixed cameras were used for this study. The research team offers the following two recommendations: (1) check PTZ cameras to determine if they can return to the exact pre-set position for similar studies, and (2) improve freeway WWD detection systems to automatically adjust

settings using reference points for minor movements of PTZ cameras and provide alerts for large movements.

- In this research, IDOD vehicles were treated as wrong-way vehicles under certain data collection scenarios for WWD detection to ensure sufficient WWD incident data to be collected. Given the fact that WWD is a very rare event in actual traffic, the performance statistics of detection system accuracy and actual detection accuracy from this study are excellent indicators for evaluating and comparing vendor's WWD detection system performances; however, they do not necessarily indicate the actual detection accuracies in actual implementation and traffic monitoring. The real system performance should be further investigated based on actual WWD incident detection over sufficiently long time after implementation or evaluated under a controlled environment with proper closure of an interstate highway segment.

The evaluation results and findings from this research project provide insight into the capabilities and accuracy of real-time video-analytic freeway WWD detection systems on WWD detection and TMC notification. The results can be used to support FDOT and other state DOTs in future implementation of WWD detection systems on limited-access facilities.

CONTENTS

List of Figures

List of Tables

1. INTRODUCTION

1.1 Background

A wrong-way driving (WWD) crash is one in which a vehicle traveling in a direction opposing the legal flow of traffic on a high-speed divided highway or access ramp collides with a vehicle traveling on the same roadway in the proper direction [1, 2]. WWD is a major safety concern along freeways and limited-access facilities in Florida. Although wrong-way crashes account for a relatively small portion of total crashes, the impact between two cars crashing into each other at high speeds in opposite directions causes a tremendous amount of damage compared to any other type of crash. Despite providing the necessary "DO NOT ENTER" and "WRONG WAY" signs and pavement markings (wrong-way arrows, etc.) per the *Manual on Uniform Traffic Control Devices* (MUTCD), wrong-way entry onto limited-access facilities continues to occur [3, 4]. According to a report published by the Florida Department of Highway Safety and Motor Vehicles in July 2016, there was an increase in WWD crashes from 2013 to 2015, with 1,351 crashes in 2013, 1,490 crashes in 2014, and 1,490 crashes in 2015, resulting 70, 94, and 96 fatalities, respectively [5]. In total, 54 percent of all WWD fatalities and 36 percent of all WWD crashes occurred in dark conditions (between 9:00 pm–5:59 am). In 2015, in 21 percent of WWD crashes, the driver was under the influence of medication or was drug or alcohol intoxicated, and in three percent of WWD crashes the driver was noted as being asleep or fatigued.

Effective traffic monitoring and incident detection is critical to ensuring the efficiency and serviceability of a transportation network system [6]. As more vehicles are traveling on the roads every day, a robust traffic monitoring system becomes an urgent need to enhance traffic management [7, 8]. Video analytics, loosely defined as automatic analyzers of events occurring in a monitored scene or video streams through video cameras, has been increasingly used in traffic monitoring and incident management [9] and play an important role in traffic flow and incident monitoring and provide insights into daily traffic [10]. Typical traffic issues that can be addressed by video analytics include traffic congestion, traffic accidents, public parking-related issues, toll operations, etc. The following main functions of video analytics have been incorporated into traffic management and help save time and provide effective traffic control and emergency management [10]:

- Traffic congestion detection
- Vehicle/pedestrian detection
- WWD detection
- Stopped vehicle detection (at non-designated parking areas)
- Vehicle classification
- License plate recognition
- Accident evidence collection

To reduce WWD incident occurrence and mitigate crash outcomes, countermeasures using ITS technologies have emerged in the past several years, and new technologies, including video analytics, continue to expand opportunities to reduce crashes and WWD incidents.

1.2 Project Overview

A previous research project funded by the Florida Department of Transportation (FDOT) Research Center and performed by the Center for Urban Transportation Research Center (CUTR) at the University of South Florida (USF) focused on comparing countermeasures installed on exit ramps and adjacent arterials for mitigating wrong-way entries onto limited-access facilities [3, 4]. If a WWD vehicle enters a limited-access facility, it is essential to have a real-time and accurate WWD detection system to instantly detect the vehicle and inform regional Traffic Management Center (TMC) personnel and responsible law enforcement officers to take immediate actions. This research project focused on the testing and evaluation of three real-time video-analytic freeway WWD detection systems currently on the market related to their capabilities for using existing cameras in real time to (1) accurately detect WWD vehicles and (2) notify TMC personnel and law enforcement officers. The evaluation results and findings from this research project can support FDOT in future implementation of WWD detection systems on limited-access facilities in Florida. This study is a joint research and development effort among FDOT, CUTR, and selected vendors that successfully tested and evaluated innovative software video analytics systems from three selected vendors under four scenarios at six study locations on their capabilities to detect WWD occurrences on interstate highways and provide alerts to TMC operators, law enforcement organizations, and others.

1.3 Project Objectives

Video analytics have been used to detect and determine temporal and spatial events in a wide range of fields of interest, where Video Content Analysis (VCA) algorithms have been applied and implemented as software on general-purpose machines or as hardware in specialized video processing units for traffic data collection and incident detection, including the detection of wrong-way vehicles. The major objective of this research was to test and evaluate selected freeway WWD detection systems currently on the market for their capabilities related to WWD vehicle detection and TMC notification and provide findings and recommendations for future implementation in Florida.

1.4 Report Organization

This report is organized into six chapters: 1) Introduction, 2) Project Plan and Execution, 3) Setup of Wrong-way Driving Detection Systems, 4) Data Collection on Freeway WWD Detection and TMC Notification, 5) Evaluation of Freeway WWD Detection Systems, and 6) Research Findings and Conclusions. References are provided at the end of the report.

2. PROJECT WORK PLAN AND EXECUTION

This chapter briefly describes the development and execution of a project work plan for constructing the evaluation of freeway WWD detection systems. To successfully accomplish project objectives, the CUTR research team coordinated closely with the FDOT Central Office, FDOT District 7 and its consultants TransCore and Lucent Group, and three selected vendors—Telegra, MetroTech, and Citilog—throughout the project period to establish and execute a comprehensive project work plan. The project work plan covered testing locations, testing methods, data collection process, performance measure, evaluation criteria, and data analysis. The six-step project work plan was followed closely by the research team to execute the tasks and complete the project.

Implementation of this six-step work project plan was as follows:

1) **Select testing locations and develop testing methods** – In 2014, five fatal WWD crashes occurred on I-275 between I-4 and I-75 in the Tampa Bay area within the jurisdiction of FDOT District 7, making this segment ideal for this study. The District had many pan–tilt–zoom (PTZ) and some fixed cameras in place along I-275 between I-4 and I-75, and six locations with PTZ cameras were initially selected for the study. Due to continual issues encountered from the PTZ cameras to keep a steady region of interest (ROI) for the WWD research, fixed cameras were later installed at the same six locations to replace the original PTZ cameras for the study. The CUTR research team worked closely with the FDOT Central Office and FDOT District 7 to select testing locations on I-275, determine camera type (fixed camera), fine-tune camera settings, and develop testing methods, data collection, and data analysis methods (see Chapters 3 and 4 for details).

2) **Coordinate with all participating parties on freeway WWD detection system testing** – After selection of testing locations and development of testing methods for WWD detection systems, the CUTR research team coordinated with all participating parties, including FDOT and the three selected vendors, on freeway WWD detection system testing. At FDOT's direction, CUTR provided a detailed work scope to the vendors and informed each of the testing process regarding data collection needs, methods, and evaluation criteria. A consulting service agreement was signed between USF and the selected vendors, and the CUTR research team further coordinated with these three vendors regarding system setup and camera setting preference and scheduled meetings with FDOT and the vendors for pre-testing system setup.

3) **Set up vendors' freeway detection systems for pre-testing** – The CUTR research team coordinated the system setup with FDOT District 7 and the selected vendors. Based on the consulting service contract, the vendors shipped their required systems, servers, and/or work stations to FDOT District 7 and worked with the District's Information Technology (IT) Manager and operators to facilitate setup of the WWD detection systems, coordinate software operation and maintenance, and assist with understanding of

technical settings and relevant parameters of the existing cameras along the I-275 corridor used for WWD detection testing. Prior to field testing, the vendors installed, configured, customized, and optimized their software on servers housed at FDOT District 7 and ensured that their systems were ready for testing.

During the pre-testing system setup, one vendor identified continual issues with FDOT's PTZ cameras, in that the cameras could not always return to the exact pre-set position to resume WWD detection data collection after contingent operations by FDOT District 7 (TMC) operators for their needed traffic monitoring activities. The PTZ camera manufacturer attempted to resolve the issues, but the problem continued to exist. Upon suggestion from FDOT District 7 managers and approval from the FDOT Project Manager, fixed cameras were installed to replace the PTZ cameras at all six study locations with assistance from FDOT District 7 consultants TransCore and Lucent Group. The details of the system setup are provided in Chapter 3.

4) **Conduct field testing on WWD detection and TMC notification** – To make sure all cameras and WWD detection systems worked properly, the CUTR research team coordinated with FDOT District 7 and the vendors to discuss and resolve potential issues in the testing procedure and adjusted the configuration details of the tested WWD detection systems as needed. After the WWD detection systems were properly installed, configured, and customized, field testing of the selected systems from the three vendors on WWD detection and TMC notification were conducted. During the field testing/data collection period, CUTR and FDOT District 7 IT closely monitored field testing and responded and resolved any issues or question vendors had.
5) **Collect WWD detection and TMC notification data** – Data collection duration was set for one week, including week and weekend days, with an additional week of data collection when needed. Most freeway WWD detection data and TMC notification data were successfully collected from the three selected vendor software video analytics systems for detailed analysis. To ensure no missing data from any vendor, two days of the second week were used for some data re-collection. The collected WWD detection data included data collection date, WWD detection time, and location information. In addition, a project-specific email account was set up to receive TMC notifications from the three vendor systems. The TMC notification data collected included TMC notification date, WWD detection time, and location information.

For both WWD detection and TMC notification data collections, video data were recorded during the entire data collection process and were reviewed as ground truth data in the data analysis. The CUTR research team closely monitored data collection and worked with the FDOT District 7 IT Manager and the vendors to ensure the quality of data collected and to resolve any problems encountered during the data collection period. The details of field testing and data collection are provided in Chapter 4.

6) **Conduct data analysis and compare performance of vendor systems** – Based on the collected data, the CUTR research team evaluated the selected vendor software video analytic systems on WWD detection and their capability to notify TMC operators and law enforcement organizations. A variety of measures were used for performance evaluation and comparison, including WWD detection system accuracy, percentage of false calls, actual WWD detection accuracy, and percentage of missed calls. The CUTR research team then compared the performance measures of the detection systems and conducted statistical analyses to compare their effectiveness. Detailed definitions of these measures and data analysis are presented in Chapter 5.

3. SETUP OF WRONG-WAY DRIVING DETECTION SYSTEMS

This chapter describes the setup of WWD detection systems for the study, including selection of testing locations, camera settings, field installation of fixed cameras, and testing methods. Considering the rarity of a WWD incident, an innovative approach was developed so sufficient WWD data could be collected and analyzed by researchers.

3.1 Testing Locations and Camera Settings

According to the project scope of work, the study area was an I-275 segment between I-4 and I-75 in the Tampa Bay area. Based on the project work plan developed, the CUTR research team coordinated with all involved parties to finalize testing locations for system setup, considering all the camera locations along the studied I-275 segment, as shown in Figure 3-1. Given the characteristics of these candidate locations regarding lighting condition, roadway and ramp geometry, lane configuration, and traffic volume information, six locations were selected, including I-275 MP45.7 Southbound, I-275 MP46.7 Southbound, I-275 MP47.6 Northbound, I-275 MP51.6 Northbound, I-275 MP57.0 Northbound, and I-275 MP58.9 Southbound.

The WWD detection systems from the selected vendors were originally set up on existing PTZ cameras at the six study locations on I-275. However, technical issues were encountered with these existing PTZ cameras. During the WWD detection setup process for the six study sites, several initial field data collections were conducted to ensure that the systems were ready for WWD data collection. One vendor identified continual problems—the PTZ cameras could not always return to the exact preset position to resume WWD detection data collection after contingent operations by FDOT District 7 TMC operators for their needed traffic monitoring activities. The problems were confirmed by the CUTR team and the FDOT District 7 IT Manager.

Although FDOT District 7, system vendors, the camera manufacturer, and the CUTR research team spent significant effort and time to identify potential problems and implement potential solutions, the PTZ camera issue could not be resolved, which compromised the progress of the project. Upon suggestion by FDOT District 7 representatives and approval by the FDOT Project Manager, a decision was made to switch from the PTZ cameras to fixed cameras at all six study locations for WWD detection data collection to move the research forward.

With support from FDOT District 7 and its contractors TransCore and Lucent Group, fixed cameras were selected and manually installed (see Figure 3-2). Each of the six cameras was mounted approximately 75–80 feet above the ground and 5-10 feet below the existing PTZ cameras. After the switch to fixed cameras, the CUTR team coordinated and worked closely with FDOT District 7 and its consultants TransCore and Lucent Group to calibrate and fine-tune the camera angles and camera views of each fixed camera for optimal camera view configuration (Figure 3-3). Thereafter, CUTR prepared a revised ROI for each of the six testing locations to the three system vendors to allow reconfiguring their systems and setups for WWD data collection.

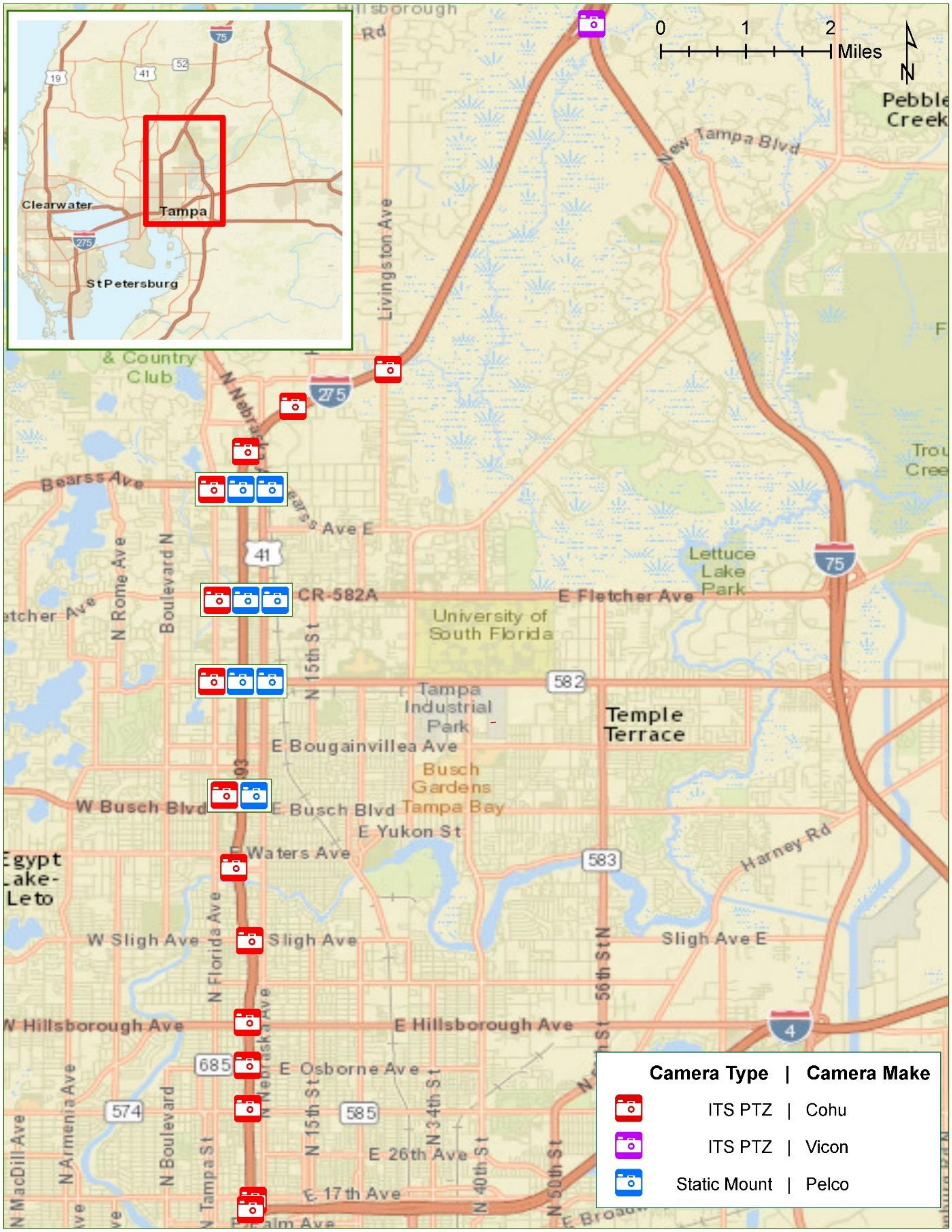


Figure 3-1 Candidate Testing Locations for WWD Detection Systems

Figure 3-2 Field Installation of Fixed Cameras

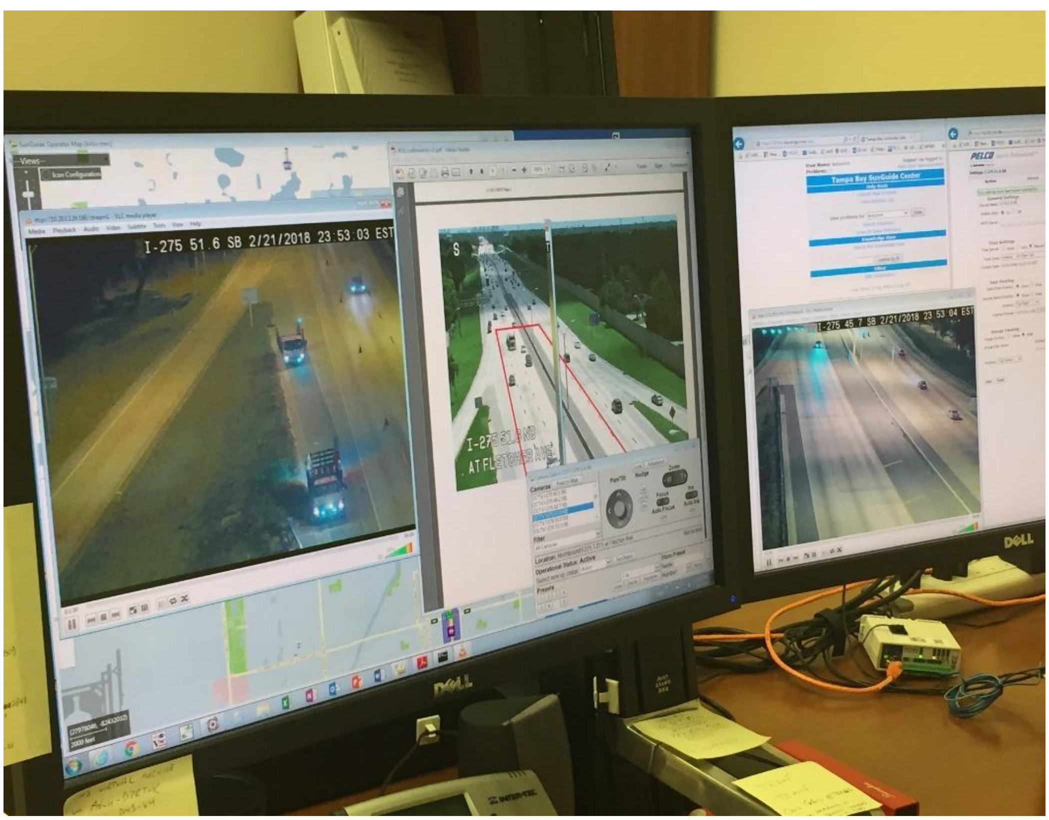


Figure 3-3 Fixed Camera ROI Calibration and Adjustment

3.2 Testing Methods

The following factors were considered for conducting a comprehensive and productive evaluation of the selected WWD detection systems:

- **WWD definition** – As WWD incidents are very rare in actual traffic, an innovative approach was needed to define WWD for this study to ensure a sufficient video data sample for the analysis. The research team needed to identify other WWDs to simulate them as WWD vehicles for this study. For example, WWD incident data showed that WWD vehicles likely travel on the inside-most lane of normal travel lanes; therefore, traffic of inside-lane driving in the opposite direction (IDOD) could also be treated as WWD traffic under certain data collection scenarios for WWD detection, as shown in Figure 3-4. For this study, the following three WWD actions were defined for WWD in the data collection as follows:
  - Actual WWD – only actual WWD was considered during the data collection procedure.
  - All as WWD – vehicles in all lanes in both directions were considered as WWD vehicles during the data collection procedure.
  - IDOD as WWD – an IDOD vehicle was treated as a WWD vehicle during the data collection procedure.

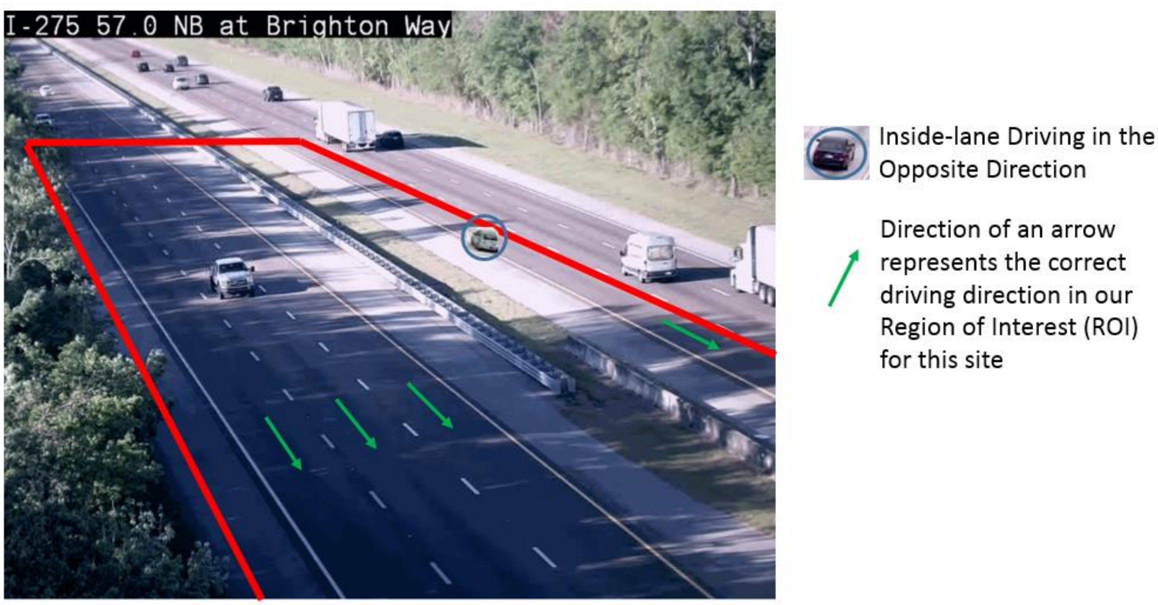


Figure 3-4 Inside-lane Driving in Opposite Direction (IDOD) Vehicle as WWD Vehicle

- **Data collection time** – Three time periods were selected for data collection to represent different freeway traffic volume and headway conditions:
  - 12:00 AM–12:00 AM (full day), normal daily traffic conditions.

  - 12:00 AM–5:00 AM, when night traffic volume is very light and vehicle headway is large.
  - 3:00 AM–4:00 AM, used to test the capability of the vendor systems in detecting consecutive WWD in both directions as WWD at MP47.6 northbound.
- **Low light condition** at night.

Based on these factors and settings in the data collection, the six testing locations were classified into four testing scenarios, as shown in Table 3-1, including:

- **Testing Scenario 1: Testing with Normal Daily Traffic Conditions** – Camera at MP46.7 was set to evaluate the performance of WWD detection systems under regular traffic conditions in which actual WWD vehicles would be detected.
- **Testing Scenario 2: Testing of Consecutive WWD in Both Directions Using One Camera** – Camera at MP47.6 was set to evaluate the performance of WWD detection systems under regular nighttime traffic conditions, and vehicles in all travel lanes of both directions were treated as WWD vehicles.
- **Testing Scenario 3: Testing under Normal Light Nighttime Traffic Conditions** – Cameras at MP45.7 and MP51.6 were set to evaluate the performance of freeway WWD detection systems under normal light nighttime traffic conditions, treating IDOD as WWD.
- **Testing Scenario 4: Testing under Low Light Nighttime Traffic Conditions** – Cameras at MP57.0 and MP58.9 were set to evaluate the performance of freeway WWD detection systems under low light nighttime traffic conditions, treating IDOD as WWD.

Table 3-1 Testing Scenarios, Purposes, Sites, WWD Definitions, and Data Collection Periods

Testing Scenario	Purpose	Site	WWD Definition	Data Collection Time (5 weekdays + 2 weekend days)
1	Testing with normal daily traffic conditions	MP46.7	Actual WWD	Full day
2	Testing consecutive WWD in both directions using one camera	MP47.6	All as WWD	3:00–4:00 AM
3	Testing under normal light nighttime traffic conditions	MP45.7	IDOD as WWD	12:00–5:00 AM
		MP51.6	IDOD as WWD	12:00–5:00 AM
4	Testing under low light nighttime traffic conditions	MP57.0	IDOD as WWD	12:00–5:00 AM
		MP58.9	IDOD as WWD	12:00–5:00 AM

For each site, a virtual region of interest (ROI) for WWD vehicle detection was assigned on the fixed camera screen in the data collection process. The WWD definition and ROI through the camera at each testing site are illustrated through Figure 3-5 through Figure 3-10.

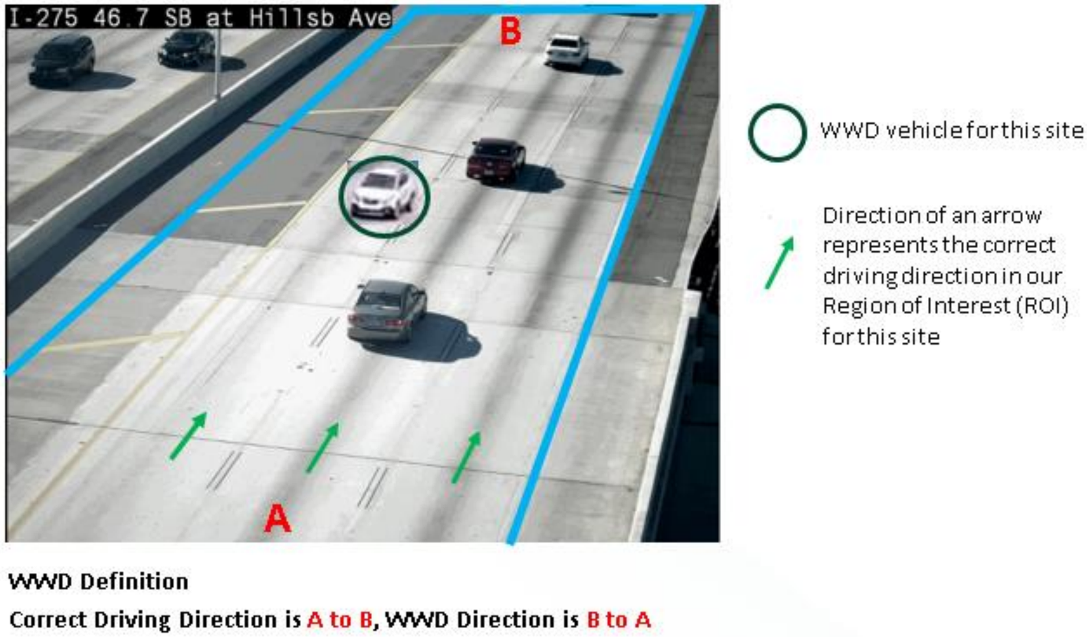


Figure 3-5 ROI and WWD Definitions at I-275 MP46.7 Southbound

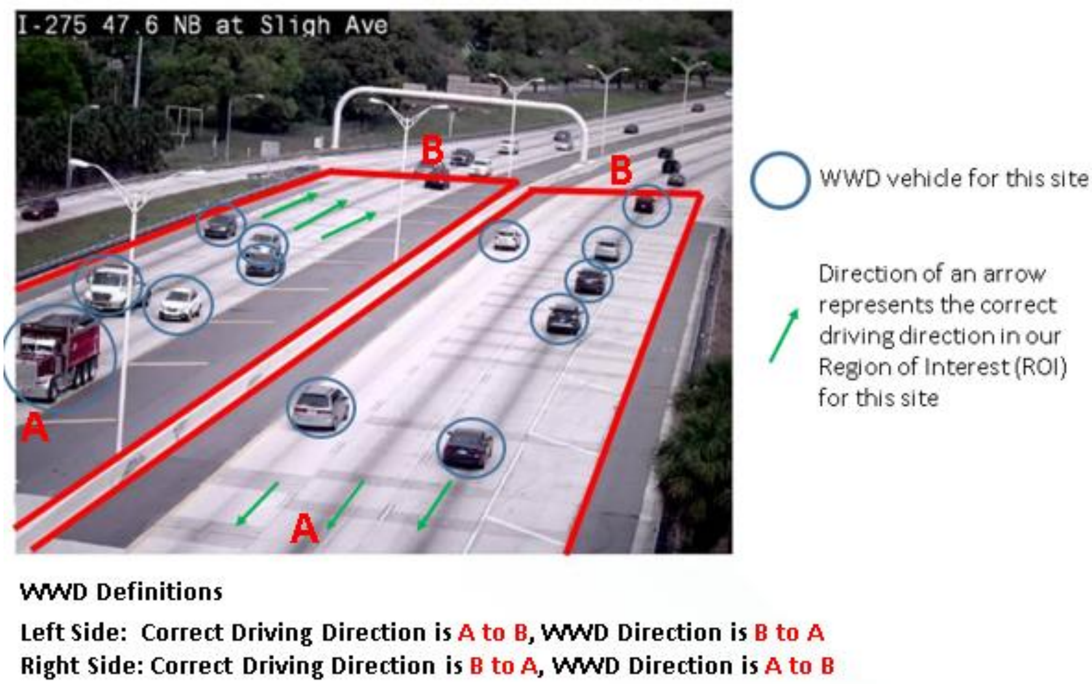


Figure 3-6 ROI and WWD Definitions at I-275 MP47.6 Northbound

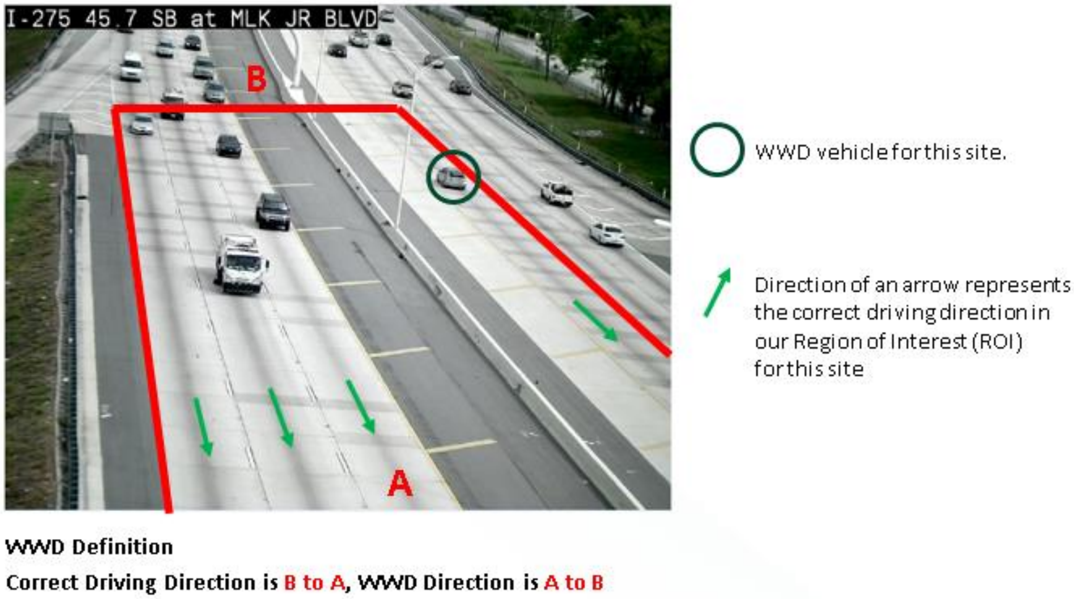


Figure 3-7 ROI and WWD Definitions at I-275 MP45.7 Southbound

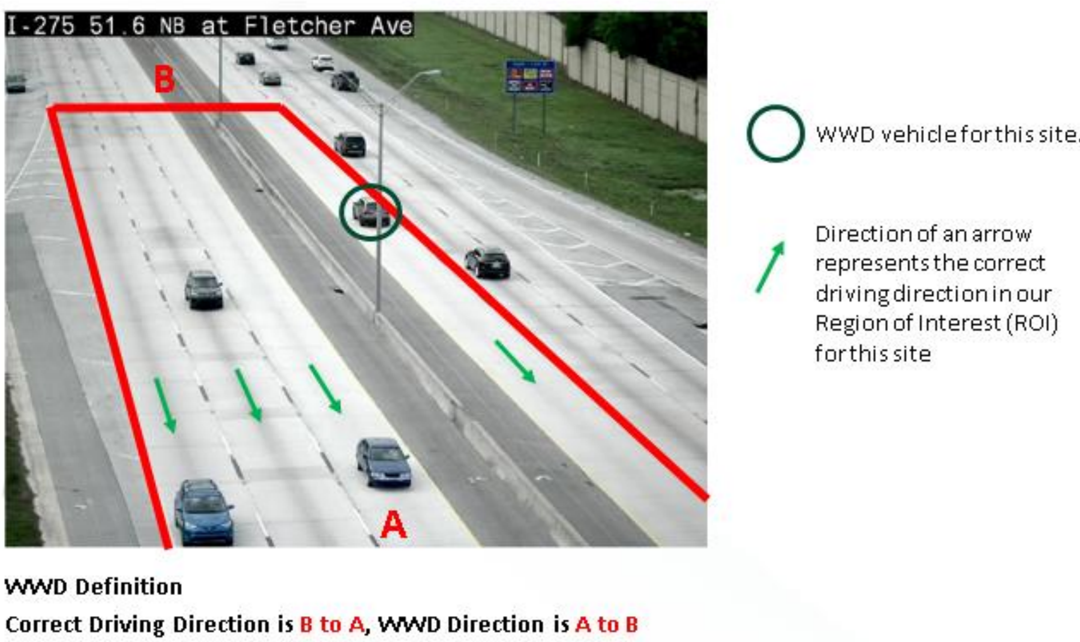


Figure 3-8 ROI and WWD Definitions at I-275 MP51.6 Northbound

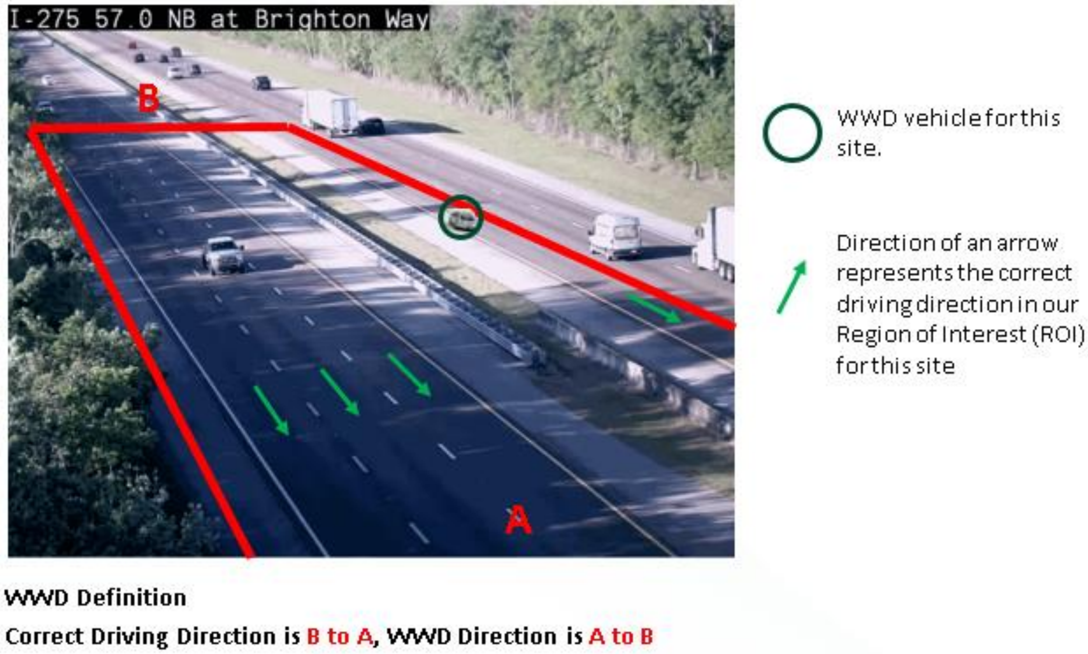


Figure 3-9 ROI and WWD Definitions at I-275 MP57.0 Northbound

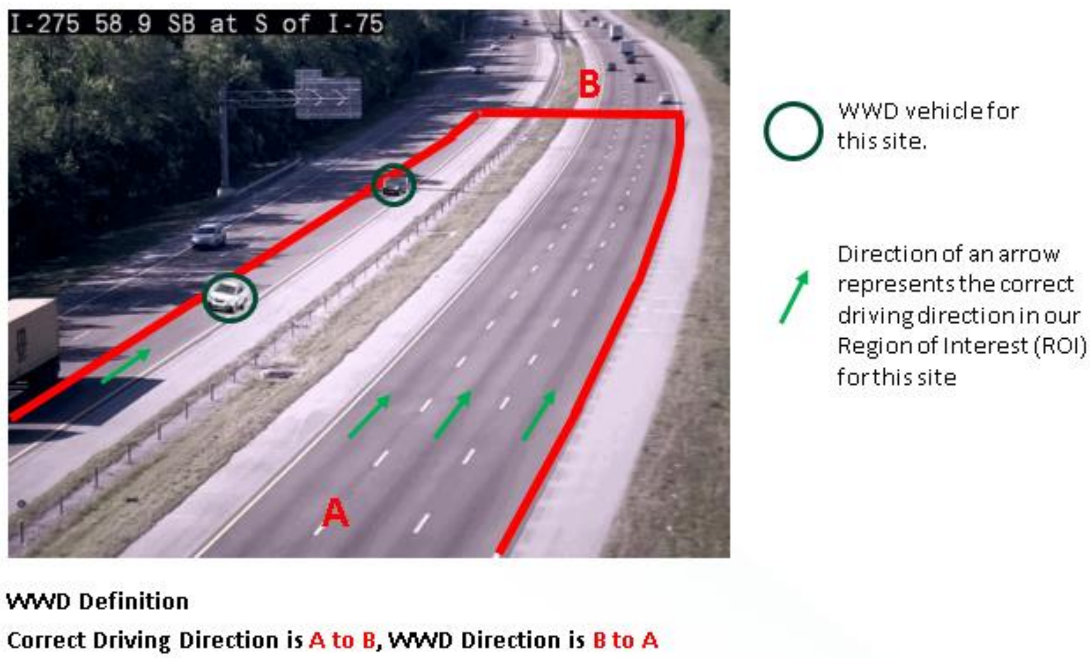


Figure 3-10 ROI and WWD Definitions at I-275 MP58.9 Southbound

Through coordination with CUTR and FDOT District 7, the vendors installed, configured, customized, and optimized their software on servers housed at FDOT District 7 and solved all issues encountered during the system setup process to ensure that their systems were ready for testing and WWD field data collection at the six study locations with fixed cameras.

4. DATA COLLECTION ON FREEWAY WWD DETECTION AND TMC NOTIFICATION

Success of data collection on freeway WWD detection and TMC notification is essential to evaluate and compare the capabilities of the vendors' real-time video-analytic freeway detection systems. This chapter describes the process and details for collecting WWD detection data and TMC notification data.

4.1 Collection of Freeway WWD Detection Data

Based on the testing and data collection methods documented in Table 3-1, the CUTR research team worked with all involved parties to complete the collection of freeway WWD data at the designated locations along the I-275 corridor between I-4 and I-75, including I-275 MP45.7 Southbound, I-275 MP46.7 Southbound, I-275 MP47.6 Northbound, I-275 MP51.6 Northbound, I-275 MP57.0 Northbound, and I-275 MP58.9 Southbound. Each vendor's WWD detection system was required to perform WWD detection in real time through the six cameras. Each system reported the number of WWD incidents detected during the data collection period through each camera following the time frame in Table 3-1. For each WWD incident, it was also required to automatically report the detailed date, time (HH:MM:SS), and location information. Table 4-1 shows an example report of WWD incidents from one vendor's WWD video analytic system. The collection of freeway WWD detection data was conducted for seven consecutive days, including five weekdays and two weekend days.

Video data through these fixed cameras were also recorded during the entire data collection process and were reviewed as ground truth data for system performance evaluation purposes (see Chapter 5). FDOT District 7 representatives assisted in the video data recording process.

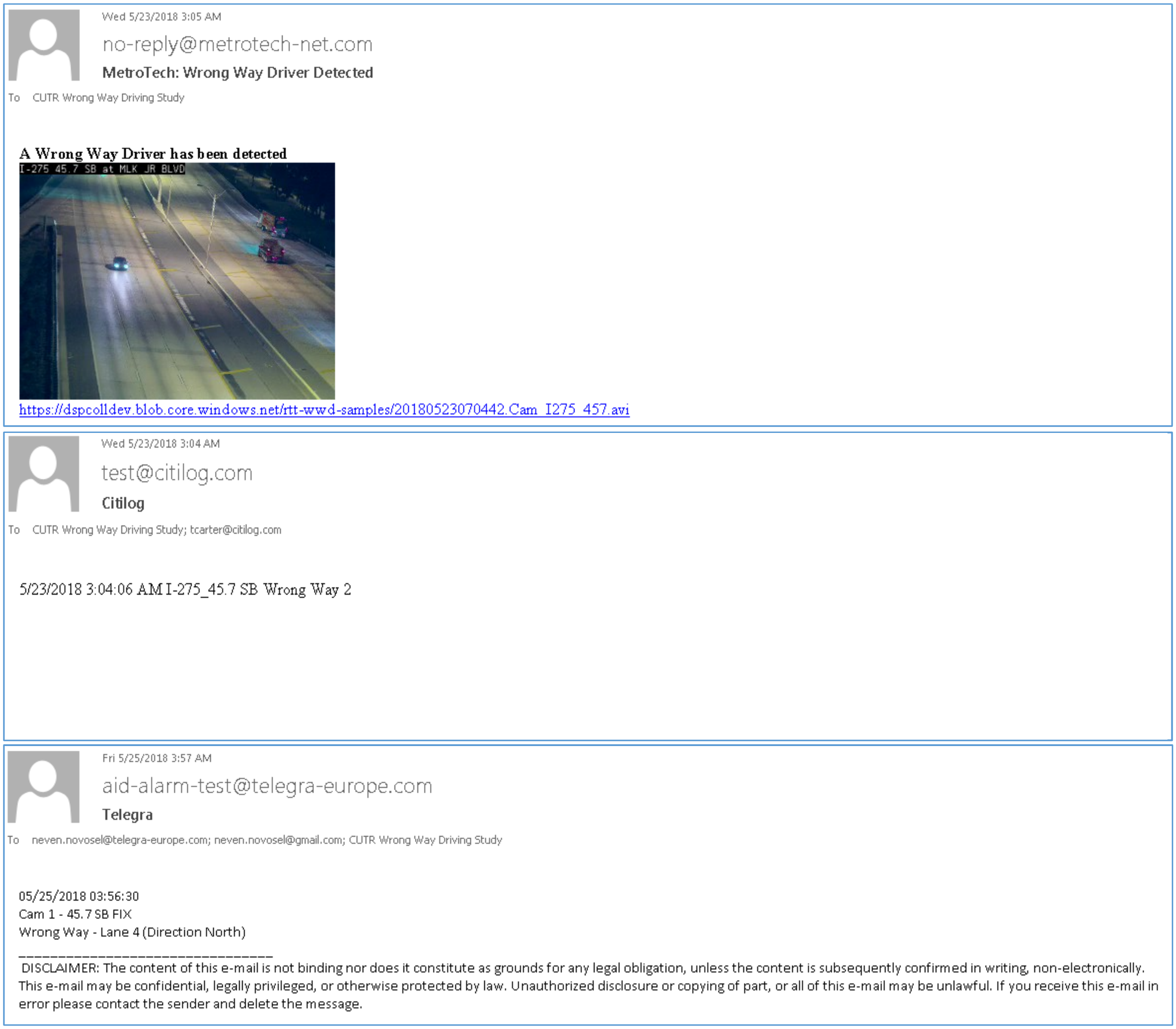
Table 4-1 Vendor 2 Sample Report of WWD Incidents by a WWD Detection System

Date - Time	Camera ID	Road ID	Segment ID	Lane ID
May 12th 2018, 03:00:30.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:00:57.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:01:25.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:01:34.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:01:41.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:02:10.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:03:00.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:03:00.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:03:35.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:03:55.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:04:06.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:04:14.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:04:37.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:04:48.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:05:12.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:05:20.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:05:36.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:05:41.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:06:10.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:07:40.000	Cam_I275_476	I275	MM 47.6	T1
May 12th 2018, 03:07:44.000	Cam_I275_476	I275	MM 47.6	T1

4.2 Collection of TMC Notification Data

According to the project scope of work, the performance of the selected vendors' WWD detection systems was evaluated using two functions—the capability to detect WWD vehicles and the capability to send notification of WWD to the TMC. Therefore, the CUTR project team also coordinated with all involved parties to complete collection of TMC notification data.

To test the capabilities of the three WWD detection systems on TMC notification, a project-related email account (CUTR Wrong-Way Driving Study, wwdstudy@cutr.usf.edu) was created solely for WWD notification purposes, and all three vendors were asked to collect WWD vehicle data of I-275 MP45.7 Southbound from 2:00 AM –4:00 AM on the same weekday. Each WWD detection system was set to automatically send an email notification when a WWD vehicle was detected by the system to the designated email with WWD occurrence date, time (HH:MM:SS), and location (site milepost and lane number) information. Original video data through the fixed camera was also collected as the ground truth data for performance evaluation purposes. In this way, the notification capabilities of these WWD detection systems could be compared based on the reported time stamp and the actual time stamp in the recorded video data. Figure 4-1 shows sample email notifications from the three WWD detection systems tested.



Wed 5/23/2018 3:05 AM
no-reply@metrotech-net.com
MetroTech: Wrong Way Driver Detected
To CUTR Wrong Way Driving Study

A Wrong Way Driver has been detected
I-275 45.7 SB at MLK JR BLVD
https://dspcolldev.blob.core.windows.net/rtt-wwd-samples/20180523070442.Cam_I275_457.avi

Wed 5/23/2018 3:04 AM
test@citilog.com
Citilog
To CUTR Wrong Way Driving Study; tcarter@citilog.com

5/23/2018 3:04:06 AM I-275_45.7 SB Wrong Way 2

Fri 5/25/2018 3:57 AM
aid-alarm-test@telegra-europe.com
Telegra
To neven.novosel@telegra-europe.com; neven.novosel@gmail.com; CUTR Wrong Way Driving Study

05/25/2018 03:56:30
Cam 1 - 45.7 SB FIX
Wrong Way - Lane 4 (Direction North)

____
DISCLAIMER: The content of this e-mail is not binding nor does it constitute as grounds for any legal obligation, unless the content is subsequently confirmed in writing, non-electronically. This e-mail may be confidential, legally privileged, or otherwise protected by law. Unauthorized disclosure or copying of part, or all of this e-mail may be unlawful. If you receive this e-mail in error please contact the sender and delete the message.

Figure 4-1 Sample Email Notifications of WWD Incident

Both freeway WWD detection data and TMC notification data were successfully collected from the vendor systems. The CUTR project team examined and compiled the data collected for the evaluation of freeway WWD detection systems outlined in Chapter 5 of this report.

5. EVALUATION OF FREEWAY WWD DETECTION SYSTEMS

This chapter includes four major sections including (1) Evaluation Methods and Data Review, (2) Evaluation of System Capability on WWD Incident Detection, (3) Evaluation of System Capability on TMC Notification, and (4) Analysis Summary.

5.1 Evaluation Methods and Data Review

5.1.1 Evaluation Methods and Criteria

To compare the performance of the three candidate WWD detection systems, the following system performance measures were developed: 1) WWD detection accuracy, 2) percentage of false calls, 3) actual WWD detection accuracy, and 4) percentage of missed calls. These measures of effectiveness are defined as follows:

- **Performance Measure #1: WWD Detection System Accuracy** – percentage of true calls on a WWD detection system over the total number of WWD calls placed by the system. An effective WWD detection system produces a high WWD detection system accuracy.

  $$\text{WWD detection system accuracy (\%)} = \frac{\textit{Total Number of True Calls}}{\textit{Total Number of WWD Detection Calls}} \times 100\%$$

- **Performance Measure #2: Percentage of False Calls** – percentage of false calls on a WWD detection system over the total number of WWD calls placed by the system. An effective WWD detection system produces a low percentage of false calls on WWD detection.

  $$\text{Percentage of false calls (\%)} = \frac{\textit{Total Number of False Calls}}{\textit{Total Number of WWD Detection Calls}} \times 100\%$$

  $$\text{Percentage of false calls (\%)} = 100\% - \text{WWD detection system accuracy (\%)}$$

- **Performance Measure #3: Actual WWD Detection Accuracy** – percentage of true calls on a WWD detection system over the total number of WWD vehicles present in the collected data. An effective WWD detection system produces a high actual WWD detection accuracy.

  $$\text{Actual WWD detection accuracy (\%)} = \frac{\textit{Total Number of True Calls}}{\textit{Total Number of WWD Vehicles Present}} \times 100\%$$

- **Performance Measure #4: Percentage of Missed Calls** – percentage of missed calls on a WWD detection system over the total number of WWD vehicles present in the collected data. An effective WWD detection system produces a low percentage of missed calls on WWD detection.

  $$\text{Percentage of missed calls (\%)} = \frac{\textit{Total Number of Missed Calls}}{\textit{Total Number of WWD Vehicles Present}} \times 100\%$$

  $$\text{Percentage of missed calls (\%)} = 100\% - \text{Actual WWD detection accuracy (\%)}$$

Elements of these measures of effectiveness are defined as follows:

- **True Call** – WWD detection call was correctly placed when a WWD vehicle was present.
- **False Call** – WWD detection call was incorrectly placed when a WWD vehicle was not present.
- **Missed Call** – WWD detection call was not placed when a WWD vehicle was present.
- **Total Number of WWD Detection Calls** – total number of WWD detection calls placed by the WWD detection system.
- **Total Number of WWD Vehicles Present** – total number of WWD vehicles present in collected data; could be obtained via permanent count station(s) or from video data review by trained the CUTR research team members.

5.1.2 Data Review

Data collection was conducted in consecutive days at each of the six designated sites along I-275, including five weekdays and two weekend days, and data for two weekdays and one weekend day were reviewed. For each of the three days selected, the time periods during which the data were reviewed for each of the six sites are shown in Table 5-1. Video data for these days and time periods were reviewed to ensure a representative data sample of sufficient size for analysis. Student research assistants were fully trained to review the data based on the definitions, and the review results were used as ground truth data for comparisons with vendor reporting data on WWD detection and identification of true detection, false calls, and missed calls. Quality assurance was conducted to ensure the reliability of review results.

Table 5-1 Days and Times of WWD Video Data Reviewed for Each Site

Testing Scenario	Purpose	Site	WWD Definition	Days Reviewed	Time for Review
1	Testing with normal daily traffic conditions	MP46.7	Actual WWD	Weekday 1	Reviews of random time conducted, as no WWD reported
				Weekday 2	
				Weekend Day	
2	Testing consecutive WWD in both directions using one camera	MP47.6	All as WWD	Weekday 1	3:00–3:30 AM
				Weekday 2	3:00–3:30 AM
				Weekend Day	3:00–3:30 AM
3	Testing under normal light nighttime traffic conditions	MP45.7	IDOD[1] as WWD	Weekday 1	12:00–3:00AM
				Weekday 2	12:00–3:00AM
				Weekend Day	12:00–3:00AM
		MP51.6	IDOD[1] as WWD	Weekday 1	12:00–3:00AM
				Weekday 2	12:00–3:00AM
				Weekend Day	12:00–3:00AM
4	Testing under low light nighttime traffic conditions	MP57.0	IDOD[1] as WWD	Weekday 1	12:00–3:00AM
				Weekday 2	12:00–3:00AM
				Weekend Day	12:00–3:00AM
		MP58.9	IDOD[1] as WWD	Weekday 1	12:00–3:00AM
				Weekday 2	12:00–3:00AM
				Weekend Day	12:00–3:00AM

[1] *IDOD: inside-lane driving in opposite direction*

In the data review procedure, the reviewers carefully examined the video data and recorded the time stamp when a WWD vehicle first and fully appeared in the ROI on the screen (see Figure 5-1). It should be noted that, for most circumstances, the WWD vehicle ran through the entire WWD lane; however, two exceptions should be carefully considered: 1) the target vehicle entered the WWD lane from the bottom border but moved to the adjacent lane before exiting the WWD lane at the upper border (see Figure 5-2), and 2) the target vehicle entered the screen on the adjacent lane and then changed lane into the WWD lane for detection (see Figure 5-3). Under either of these two circumstances, the time stamp when the target vehicle fully entered into the WWD lane (from the bottom border for Condition 1 and from the right border of the WWD lane for Condition 2) was recorded, as highlighted in each figure.

Figure 5-1 Data Review Example of WWD Vehicle and Time Stamp (base video image provided by Vendor 1)

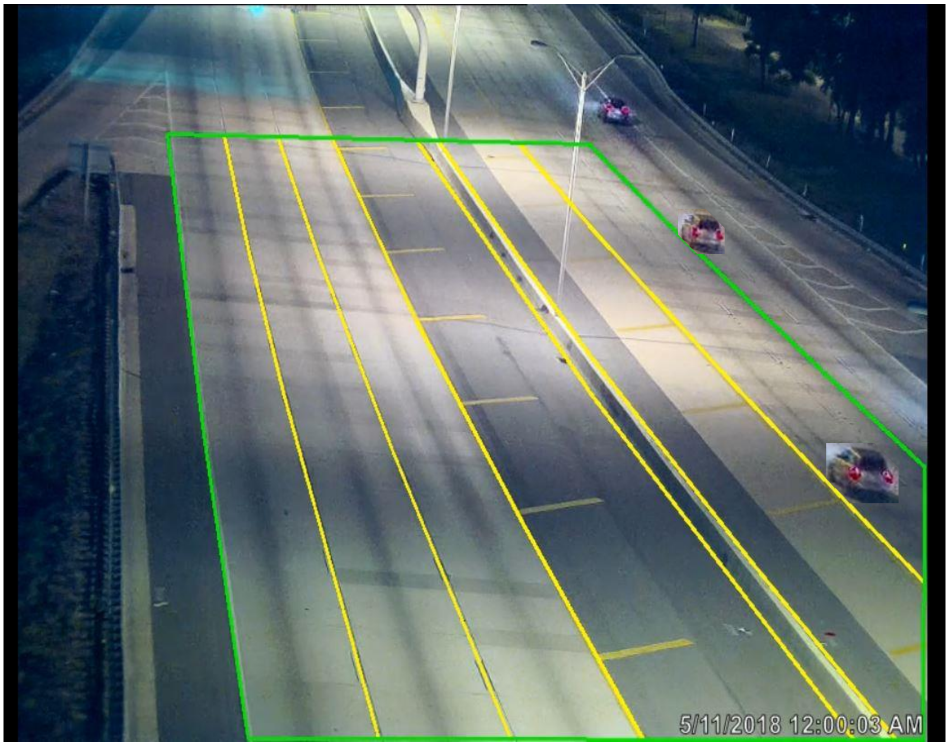


Figure 5-2 Target Vehicle Lane-change Out of WWD Lane
(base video image provided by Vendor 1)

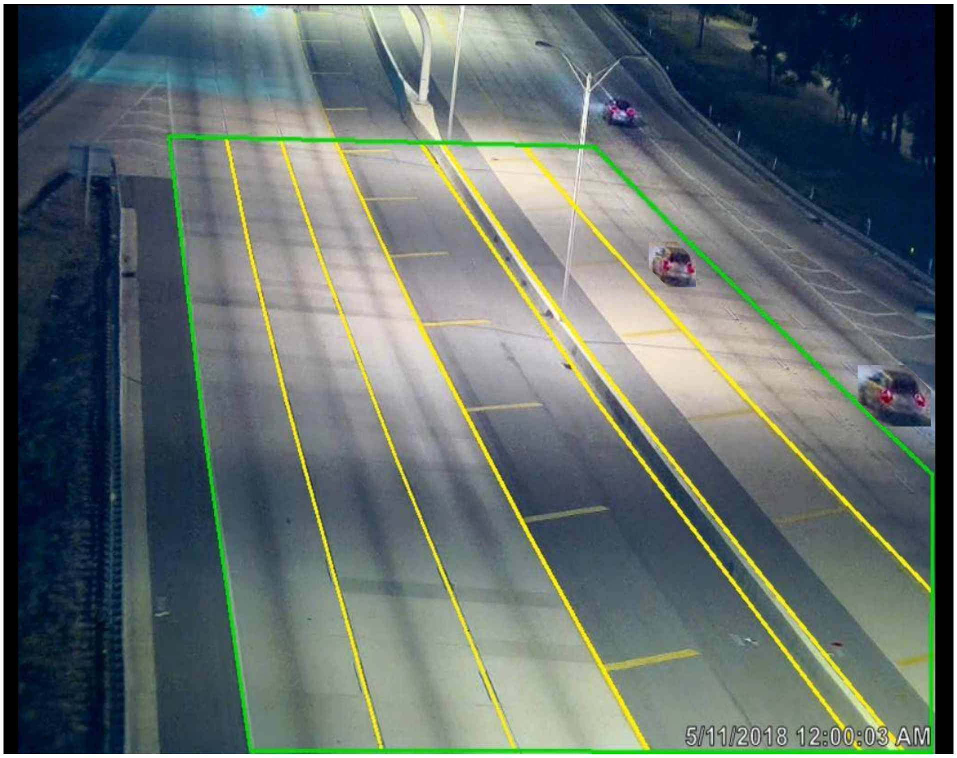


Figure 5-3 Target Vehicle Lane-change into WWD Lane
(base video image provided by Vendor 1)

5.1.3 Significance Test

The performance of different vendor systems for WWD detection were compared. Chi-square tests were used to determine whether differences in the measures of effective detection between vendors were statistically significant:

$$H_0: P_{v\_i} = P_{v\_j} \ (i = 1, 2, 3, j = 1, 2, 3, i \neq j)$$

$$H_a: P_{v\_i} \neq P_{v\_j} \ (i = 1, 2, 3, j = 1, 2, 3, i \neq j)$$

where, P_{v_i} (P_{v_j}) is the statistical value under comparison for Vendor i (Vendor j).

The comparisons of the different measures of effectiveness are listed in Section 1.1 for each pair of vendor systems. All hypothesis tests were conducted at a minimum confidence level of 95%.

5.2 Evaluation of System Capability on WWD Incident Detection

5.2.1 Evaluation of System Capability on WWD Incident Detection by Scenarios

To comprehensively evaluate the performance of vendor systems on WWD incident detection, the six test sites were classified into four scenarios, as indicated in Section 1.1. The performance of these systems was compared under each of these four scenarios; the results are as follows:

- **Testing Scenario 1: Testing with Normal Daily Traffic Conditions** – Camera at MP46.7 was set to evaluate the performance of WWD detection systems under regular traffic conditions, where actual WWD vehicles would be detected. During the full week data collection, no WWD vehicle was detected. Therefore, no performance evaluation under this condition was conducted.
- **Testing Scenario 2: Testing of Consecutive WWD in Both Directions Using One Camera** – Camera at MP47.6 was set to evaluate the performance of WWD detection systems under regular nighttime traffic conditions, and vehicles in all travel lanes of both directions were treated as WWD vehicles. The analysis results regarding true calls, false calls, and missed calls are shown in Table 5-2.

Table 5-2 Data Review Results for Consecutive WWD Detection in Both Directions

Day of Review	Ground Truth	Vendor 1			Vendor 2			Vendor 3		
		True Call	***False Call***	***Missed Call***	***True Call***	***False Call***	***Missed Call***	***True Call***	***False Call***	***Missed Call***
Weekday 1	377	359	38	18	319	131	58	10	11	367
Weekday 2[1]	426/463	419	19	7	376	32	50	81	10	382
Weekend[2]	1,030/950	1,017	62	13	922	49	108	183	24	767
Total	1,833/1,790	1,795	119	38	1,617	212	216	274	45	1,516

[1] Due to unexpected technical difficulty in data collection, Vendor 3 was not able to report WWD data for MP47.6 on this day. Therefore, WWD data on another weekday (Weekday 3) at the same site during the same period were used here for Vendor 3. Ground truth and performance data on Weekday 3 are underlined.

[2] Due to unexpected technical difficulty in data collection, Vendor 3 was not able to report WWD data on this weekend day (Weekend Day 1). Therefore, make-up data collection was conducted on another weekend day (Weekend Day 2) during the same period for Vendor 3. Ground truth and performance data on Weekend Day 2 are underlined.

Based on the number of true calls, false calls, and missed reported in Table 5-2, the measures of effectiveness were calculated and are summarized in Table 5-3. Significance tests were conducted to assess the difference regarding the performance of vendor systems. The test results are presented in Table 5-4.

Table 5-3 Performance Evaluation for Consecutive WWD Detection in Both Directions Based on Measures of Effectiveness

Vendor #	Measure of Effectiveness			
	Detection System Accuracy	*% False Calls*	*Actual Detection Accuracy*	*% Missed Calls*
Vendor 1	93.78%	6.22%	97.93%	2.07%
Vendor 2	88.41%	11.59%	88.22%	11.78%
Vendor 3	85.89%	14.11%	15.26%	84.74%

Table 5-4 Measure of Effectiveness Comparison between Vendors for Consecutive WWD Detection in Both Directions

Vendor Comparison	Difference in Measure of Effectiveness			
	Detection System Accuracy		*Actual Detection Accuracy*	
	Value	P-value	Value	P-value
Vendors 1 and 2	5.37%	<0.0001	9.71%	<0.0001
Vendors 1 and 3	7.89%	<0.0001	82.66%	<0.0001
Vendors 2 and 3	3.27%	0.2014	72.95%	<0.0001

As shown in Table 5-3 and Table 5-4:

- Detection System Accuracy (proportion of true calls in all WWD calls):
  - The system from Vendor 1 had the best performance (most true calls and correspondingly fewest false calls under the same condition), showing a detection system accuracy of 93.78%. The system from Vendor 2 was second, with a detection system accuracy of 88.41%, followed by the system from Vendor 3, with a detection system accuracy of 85.89%.
  - The differences between Vendors 1 and 2 and Vendors 1 and 3 are significant at 5% significance level; the difference between Vendors 2 and 3 was not significant at 5% significance level.
- Actual Detection Accuracy (proportion of true notification in all WWD vehicles present):
  - The system from Vendor 1 had the best performance (fewest missed calls under the same condition), showing an actual detection accuracy of 97.93%. The system from Vendor 2 was second, with an actual detection accuracy of 88.22%, followed by the system from Vendor 3, with an actual detection accuracy of 15.26%.

- The differences between Vendors 1 and 2, Vendors 1 and 3, and Vendors 2 and 3 were significant at 5% significance level.

- **Testing Scenario 3: Testing under Normal Light Nighttime Traffic Conditions** – Cameras at MP45.7 and MP51.6 were set to evaluate the performance of freeway WWD detection systems under nighttime traffic conditions with normal light, treating IDOD as WWD. The analysis results regarding true calls, false calls, and missed calls are shown in Table 5-5.

Table 5-5 Data Review Results for Testing under Normal Light Nighttime Traffic Conditions

Day of Review	Site	Ground Truth	Vendor 1			Vendor 2			Vendor 3		
			True Call	*False Call*	*Missed Call*	*True Call*	*False Call*	*Missed Call*	*True Call*	*False Call*	*Missed Call*
Weekday 1	MP45.7	297	265	9	32	75	26	222	8	11	289
	MP51.6	98	93	3	5	35	9	63	3	3	95
Weekday 2	MP45.7[1]	305/364	276	6	29	262	10	43	12	0	352
	MP51.6	80	79	3	1	59	5	21	22	3	58
Weekend[2]	MP45.7	976/962	864	20	112	800	23	176	42	26	920
	MP51.6	190/177	177	0	13	156	5	34	3	38	174
Total		1,946/1,978	1754	41	192	1,387	78	559	90	81	1,888

[1] Due to unexpected technical difficulty in data collection, Vendor 3 was not able to report WWD data for this site on this day. Therefore, WWD data on another weekday (Weekday 3) at the same site during the same period were used here for Vendor 3. Ground truth and performance data on Weekday 3 are underlined.
[2] Due to unexpected technical difficulty in data collection, Vendor 3 was not able to report WWD data on this weekend day (Weekend Day 1). Therefore, make-up data collection was conducted on another weekend day (Weekend Day 2) during the same period for Vendor 3. Ground truth and performance data on Weekend Day 2 are underlined.

Based on the number of true calls, false calls, and missed calls reported in Table 5-5, the measures of effectiveness were calculated and are summarized in Table 5-6. Significance tests were conducted to assess the difference regarding the performance of vendor systems, and test results are presented in Table 5-7.

Table 5-6 Performance Evaluation for Testing under Normal Light Nighttime Traffic Conditions Based on Measures of Effectiveness

Vendor #	Measure of Effectiveness			
	Detection System Accuracy	*% False Calls*	*Actual Detection Accuracy*	*% Missed Calls*
Vendor 1	97.72%	2.28%	90.13%	9.87%
Vendor 2	94.68%	5.32%	71.27%	28.73%
Vendor 3	52.63%	47.37%	4.55%	95.45%

Table 5-7 Measure of Effectiveness Comparison between Vendors for Testing under Normal Light Nighttime Traffic Conditions

Vendor Comparison	Difference in Measure of Effectiveness			
	Detection System Accuracy		*Actual Detection Accuracy*	
	Value	P-value	Value	P-value
Vendors 1 and 2	3.04%	<0.0001	18.86%	<0.0001
Vendors 1 and 3	45.08%	<0.0001	85.58%	<0.0001
Vendors 2 and 3	42.04%	<0.0001	66.72%	<0.0001

As shown in Table 5-6 and Table 5-7, under nighttime traffic conditions with normal lighting:

- Detection System Accuracy (proportion of true calls in all WWD calls):
  - The system from Vendor 1 had the best performance (most true calls and correspondingly fewest false calls under the same condition), showing a detection system accuracy of 97.72%. The system from Vendor 2 was second, with a detection system accuracy of 94.68%, followed by the system from Vendor 3, with a detection system accuracy of 52.63%.
  - The differences between Vendors 1 and 2, Vendors 1 and 3, and Vendors 2 and 3 were significant at 5% significance level.
- Actual Detection Accuracy (proportion of true calls in all WWD vehicles present):
  - The system from Vendor 1 had the best performance (fewest missed calls under the same condition), showing an actual detection accuracy of 90.13%. The system from Vendor 2 was second, with an actual detection accuracy of 71.27%, followed by the system from Vendor 3, with an actual detection accuracy of 4.55%.
  - The differences between Vendors 1 and 2, Vendors 1 and 3, and Vendors 2 and 3 were significant at 5% significance level.

- **Testing Scenario 4: Testing under Low Light Nighttime Traffic Conditions** – Cameras at MP57.0 and MP58.9 were set to evaluate the performance of freeway WWD detection systems under low light nighttime traffic conditions, treating IDOD as WWD. The analysis results regarding true calls, false calls, and missed calls are shown in Table 5-8.

Table 5-8 Data Review Results for Testing under Low Light Nighttime Traffic Condition

Day of Review	Site	Ground Truth	Vendor 1			Vendor 2			Vendor 3		
			True Call	*False Call*	*Missed Call*	*True Call*	*False Call*	*Missed Call*	*True Call*	*False Call*	*Missed Call*
Weekday 1	MP57.0	89	80	5	9	58	30	31	62	98	27
	MP58.9	79	73	8	6	62	46	17	0	1	79
Weekday 2	MP57.0	66	61	7	5	37	7	29	3	59	63
	MP58.9	99	98	6	1	81	25	18	1	85	98
Weekend[1] (Day1/ Day2)	MP57.0	139/118	136	13	3	65	3	74	34	99	84
	MP58.9	95/96	95	1	0	81	13	14	40	122	56
Total		206/200	205	1	1	178	24	28	69	325	131

[1] Due to unexpected technical difficulty in data collection, Vendor 3 was not able to report WWD data on this weekend day (Weekend Day 1). Therefore, make-up data collection was conducted on another weekend day (Weekend Day 2) during the same period for Vendor 3. Ground truth and performance data on Weekend Day 2 are underlined.

Based on the number of true calls, false calls, and missed reported in Table 5-8, the measures of effectiveness were calculated and are summarized in Table 5-9. Significance tests were conducted to assess the difference regarding the performance of vendor systems, and the test results are presented in Table 5-10.

Table 5-9 Performance Evaluation for Testing under Low Light Nighttime Traffic Conditions Based on Measures of Effectiveness

Vendor #	Measure of Effectiveness			
	Detection System Accuracy	*% False Calls*	*Actual Detection Accuracy*	*% Missed Calls*
Vendor 1	94.23%	5.77%	96.31%	3.69%
Vendor 2	78.08%	21.92%	70.94%	29.06%
Vendor 3	20.22%	79.78%	25.96%	74.04%

Table 5-10 Measure of Effectiveness Comparison between Vendors for Testing under Low Light Nighttime Traffic Conditions

Vendor Comparison	Difference in Measure of Effectiveness			
	Detection System Accuracy		*Actual Detection Accuracy*	
	Value	P-value	Value	P-value
Vendors 1 and 2	16.14%	<0.0001	25.37%	<0.0001
Vendors 1 and 3	74.01%	<0.0001	70.35%	<0.0001
Vendors 2 and 3	57.87%	<0.0001	44.98%	<0.0001

As shown in Table 5-9 and Table 5-10, under low light nighttime traffic condition:

- Detection System Accuracy (proportion of true calls in all WWD calls):
  - The system from Vendor 1 had the best performance (most true calls and correspondingly fewest false calls under the same condition), showing a

detection system accuracy of 94.23%. The system from Vendor 2 was second, with a detection system accuracy of 78.08%, followed by the system from Vendor 3, with a detection system accuracy of 20.22%.
    - The differences between Vendors 1 and 2, Vendors 1 and 3, and Vendors 2 and 3 were significant at 5% significance level.
  - Actual Detection Accuracy (proportion of true calls in all WWD vehicles present):
    - The system from Vendor 1 had the best performance (fewest missed calls under the same condition), showing an actual detection accuracy of 96.31%. The system from Vendor 2 was second, with an actual detection accuracy of 70.94%, followed by the system from Vendor 3, with an actual detection accuracy of 25.96%.
    - The differences between Vendors 1 and 2, Vendors 1 and 3, and Vendors 2 and 3 were significant at 5% significance level.

5.2.2 Comparison of System Capability on WWD Incident Detection in Different Scenarios

A performance evaluation was also conducted for each system under different testing scenarios, and significance tests were conducted for each group to identify significance of performance variation. Since there were no WWD vehicles detected in the first testing scenario, it was not included in the comparison analysis. The results are shown in Table 5-11 and Table 5-12 .

Table 5-11 Summary of System Performance Comparison in Different Testing Scenarios

Vendor ID	Scenario ID	Detection System Accuracy	Actual Detection Accuracy
Vendor 1	Scenario 2 (Consecutive WWD in Both Directions)	93.78%	97.93%
	Scenario 3 (Nighttime Traffic with Normal Light)	97.72%	90.13%
	Scenario 4 (Nighttime Traffic with Low Light)	94.23%	96.31%
Vendor 2	Scenario 2 (Consecutive WWD in Both Directions)	88.41%	88.22%
	Scenario 3 (Nighttime Traffic with Normal Light)	94.68%	71.27%
	Scenario 4 (Nighttime Traffic with Low Light)	78.08%	70.94%
Vendor 3	Scenario 2 (Consecutive WWD in Both Directions)	85.89%	15.26%
	Scenario 3 (Nighttime Traffic with Normal Light)	52.63%	4.55%
	Scenario 4 (Nighttime Traffic with Low Light)	20.22%	25.96%

Table 5-12 Measure of Effectiveness Comparison in Different Testing Scenarios

Vendor Comparison		Difference in Measure of Effectiveness			
		Detection System Accuracy		*Actual Detection Accuracy*	
		Value	**P-value**	**Value**	**P-value**
Vendor 1	Scenarios 2 vs 3	-3.94%	<0.0001	7.80%	<0.0001
	Scenarios 2 vs 4	-0.45%	0.6747	1.62%	0.0217
	Scenarios 3 vs 4	3.49%	<0.0001	-6.18%	<0.0001
Vendor 2	Scenarios 2 vs 3	-6.27%	<0.0001	16.95%	<0.0001
	Scenarios 2 vs 4	10.33%	<0.0001	17.28%	<0.0001
	Scenarios 3 vs 4	16.60%	<0.0001	0.33%	0.8700
Vendor 3	Scenarios 2 vs 3	33.26%	<0.0001	10.71%	<0.0001
	Scenarios 2 vs 4	65.67%	<0.0001	-10.70%	<0.0001
	Scenarios 3 vs 4	32.41%	<0.0001	-21.41%	<0.0001

Based on the results in Table 5-11 and Table 5-12, it was found that the systems from the three vendors show different performance under different testing scenarios. The performance of the WWD detection system from Vendor 1 was the best with high accuracy and the least from Vendor 3 with low accuracy. The majority of these differences is significant between different scenarios:

- Detection System Accuracy (proportion of true calls in all WWD calls):
  - The system from Vendor 1 performed best under Testing Scenario 3, as indicated by the fact that the system had the highest detection system accuracy of 97.72%, and the differences between Scenarios 2 and 3 and Scenarios 3 and 4 were both significant at 5% significance level. The systems performed similarly under Testing Scenarios 2 and 4, as indicated by the result that the difference of detection system accuracy values was not significant at 5% significance level.
  - The system from Vendor 2 performed best under Testing Scenario 3, with the highest detection system accuracy of 94.68%, followed by the performance under Testing Scenario 2, with a detection system accuracy of 88.41%. The system performed worst in Testing Scenario 4 among all three scenarios, with a detection system accuracy of 78.08%. The difference between each pair of testing scenarios was significant at 5% significance level.
  - The system from Vendor 3 performed best under Testing Scenario 2, with the highest detection system accuracy of 85.89%, followed by the performance under Testing Scenario 3, with a detection system accuracy of 52.63%. The system performed third in Testing Scenario 4 among all three scenarios, with a detection system accuracy of 20.22%. The difference between each pair of testing scenarios was significant at 5% significance level.

- Actual Detection Accuracy (proportion of true calls in all WWD vehicles present):
  - The system from Vendor 1 performed best under Testing Scenario 2, with the highest actual detection accuracy of 97.93%, followed by the performance under Testing Scenario 4, with an actual detection accuracy of 96.31%. The system performed third in Testing Scenario 3 among all three scenarios, with an actual detection accuracy of 90.13%. The difference between each pair of testing scenarios was significant at 5% significance level.
  - The system from Vendor 2 performed best under Testing Scenario 2, with the highest actual detection accuracy of 88.22%, followed by the performance under Testing Scenario 3, with an actual detection accuracy of 71.27%. The system performed third in Testing Scenario 4 among all three scenarios, with an actual detection accuracy of 70.94%. The differences between Scenarios 2 and 3 and Scenarios 2 and 4 were both significant at 5% significance level. The difference between Scenarios 3 and 4 was not significant at 5% significance level.
  - The system from Vendor 3 performed best under Testing Scenario 4, with the highest actual detection accuracy of 25.96%, followed by the performance under Testing Scenario 2, with an actual detection accuracy of 15.26%. The system performed third in Testing Scenario 3 among all three scenarios, with an actual detection accuracy of 4.55%. The difference between each pair of testing scenarios was significant at 5% significance level.

5.2.3 Systems Performance Comparison under Normal and Low Light Conditions

As shown in Table 5-11 and Table 5-12, systems from all vendors show a consistent pattern performing significantly better under nighttime traffic with normal light conditions than nighttime traffic with low light conditions in terms of detection system accuracy (true calls vs. false calls). However, in terms of actual detection accuracy (true calls vs. missed calls), the systems from Vendor 1 and Vendor 3 performed better under nighttime traffic with low light conditions than nighttime traffic with normal light conditions, and the system from Vendor 2 yielded comparable performance under the two lighting conditions. It would be beneficial to explore possible reasons why Vendors 1 and 3 had better performance on actual detection accuracy under nighttime traffic with low light conditions than those from nighttime traffic with normal light conditions. Because of poor performance of the pedestrian detection system from Vendor 3, the following exploration focuses on the system performance from Vendors 1 and 2.

- In this research, MP45.7 and MP51.6 along I-275 were selected as testing sites for nighttime traffic with normal light conditions, where traffic volume was higher and led to a shorter headway. On the other hand, MP57.0 and MP58.9 along I-275 were selected as testing sites for nighttime traffic with low light conditions, where traffic volume was lighter and led to a longer headway. In addition to the factor of traffic volumes/vehicle headways, the color contrast under low light conditions could be sharper than normal light conditions (see Figure 5-4 and Figure 5-5 for comparison), so it is possible that vehicles could be more easily detected and less likely to be missed under low light conditions for the system of Vendor 1.

- The system from Vendor 1 seemed less likely to miss potential vehicles under low light conditions, so it may be more sensitive to disturbance lighting (i.e., vehicles on adjacent lanes) leading to a false call. Therefore, it was possible to induce a slightly lower detection system accuracy under normal light conditions with heavier traffic volume.

Figure 5-4 Video Stream under Nighttime Normal Light Conditions

Figure 5-5 Video Stream under Nighttime Low Light Conditions

To test if either traffic volume or lighting condition had individual influence on system performance, detection system accuracy and actual detection accuracy were calculated by each individual hour for weekdays and weekend day(s), as shown in Table 5-13, Table 5-14, and Table 5-15.

Table 5-13 System Performance by Hour on Weekday 1

	Site	Time Period	Actual Volume (Ground Truth)	Detection System Accuracy			Actual Detection Accuracy		
				Vendor 1	Vendor 2	Vendor 3	Vendor 1	Vendor 2	Vendor 3
Weekday 1	MP45.7	12:00:00 AM-12:59:59 AM	182	95.68%	78.43%	44.44%	85.16%	21.98%	2.20%
		1:00:00 AM-1:59:59 AM	80	100.00%	74.19%	50.00%	97.50%	28.75%	5.00%
		2:00:00 AM-2:59:59 AM	35	94.12%	63.16%	0.00%	91.43%	34.29%	0.00%
	MP51.6	12:00:00 AM-12:59:59 AM	56	98.18%	83.33%	66.67%	96.43%	35.71%	3.57%
		1:00:00 AM-1:59:59 AM	27	96.15%	63.64%	N/A	92.59%	25.93%	0.00%
		2:00:00 AM-2:59:59 AM	15	93.33%	88.89%	33.33%	93.33%	53.33%	6.67%
	MP57.0	12:00:00 AM-12:59:59 AM	46	90.20%	73.17%	50.00%	100.00%	65.22%	65.22%
		1:00:00 AM-1:59:59 AM	25	100.00%	63.33%	30.36%	80.00%	76.00%	68.00%
		2:00:00 AM-2:59:59 AM	18	100.00%	50.00%	34.09%	77.78%	50.00%	83.33%
	MP58.9	12:00:00 AM-12:59:59 AM	39	92.50%	64.00%	0.00%	94.87%	82.05%	0.00%
		1:00:00 AM-1:59:59 AM	25	85.71%	57.14%	N/A	96.00%	80.00%	0.00%
		2:00:00 AM-2:59:59 AM	15	92.31%	43.48%	N/A	80.00%	66.67%	0.00%

Table 5-14 System Performance by Hour on Weekday 2

	Site	Time Period	Actual Volume (Ground Truth)	Detection System Accuracy			Actual Detection Accuracy		
				Vendor 1	Vendor 2	Vendor 3	Vendor 1	Vendor 2	Vendor 3
Weekday 2 (Wkday2/Wkday3)[1]	MP45.7	12:00:00 AM-12:59:59 AM	172/204	97.37%	96.69%	67.57%	86.05%	84.88%	12.25%
		1:00:00 AM-1:59:59 AM	88/92	100.00%	97.44%	59.09%	98.86%	86.36%	14.13%
		2:00:00 AM-2:59:59 AM	45/68	95.35%	93.02%	44.44%	91.11%	88.89%	5.88%
	MP51.6	12:00:00 AM-12:59:59 AM	42	100.00%	92.59%	100.00%	97.62%	59.52%	21.43%
		1:00:00 AM-1:59:59 AM	18	94.74%	83.33%	80.00%	100.00%	83.33%	22.22%
		2:00:00 AM-2:59:59 AM	20	90.91%	100.00%	81.82%	100.00%	95.00%	45.00%
	MP57.0	12:00:00 AM-12:59:59 AM	37	96.97%	95.00%	6.67%	86.49%	51.35%	5.41%
		1:00:00 AM-1:59:59 AM	14	82.35%	57.14%	0.00%	100.00%	57.14%	0.00%
		2:00:00 AM-2:59:59 AM	15	83.33%	100.00%	5.00%	100.00%	66.67%	6.67%
	MP58.9	12:00:00 AM-12:59:59 AM	48	95.92%	85.71%	2.22%	97.92%	75.00%	2.08%
		1:00:00 AM-1:59:59 AM	33	94.29%	71.11%	0.00%	100.00%	96.97%	0.00%
		2:00:00 AM-2:59:59 AM	18	90.00%	68.42%	0.00%	100.00%	72.22%	0.00%

[1] Due to unexpected technical difficulty in data collection, Vendor 3 was not able to report WWD data for MP45.7 on this day. Therefore, WWD data on another weekday (Weekday 3) at the same site during the same period were used here for Vendor 3. Ground truth and performance data on Weekday 3 were underlined.

Table 5-15 System Performance by Hour on Weekend

	Site	Time Period	Actual Volume (Ground Truth)	Detection System Accuracy			Actual Detection Accuracy		
				Vendor 1	Vendor 2	Vendor 3	Vendor 1	Vendor 2	Vendor 3
Weekend (Wkd1/Wkd2)[1]	MP45.7	12:00:00 AM-12:59:59 AM	481/462	96.54%	95.00%	67.57%	87.11%	79.00%	5.41%
		1:00:00 AM-1:59:59 AM	287/298	98.02%	98.76%	59.09%	86.06%	83.28%	4.36%
		2:00:00 AM-2:59:59 AM	206/202	100.00%	100.00%	44.44%	96.12%	87.86%	1.98%
	MP51.6	12:00:00 AM-12:59:59 AM	108/94	100.00%	95.60%	0.00%	91.67%	80.56%	0.00%
		1:00:00 AM-1:59:59 AM	57/61	100.00%	98.00%	10.00%	96.49%	85.96%	3.28%
		2:00:00 AM-2:59:59 AM	25/22	100.00%	100.00%	8.33%	92.00%	80.00%	4.55%
	MP57.0	12:00:00 AM-12:59:59 AM	75/61	92.41%	97.14%	50.85%	97.33%	45.33%	49.18%
		1:00:00 AM-1:59:59 AM	34/47	89.19%	88.89%	8.89%	97.06%	47.06%	8.51%
		2:00:00 AM-2:59:59 AM	30/10	90.91%	100.00%	0.00%	100.00%	50.00%	0.00%
	MP58.9	12:00:00 AM-12:59:59 AM	95/98	98.96%	86.32%	24.54%	100.00%	86.32%	40.82%
		1:00:00 AM-1:59:59 AM	70/65	100.00%	88.41%	15.20%	98.57%	87.14%	29.23%
		2:00:00 AM-2:59:59 AM	41/37	100.00%	92.11%	9.43%	100.00%	85.37%	27.03%

[1] Due to unexpected technical difficulty in data collection, Vendor 3 was not able to report WWD data on this weekend day (Weekend Day 1). Therefore, make-up data collection was conducted on another weekend day (Weekend Day 2) during the same period for Vendor 3. Ground truth and performance data on Weekend Day 2 were underlined.

By reviewing the data from the three tables, it can be observed that when holding lighting conditions constant (same lighting conditions) by comparing the statistics for MP45.7 and MP51.6 (normal light conditions) or comparing the statistics for MP57.0 and MP58.9 (low light conditions), a clear pattern was not observed that large traffic volume will lead to a significant difference in detection system accuracy and actual detection accuracy for Vendor 2. However, it shows lower actual detection accuracy rates for large traffic volume conditions (12:00–1:00 AM on Weekday 1, 12:00–1:00 AM for Weekday 2, and 12:00–2:00 AM for MP45.7) for Vendor 2.

Similarly, for similar traffic volumes, comparing the statistics for MP51.6 and MP57.0/58.9 on the same day shows in a considerable number of cases in which better light conditions lead to higher detection system accuracy (i.e., Vendor 1 at MP51.6 vs. MP58.9 on Weekday 1; Vendor 2 at MP51.6 vs. MP57.0 on Weekday 1; Vendor 1 and Vendor 2 at MP51.6 vs. MP57.0/58.9 on Weekday 2; Vendor 1 and Vendor 2 at MP51.6 and MP58.9 on Weekend); therefore, the influence of lighting condition on detection system accuracy can be confirmed to some extent. Regarding actual detection accuracy, it was shown in several comparison cases (i.e., Vendors 1 and 2 at MP51.6 vs. MP57.0/58.9 on Weekday 1, Weekday 2 and weekend) that system performances vary under low light conditions and normal light conditions. Researchers cannot conclude that lighting conditions have a significant impact on actual detection accuracy. There may be other reasons regarding system hardware/software sensitivity characteristics that lead to the difference.

5.2.4 Overall Evaluation of System Capability on WWD Incident Detection

This research project compared ground truth data with vendor reporting data for system performance evaluation based on the identification of true detection, false calls, and missed calls. The number of true calls, false calls, and missed calls for each vendor on each day reviewed were calculated by summing the corresponding values at these sites for each day (shown in Table 5-16), and the results are presented in Table 5-17. The measures of effectiveness based on the total values in Table 5-17 are summarized in Table 5-18.

Table 5-16 Vendor System Performance on True, False, and Missed Detections

Day of Review	Site	Ground Truth	Vendor 1			Vendor 2			Vendor 3		
			True	*False*	*Missed*	*True*	*False*	*Missed*	*True*	*False*	*Missed*
Weekday 1	MP45.7	297	265	9	32	75	26	222	8	11	289
	MP46.7	No WWD incident reported during data collection									
	MP47.6	377	359	38	18	319	131	58	10	11	367
	MP51.6	98	93	3	5	35	9	63	3	3	95
	MP57.0	89	80	5	9	58	30	31	62	98	27
	MP58.9	79	73	8	6	62	46	17	0	1	79
Weekday 2[1] (Wkday2/ Wkday3)	MP45.7	305/364	276	6	29	262	10	43	12	0	352
	MP46.7	No WWD incident reported during data collection									
	MP47.6	426/463	419	19	7	376	32	50	81	10	382
	MP51.6	80	79	3	1	59	5	21	22	3	58
	MP57.0	66	61	7	5	37	7	29	3	59	63
	MP58.9	99	98	6	1	81	25	18	1	85	98
Weekend[2] (Wkd1/ Wkd2)	MP45.7	976/962	864	20	112	800	23	176	42	26	920
	MP46.7	No WWD incident reported during data collection									
	MP47.6	1,030/950	1,017	62	13	922	49	108	183	24	767
	MP51.6	190/177	177	0	13	156	5	34	3	38	174
	MP57.0	139/118	136	13	3	65	3	74	34	99	84
	MP58.9	206/200	205	1	1	178	24	28	69	325	131

[1] Due to unexpected technical difficulty in data collection, Vendor 3 was not able to report WWD data for MP45.7 and MP47.6 on this day. Therefore, WWD data on another weekday (Weekday 3) at the same sites during the same period were used for Vendor 3. Ground truth and performance data on Weekday 3 are underlined.

[2] Due to unexpected technical difficulty in data collection, Vendor 3 was not able to report WWD data on this weekend day (Weekend Day 1). Therefore, make-up data collection was conducted on another weekend day (Weekend Day 2) during the same period for Vendor 3. The first value in ground truth data is for Vendors 1 and 2, and the second value (underlined) is for Vendor 3.

Table 5-17 Data Review Results of System Capability on WWD Incident Detection Based on Overall Data

Day of Review	Ground Truth	Vendor 1			Vendor 2			Vendor 3		
		True Call	*False Call*	*Missed Call*	*True Call*	*False Call*	*Missed Call*	*True Call*	*False Call*	*Missed Call*
Weekday 1	940	870	63	70	549	242	391	83	124	857
Weekday 2	976/1,072	933	41	43	815	79	161	119	157	953
Weekend	2,541/2,407	2,399	96	142	2,121	104	420	331	512	2,076
Total	4,457/4,419	4,202	200	255	3,485	425	972	533	793	3,886

Table 5-18 Performance Evaluation for Overall Dataset Based on Measures of Effectiveness

Vendor #	Measure of Effectiveness			
	Detection System Accuracy	*% False Calls*	*Actual Detection Accuracy*	*% Missed Calls*
Vendor 1	95.46%	4.54%	94.28%	5.72%
Vendor 2	89.13%	10.87%	78.19%	21.81%
Vendor 3	40.20%	59.80%	12.06%	87.94%

Based on the results in Table 5-18, the differences and significance regarding these measures between different vendors were calculated and are summarized in Table 5-19.

Table 5-19 Measure of Effectiveness Comparison between Vendors for Overall Dataset

Vendor Comparison	Difference in Measure of Effectiveness			
	Detection System Accuracy		*Actual Detection Accuracy*	
	Value	**P-value**	**Value**	**P-value**
Vendors 1 and 2	6.33%	<0.0001	16.09%	<0.0001
Vendors 1 and 3	55.26%	<0.0001	82.22%	<0.0001
Vendors 2 and 3	48.93%	<0.0001	66.13%	<0.0001

As shown in Table 5-18 and Table 5-19:

- Detection System Accuracy (proportion of true notification in all notifications):
  - The system from Vendor 1 had the best performance (most true calls and correspondingly fewest false calls under the same condition), showing a detection system accuracy of 95.46%. The system from Vendor 2 was second, with a detection system accuracy of 89.13%, followed by the system from Vendor 3, with a detection system accuracy of 40.20%.
  - The differences between Vendors 1 and 2, Vendors 1 and 3, and Vendors 2 and 3 were significant at 5% significance level.
- Actual Detection Accuracy (proportion of true notification in all WWD vehicles present):
  - The system from Vendor 1 had the best performance (fewest missed calls under the same condition), showing an actual detection accuracy of 94.28%. The system from Vendor 2 was second, with an actual detection accuracy of 78.19%, followed by the system from Vendor 3, with an actual detection accuracy of 12.06%.
  - The differences between Vendors 1 and 2, Vendors 1 and 3, and Vendors 2 and 3 were significant at 5% significance level.

Therefore, the system from Vendor 1 had the best performance, followed by the system from Vendor 2. The system from Vendor 3 had inferior performance than the other two.

Considering that WWD incidents are rare traffic events, in this research, the IDOD configuration was used to simulate WWD incidents to collect sufficient WWD incident data. The performance statistics of detection system accuracy and actual detection accuracy from this study are excellent indicators for evaluating and comparing vendor's WWD detection system performances; however, they do not necessarily indicate the true detection accuracies in actual implementation and traffic monitoring. The real system performance should be further investigated based on actual WWD incident detection over sufficiently long time after implementation or evaluated under a controlled environment with proper closure of an interstate highway segment.

5.3 Evaluation of System Capability on TMC Notification

In addition to evaluating the capability of vendor systems on WWD incident detection, to test the capabilities of the three vendors' WWD detection systems on TMC notification, a project-related email account (wwdstudy@cutr.usf.edu) was created solely for WWD notification purposes, and all three vendors were asked to report WWD vehicle data for I-275 MP45.7 Southbound from 2:00–4:00 AM on the same weekday. Each WWD detection system was set to automatically send a notification email when a WWD vehicle was detected by the system to the designated email that included the WWD occurrence date, time (HH:MM:SS), and location (site milepost and lane number) information. Table 5-20 summarizes the number of WWD vehicles detected and the number of WWD notifications sent to the TMC by each vendor system.

Table 5-20 Comparison of System Capability on TMC Notification

Vendor ID	Number of WWD Vehicles Detected	Number of WWD Notifications Sent to TMC	% of Notifications Sent
Vendor 1	146	146	100%
Vendor 2	119	119	100%
Vendor 3	30	30	100%

As shown, all three candidate systems were able to send email notifications if they detected a WWD vehicle. Therefore, there was no issue with TMC notification connection.

Additionally, video data were collected at I-275 MP45.7 Southbound during the same period and reviewed as ground truth data, where a detailed timestamp when a WWD vehicle on a designated lane was first fully present on the video screen and was recorded. The ground truth data were compared with the email notification results received by the project-related email account to identify true calls, false calls, and missed calls by each system. The data review results are summarized in Table 5-21.

Table 5-21 Data Review Results of WWD Detection for Each Vendor System

Day of Review	Ground Truth	Vendor 1			Vendor 2			Vendor 3		
		True Call	*False Call*	*Missed Call*	*True Call*	*False Call*	*Missed Call*	*True Call*	*False Call*	*Missed Call*
Day 1	129				119	0	10	21	9	108
Day 2[1]	146	144	2	2						

[1] Due to technical issue with the system on Day 1, Vendor 1 conducted TMC notification data collection on a second weekday at the same site during the same period for evaluation.

5.4 Analysis Summary

The following conclusions can be drawn based on the analysis in this chapter:

- WWD is a very rare traffic incident, based on the fact that there were no actual WWD vehicles detected in the first testing scenario under normal traffic conditions.

- In testing of consecutive WWD vehicles in both directions using one camera, the system from Vendor 1 showed the best performance regarding the proposed measures of effectiveness, with 94% for detection system accuracy and 98% for actual detection accuracy. The system from Vendor 2 ranked second, with 88% for detection system accuracy and 88% for actual detection accuracy. The system from Vendor 3 ranked third, with 86% for detection system accuracy and 15% for actual detection accuracy. The differences for detection system accuracy between Vendors 1 and 2 and Vendors 1 and 3 were significant at 5% significance level; the differences for actual detection accuracy for each pair of vendor systems were significant at 5% significance level.
- In testing under normal light nighttime traffic conditions, the system from Vendor 1 showed the best performance for the proposed measures of effectiveness, with 98% for detection system accuracy and 90% for actual detection accuracy. The system from Vendor 2 ranked second, with 95% for detection system accuracy and 71% for actual detection accuracy. The system from Vendor 3 ranked third, with 53% for detection system accuracy and 5% for actual detection accuracy. For detection system accuracy and actual detection accuracy, the differences between each pair of vendor systems were significant at 5% significance level.
- In testing under low light nighttime traffic conditions, the system from Vendor 1 showed the best performance for the proposed measures of effectiveness, with 94% for detection system accuracy and 96% for actual detection accuracy. The system from Vendor 2 ranked second, with 78% for detection system accuracy and 71% for actual detection accuracy. The system from Vendor 3 ranked third, with 20% for detection system accuracy and 26% for actual detection accuracy. Regarding detection system accuracy and actual detection accuracy, the differences between each pair of vendor systems were significant at 5% significance level.
- The comparison of different testing scenarios showed varied performance of the same WWD detection system, and most of these differences between a pair of testing scenarios were significant at 5% significance level. Additionally, it was found that systems from all three vendors performed better under nighttime traffic with normal light conditions than nighttime traffic with low light conditions for detection system accuracy, but showed various patterns for actual detection accuracy. Possible reasons may include traffic volumes, color contrast between low light and normal light conditions, interactions between traffic volume and lighting conditions, vendor system hardware/software mechanical and sensitivity characteristics, etc.
- According to the overall results, the system from Vendor 1 showed the best performance regarding the proposed measures of effectiveness, followed by the system from Vendor 2; the system from Vendor 3 ranked third. For both detection system accuracy and actual detection accuracy, the differences between each pair of vendor systems were significant at 5% significance level.

- The freeway WWD detection evaluation on the three studied video analytic systems shows that the accuracy of vendor systems varies significantly. The best system can achieve an overall 95% detection system accuracy and 94% actual detection accuracy and potentially could achieve higher accuracy with proper improvement and enhancement.
- From a qualitative perspective, all three candidate systems were able to send an email notification if a WWD was detected; there were no issues with TMC notification connection.
- The performance statistics of detection system accuracy and actual detection accuracy from this study are excellent indicators for evaluating and comparing vendor's WWD detection system performances; however, they do not necessarily indicate the true detection accuracies in actual implementation and traffic monitoring. The real system performance should be further investigated based on actual WWD incident detection over sufficiently long time after implementation or evaluated under a controlled environment with proper closure of an interstate highway segment.

6. RESEARCH FINDINGS AND CONCLUSIONS

It is of practical importance to implement real-time and accurate WWD systems on limited-access facilities to instantly detect WWD vehicles and inform regional TMC personnel and responsible law enforcement officers to take immediate actions to prevent the occurrence of a potential wrong-way crash, due to the fact that wrong-way crashes generally lead to fatalities and/or significant injuries and tremendous property damage. Sponsored by FDOT, this project successfully evaluated freeway WWD detection systems currently on the market from three vendors regarding their capabilities for real-time WWD vehicle detection and TMC notification. Six testing locations were selected on an I-275 segment between I-4 and I-75 in the Tampa Bay area, and these locations were assigned into four testing scenarios based on testing time, lighting conditions and WWD definitions, including 1) testing with normal daily traffic conditions; 2) testing consecutive WWD in both directions; 3) testing under normal light nighttime traffic conditions; 4) testing under low light nighttime traffic conditions. Data collection using existing cameras was conducted for a full week, and video of two weekdays and one weekend day were reviewed to ensure a sufficient data sample was extracted for analysis. Five measures were proposed and used for performance evaluation process, including 1) WWD detection accuracy, 2) percentage of false calls, 3) actual WWD detection accuracy, and 4) percentage of missed calls.

Research findings, conclusions and recommendations include the following:

- WWD is a very rare traffic incident, as confirmed by this study—no actual WWD vehicles were detected under normal traffic conditions during a week of data collection period.
- In testing of vendor systems to detect consecutive WWD vehicles in both directions using one camera, the system from Vendor 1 showed the best performance regarding both detection system accuracy (94%) and actual detection accuracy (98%). The system from Vendor 2 ranked second, and the system from Vendor 3 ranked third. The differences for detection system accuracy between Vendors 1 and 2 and Vendors 1 and 3 were significant at 5% significance level; the differences for actual detection accuracy for each pair of vendor systems were significant at 5% significance level.
- In testing under normal light nighttime traffic conditions, the system from Vendor 1 showed the best performance regarding both detection system accuracy (98%) and actual detection accuracy (90%). The system from Vendor 2 ranked second, and the system from Vendor 3 ranked third. For both detection system accuracy and actual detection accuracy, the differences between each pair of vendor systems were significant at 5% significance level.
- In under low light nighttime traffic conditions, the system from Vendor 1 showed the best performance regarding both detection system accuracy (94%) and actual detection accuracy (96%). The system from Vendor 2 ranked second, and the system from Vendor

3 ranked third. Regarding both detection system accuracy and actual detection accuracy, the differences between each pair of vendor systems were significant at 5% significance level.

- No conclusion could be reached regarding the performance for Actual Detection Accuracy under nighttime traffic with normal light conditions and the nighttime traffic with low light conditions. Normal light conditions provided better illumination, but low light conditions seemed to provide better contrast, and both had their own advantages. Further research on this subject is recommended.
- Overall, the results from freeway WWD detection data, TMC notification data, and statistical analysis illustrated that the system from Vendor 1 showed the best performance regarding the proposed measures of effectiveness, followed by the system from Vendor 2; the system from Vendor 3 ranked third. For both detection system accuracy and actual detection accuracy, the difference between each pair of vendor systems was significant at 5% significance level.
- System performance from the three vendors on WWD detection based on this study varied significantly, indicating that system performance of real-time video-analytic freeway WWD detection systems highly depends on the individual vendor's system. The highest system performance was by Vendor 1, achieving 95% detection system accuracy and 94% actual detection accuracy. The lowest system performance was by Vendor 3 and had an overall 40% detection system accuracy and 12% actual detection accuracy. Vendor 2 had an overall 89% detection system accuracy and 78% actual detection accuracy. The best system potentially could achieve an even higher accuracy with proper improvement and enhancement.
- Analysis of TMC notification data revealed that all three systems were able to send an email notification if a WWD was detected; there were no issues with TMC notification connection.
- During system setup, it was revealed that PTZ cameras could not always return to the exact pre-set position to resume WWD detection data collection after contingent operations by FDOT District 7 TMC operators for their needed traffic monitoring activities. To overcome this, fixed cameras were used for this study. The research team offers the following two recommendations: (1) check PTZ cameras to determine if they can return to the exact pre-set position for similar studies, and (2) improve freeway WWD detection systems to automatically adjust settings using reference points for minor movements of PTZ cameras and provide alert for a large movement.
- In this research, IDOD vehicles were treated as wrong-way vehicles under certain data collection scenarios for WWD detection to ensure sufficient WWD incident data to be collected. Given the fact that WWD is a very rare event in actual traffic, the performance statistics of detection system accuracy and actual detection accuracy from this study are excellent indicators for evaluating and comparing vendor's WWD detection system

performances; however, they do not necessarily indicate the actual detection accuracies in actual implementation and traffic monitoring. The real system performance should be further investigated based on actual WWD incident detection over sufficiently long time after implementation or evaluated under a controlled environment with proper closure of an interstate highway segment.

- FLIR TrafiSense was successfully demonstrated in Arizona on WWD detection. According to the vendor, FLIR TrafiSense is the world's first integrated thermal traffic sensor. It is highly recommended for a pilot testing in Florida.

The evaluation results and findings from this research provide insight into the capabilities and accuracy of real-time video-analytic freeway WWD detection systems on WWD detection and TMC notification and they can be used to support FDOT and other state DOT in future implementation of WWD detection systems on limited-access facilities.

REFERENCES

1. Lin, P.-S., S. Ozkul, and C. Chandler. "Evaluation on the Perceived Effectiveness of Red RRFB Configurations to Reduce Wrong-Way Driving." In J. Z. Shon, P-Y. Tseng, Z. Chen, and S-C. Lo, eds. *Bridging the East and West:Theories and Practices of Transportation in the Asia Pacific – Proceedings of the 11th Asia Pacific Transportation Development Conference and 29th ICTPA Annual Conference, May 27-29, 2016, Hsinchu, Taiwan*. Reston, VA: American Society of Civil Engineers, pp. 206-213. https://doi.org/10.1061/9780784479810.024.

2. Ozkul, S., and P.-S. Lin. "Evaluation of Red RRFB Implementation at Freeway Off-Ramps and Its Effectiveness on Alleviating Wrong-Way Driving." *Transportation Research Procedia*, Vol. 22, 2017, pp. 570-579. https://doi.org/10.1016/J.TRPRO.2017.03.046.

3. Lin, P.-S., S. Ozkul, R. Guo, and C. Chen. "Assessment of Countermeasure Effectiveness and Informativeness in Mitigating Wrong-Way Entries onto Limited-Access Facilities." *Accident Analysis and Prevention*, Vol. 116, 2018, pp. 79-93. https://doi.org/10.1016/j.aap.2017.11.027.

4. Lin, P.-S., S. Ozkul, W. R. Boot, P. Alluri, L. T. Hagen, and R. Guo. *Comparing Countermeasures for Mitigating Wrong-Way Entries onto Limited Access Facilities*. Center for Urban Transportation Research, University of South Florida, Tampa, FL, 2017. Retrieved from the Florida Department of Transportation Research Center website: http://www.fdot.gov/research/Completed_Proj/Summary_ TE/FDOT-BDV25-977-29-rpt.pdf

5. Florida Department of Highway Safety and Motor Vehicles. *Wrong Way Driving Awareness Month Campaign Evaluation Report*. Tallahassee, FL, 2016. Retrieved from the Florida Department of Highway Safety and Motor Vehicles website: https://www.flhsmv.gov/pdf/wrongway/wrongwaydriving-evaluationreport-2016.pdf.

6. Tai, J.-C., S.-T. Tseng, C.-P. Lin, and K.-T. Song. "Real-Time Image Tracking for Automatic Traffic Monitoring and Enforcement Applications." *Image and Vision Computing*, Vol. 22, No. 6, 2004, pp. 485-501. https://doi.org/https://doi.org/10.1016/j.imavis.2003.12.001.

7. Cheung, S. S., and C. Kamath. "Robust Techniques for Background Subtraction in Urban Traffic Video." In S. Panchanathan, and B. Vasudev, eds. *Proceedings SPIE 5308, Visual Communications and Image Processing 2004, January 18-22, 2004, San Jose, California*. https://doi.org/10.1117/12.526886.

8. Kim, S. H., J. Shi, A. Alfarrarjeh, D. Xu, Y. Tan, and C. Shahabi. "Real-Time Traffic Video Analysis Using Intel Viewmont Coprocessor." In: Madaan A., Kikuchi S., and

Bhalla S., eds. *Databases in Networked Information Systems, DNIS 2013, March 25-27, 2013, Aizu-Wakamatsu, Japan*. Lecture Notes in *Computer Science,* Volume 7813. Berlin, Heidelberg: Springer, pp. 150-160. https://doi.org/10.1007/978-3-642-37134-9_12.

9. Regazzoni, C. S., A. Cavallaro, Y. Wu, J. Konrad, and A. Hampapur. Video Analytics for Surveillance: Theory and Practice [From the Guest Editors]. *IEEE Signal Processing Magazine*, Vol. 27, No. 5, 2010, pp. 16-17. https://doi.org/10.1109/MSP.2010.937451.

10. Pati, S. Role of Video Analytics in Smart City Traffic Control (webpage). *EINFOCHIPS*. https://www.einfochips.com/blog/role-video-analytics-smart-city-traffic-control/.