Evaluating the Effectiveness of the Strategic Response Plan to Wrong-way Driving Events on Freeways

Final Report

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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.

METRIC CONVERSION TABLE

U.S. UNITS TO SI* (MODERN METRIC) UNITS

LENGTH

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
in	inches	25.400	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.610	kilometers	km
mm	millimeters	0.039	inches	in
m	meters	3.280	feet	ft
m	meters	1.090	yards	yd
km	kilometers	0.621	miles	mi

AREA

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
in^2	square inches	645.200	square millimeters	mm^2
ft^2	square feet	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	2.590	square kilometers	km^2
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.470	acres	ac
km^2	square kilometers	0.386	square miles	mi^2

VOLUME

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
fl oz	fluid ounces	29.570	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
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3

NOTE: volumes greater than 1,000 L shall be shown in m^3.
*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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16. Abstract

Wrong-way driving (WWD) on freeways is a serious traffic safety concern, with national statistics reporting an average of 355 fatalities annually due to WWD crashes. Recognizing this critical issue, the Florida Department of Transportation (FDOT) has implemented a comprehensive strategic response plan aimed at reducing the frequency and severity of WWD incidents on freeways. This plan combines policy changes, innovative engineering solutions, and advanced technologies, including dynamic message signs (DMS), closed-circuit television (CCTV) cameras, and highway advisory radio (HAR). The plan also incorporates multi-agency coordination between Regional Transportation Management Centers (RTMCs), the Florida Highway Patrol (FHP), and the Road Rangers Service Patrol (RRSP) to ensure a timely and effective response.

This research evaluated FDOT's strategic response plan to assess its effectiveness in improving real-time WWD event management and response coordination. A nationwide survey of state departments of transportation (DOTs) identified best practices in WWD countermeasures, technologies, and response strategies. In Florida, each FDOT district and the Florida Turnpike Enterprise (FTE) detailed their approaches to addressing WWD incidents. Insights from the survey were leveraged to refine FDOT's approach, focusing on areas such as signing, pavement markings, and integration of detection systems. Additionally, five years (2018-2022) of SunGuide™ WWD event logs were sampled and reviewed to understand the existing responses to WWD incidents in Florida.

Real-world traffic data analysis, using the Regional Integrated Transportation Information System (RITIS), DMS location, and SunGuide™ data sources, evaluated driver responses to DMS messages designed to notify right-way traffic during WWD incidents. Results revealed that clear, concise messages with actionable guidance significantly improved driver behavior, reducing the risk of WWD crashes. Furthermore, a human factors study utilizing a driving simulator evaluated the comprehension of WWD-related DMS messages across diverse driver groups under varying roadway and environmental conditions. Findings from this study provided recommendations for optimizing DMS message formats to enhance driver understanding and response.

The study concluded that FDOT's strategic response plan effectively mitigates WWD events and has effective coordination across stakeholders. Recommendations include refining DMS messaging based on human factors insights, enhancing data sharing between agencies, and expanding the use of innovative detection technologies at high-risk locations for WWD entries. These measures could enable FDOT to continue addressing the critical issue of WWD on freeways, ultimately improving traffic safety and saving lives.

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EXECUTIVE SUMMARY

Wrong-way driving (WWD) on freeways is a critical safety issue, with national data indicating an average of 355 fatalities annually caused by WWD crashes. These incidents often result in severe injuries and fatalities due to the high-speed, head-on nature of these collisions. The Florida Department of Transportation (FDOT) developed a strategic response plan to mitigate WWD incidents in response to this pressing concern. This plan integrates engineering solutions, policy adjustments, advanced technologies, and multi-agency coordination to enhance WWD detection, management, and prevention.

FDOT's strategic response plan employs a combination of countermeasures, including dynamic message signs (DMS), closed-circuit television (CCTV) cameras, and highway advisory radio (HAR), to alert wrong-way drivers and right-way motorists in real time. It also establishes robust communication protocols between Regional Transportation Management Centers (RTMCs), the Florida Highway Patrol (FHP), and the Road Rangers Service Patrol (RRSP) to ensure swift responses to WWD events. This research evaluates the effectiveness of these measures and identifies opportunities for improvement.

State-of-the-practice Review

A nationwide survey of state departments of transportation (DOTs) revealed best practices and innovative WWD detection and prevention strategies, which provided insights into FDOT's approach. In Florida, each FDOT district and the Florida Turnpike Enterprise (FTE) elaborated on their strategies for responding to WWD incidents. After conducting the state-of-the-practice survey, five years of SunGuide™ event logs were sampled and reviewed to understand the existing responses to WWD incidents in Florida. SunGuide™ event logs showed the timeline of how a certain WWD incident was responded to until it was closed. The review aimed to analyze how the responses to WWD events follow the standard operating procedures (SOPs) set for each FDOT District and the FTE. The findings highlighted the efficiency and effectiveness of the FDOT's real-time response to WWD events. DMSs were found to be the most common Intelligent Transportation System (ITS) technology to warn right-way drivers when responding to WWD incidents.

Performance Analysis of DMS Messaging

Real-world data from the Regional Integrated Transportation Information System (RITIS) demonstrated the impact of WWD-related DMS messages on traffic behavior. Speed and lane use data were used to examine the traffic behavioral changes linked to WWD-related DMS alerts. Speed reductions and lane shifts to slower designated lanes were interpreted as compliance and comprehension by the right-way drivers of the WWD-related DMS alerts during WWD incidents. The analysis confirmed that timely and well-designed messages reduce WWD crash risks by alerting right-way drivers regarding potential WWD incidents. The study also documented that traffic compliance and situational awareness are influenced by the existing FDOT messaging strategies.

Analysis of Human Factors

A driving simulator study was conducted to evaluate how individual drivers interpret and respond to DMS messages related to different WWD scenarios. The simulation scenarios were developed and programmed to assess how different WWD-related DMSs influence drivers' responses to the alerts and whether it improves their chances of avoiding WWD crashes. The experiment involved both existing WWD-related DMS and the proposed ones and examined each for their effectiveness in improving drivers' safety in response to WWD incidents. Results showed that clear, concise messaging with actionable instructions significantly improves driver comprehension, response times, and hence safety. These findings were critical in refining message formats for maximum effectiveness across diverse driver demographics and environmental conditions.

Best Practices, Lessons Learned, and Recommendations

The study documented best practices for WWD incident management, including:

- Leveraging advanced detection technologies to mitigate WWD incidents
- Enhancing interagency communication for coordinated responses
- Documenting any challenges experienced when responding to WWD incidents
- Updating WWD response protocols in SOPs with technological changes and continuous research
- Emphasizing the use of DMS in alerting right-way drivers during WWD incidents
- Standardizing DMS messaging formats based on human factors research
- Integrating WWD-related DMS with navigation apps and in-vehicle systems
- Launching public awareness campaigns on the WWD risks and the related DMS alerts
- Promoting continuous research on WWD risks and countermeasures

Challenges faced in this study included ensuring consistent technology performance and addressing variations in driver behavior under different conditions. Key recommendations for FDOT include improving real-time coordination, strengthening data-sharing protocols among agencies when responding to WWD events, and refining DMS messages using behavioral insights. Further research should also explore different types of WWD-related DMS alerts that work effectively and efficiently.

This research underscores the effectiveness of FDOT's strategic response plan in mitigating WWD incidents, providing strong evidence of its role in enhancing safety on Florida's freeways. The study also highlights areas needing further improvement to minimize the WWD risks effectively. By implementing the recommendations from this study, FDOT can continue to enhance safety and reduce fatalities caused by WWD crashes on Florida's freeways. The recommended strategies and efforts will not only reduce fatalities and injuries associated with WWD incidents but also foster public confidence in Florida's commitment to proactive, data-driven safety initiatives. Ultimately, the continuous evolution of these strategies will contribute to saving lives and strengthening the resilience of Florida's freeway network for all road users.

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LIST OF ACRONYMS/ABBREVIATIONS

CCTV	Closed-Circuit Television
CFX	Central Florida Expressway Authority
CL	Confidence Level
CITI	Collaborative Institutional Training Initiative
CV	Cross Validation
DMS	Dynamic Message Sign
DOT	Department of Transportation
DTE	Decision Tree Ensemble
ESR	Events with Speed Reduction
ESSR	Events with Significant Speed Reduction
FDOT	Florida Department of Transportation
FHP	Florida Highway Patrol
FTE	Florida Turnpike Enterprise
GPS	Global Positioning System
HAR	Highway Advisory Radio
IDS	Incident Detection Subsystem
ITS	Intelligent Transportation Systems
IPAW	Integrated Public Alert and Warning System
LEO	Law Enforcement Officer
LL	Left Lanes
MELR	Mixed Effect Linear Regression
mph	Miles per Hour
MVDS	Mainline Vehicle Detection System
NML	Number of WWD Events Involving Moving to the Lane
NWD	Non-Warning DMS
NSL	Number of WWD Events Involving Shifting from the Lane
NSML	Number of WWD Events Involving Significant Moving to the Lane
NSSL	Number of WWD Events Involving Significant Shifting from the Lane
RITIS	Regional Integrated Transportation Information System
RL	Right Lanes
RMSE	Root Mean Square Error
RRSP	Road Rangers Service Patrol
RTMC	Regional Transportation Management Center
SDL	Scenario Definition Language
SOP	Standard Operating Procedures
TLPCR	Total Lane Proportion Change Readings
TMC	Transportation Management Center
TOC	Transportation Operations Center
TSM&O	Transportation Systems Management and Operations
TTC	Time to Collision
UC	Wrong-way Driver Reported, Use Caution
UEC	Wrong-way Driver Reported, Use Extreme Caution
vphpl	Vehicles per Hour per Lane
vpmpl	Vehicles per Mile per Lane

WWD	Wrong-Way Driving
WWVDS	Wrong Way Vehicle Detection Systems

CHAPTER 1
INTRODUCTION

1.1 Background

Wrong-way driving (WWD), particularly on freeways, poses a significant threat to public safety, endangering both wrong-way drivers and other motorists. On average, approximately 355 fatalities occur annually in the United States due to WWD incidents (National Transportation Safety Board, 2012). Given the severity of these crashes, WWD mitigation has become a national priority, with states implementing strategies aligned with the 4E's—Engineering, Education, Enforcement, and Emergency Medical Services. These efforts are supplemented by policy reforms and the adoption of advanced technologies to detect, verify, and address WWD incidents in real time (Finley et al., 2014). In Florida, the Florida Department of Transportation (FDOT) has taken a proactive approach to addressing WWD by drafting and implementing strategic countermeasures. FDOT's multifaceted strategy includes:

- **Policy Initiatives:** Initiating leadership-driven policy changes to enable actionable WWD mitigation plans.
- **Comprehensive Research:** Investigating crash patterns, driver behaviors (especially intoxication-related), and WWD causes.
- **Pilot Countermeasures:** Testing and comparing various mitigation strategies for effectiveness.
- **WWD Countermeasure Implementation Plan:** Designing and executing an extensive response plan.
- **Strategic Response Vision:** Developing a systematic response framework for WWD events on freeways.

WWD countermeasures are designed to deter wrong-way drivers from entering freeways through exit ramps. When initial warnings fail, the final line of defense includes alerting right-way drivers and law enforcement to minimize crash risks. A strategic and timely response to ongoing WWD events involves the integration of both traditional (including WRONG WAY signs) and modern approaches (involving intelligent detection, verification, and response), including:

- **Verification:** Utilizing closed-circuit television (CCTV) cameras, Road Rangers Service Patrol (RRSP), and Florida Highway Patrol (FHP) to confirm WWD incidents.
- **Public Alerts:** Employing dynamic message signs (DMSs), highway advisory radio (HAR), and navigation apps like Waze to notify motorists.
- **Coordination:** Engaging Regional Transportation Management Centers (RTMC) to collaborate with multiple agencies, such as the FHP and RRSP, for a unified response.
- **Documentation:** Recording incidents and response efforts through the SunGuide™ application.

Effective intervention requires a well-coordinated and interagency response plan. FDOT has developed a WWD strategic response plan, which has been disseminated to the districts' RTMC operators through standard operating procedures (SOPs) to ensure consistent and effective implementation.

1.2 Research Goal and Objectives

This research project aimed to thoroughly evaluate FDOT's strategic response plan for addressing WWD events on freeways. It sought to assess the plan's effectiveness in enabling a consistent, well-coordinated, and efficient response. By leveraging existing Intelligent Transportation Systems (ITS) such as DMSs and CCTV cameras and Transportation Systems Management and Operations (TSM&O) strategies, this study intended to optimize real-time responses to WWD incidents on freeways. The specific objectives include:

- Identify best practices nationwide for responding to WWD incidents on freeways.
- Assess the effectiveness of the existing WWD response plan outlined in the RTMC SOPs.
- Evaluate the impact and efficiency of WWD DMS messaging in mitigating WWD events.

These objectives will help refine Florida's strategies to mitigate WWD incidents, enhance safety outcomes, and serve as a model for other states.

1.3 Report Organization

This report is organized as follows:

- Chapter 1 provides a brief introduction to this research effort.
- Chapter 2 presents the nationwide and Florida-specific survey results on WWD countermeasures.
- Chapter 3 reviews the efficiency and effectiveness of the existing FDOT's response to WWD incidents on freeways.
- Chapter 4 evaluates the real-time real-world understanding of right-way drivers to WWD-related DMS and how they respond to those signs.
- Chapter 5 analyzes the comprehension and responses of right-way drivers to WWD-related DMS in a driving simulator setting.
- Chapter 6 summarizes this research effort and provides recommendations.

CHAPTER 2
STATE-OF-THE-PRACTICE SURVEY ON COUNTERMEASURES AND RESPONSE PLANS FOR RESPONDING TO WRONG-WAY DRIVING (WWD) EVENTS ON FREEWAYS

This chapter outlines the survey results that aimed to gather information on the existing policies, countermeasures, and response plans or procedures for responding to WWD events in Florida and other states. A nationwide survey was developed to reach transportation agencies, focusing on the state-of-the-practice policies and response plans or procedures for attending WWD events on freeways. This chapter provides the findings on the state-of-the-practice on countermeasures and response plans or procedures for attending WWD events. The chapter also includes the messages that the agencies publish on DMSs during active WWD events. The information presented in this chapter aims to help transportation agencies improve their WWD response plans and reduce the number of WWD incidents on limited-access facilities.

2.1 Survey Design

The survey design process involved several steps. First, the research team identified the points of contact from each state Department of Transportation (DOT). The team then prepared the survey questions that aimed to identify critical information such as the countermeasures used by agencies to prevent WWD entries, the types of signing and pavement markings and technologies used to prevent WWD events, the detection and reporting methods of wrong-way drivers, approaches to monitoring the trajectory of wrong-way drivers, the specific response plan or procedures for attending WWD events, the documented information during the WWD event management, and also the messages published on DMSs.

Once the survey questions were finalized, the next step was to submit them to the project managers for review and approval. The survey was created to be brief and concise, not taking too long for the respondents to complete. The survey consisted of 16 questions, which are listed in Appendix A. The questions were posted online using Qualtrics (http://www.qualtrics.com), and the survey was also administered through the same website. Qualtrics is an online survey platform that enables users to design and distribute surveys and analyze and visualize the resulting data. A screenshot of the website's interface is provided in Figure 2-1.

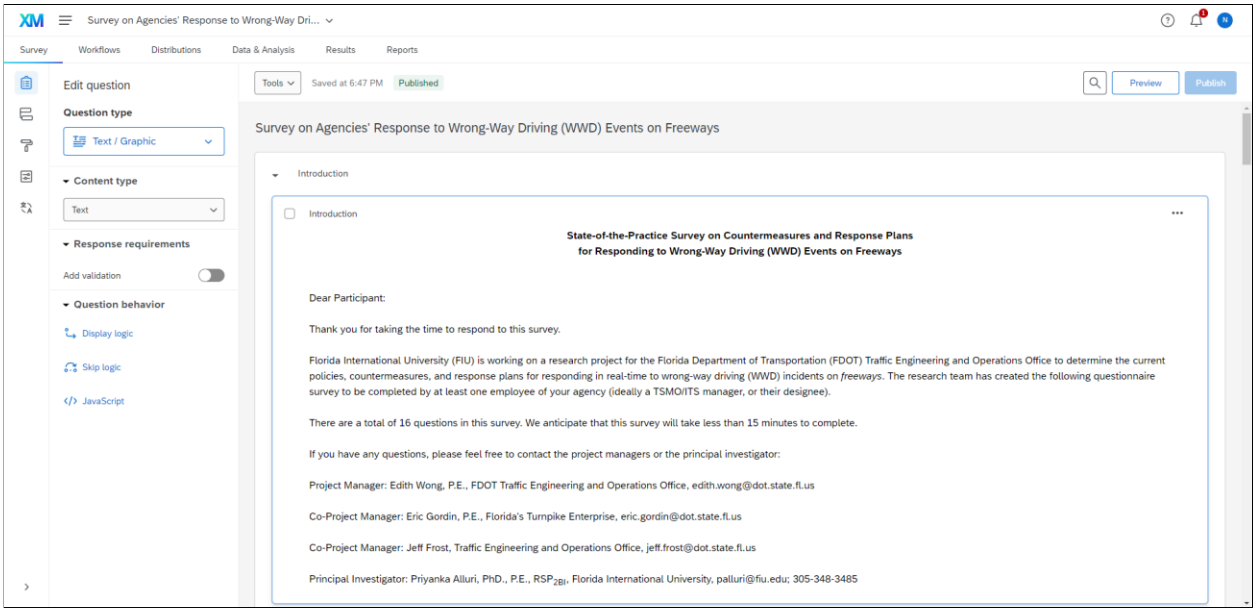

Figure 2-1: Qualtrics Online Survey Platform Interface

2.2 Survey Distribution

The survey was distributed to 102 contacts from the 50 state DOT (or similar) agencies. Emails with a link to the survey website were sent to the agencies, explaining the project's purpose, how long it would take to complete, and providing instructions on how to fill out the questionnaire. Contact details of the project managers and the principal investigator were also included. Specifically in Florida, the survey was emailed to the eight Florida Department of Transportation (FDOT) districts, including Districts 1-7 (D1-D7) and the Florida Turnpike Enterprise (FTE). Table 2-1 lists the invited agencies and the respondent's positions within the agency.

Follow-up emails were sent, and phone calls were made to ensure a high response rate. A total of two reminders were sent to those who had not responded; an extension period was also provided to give the respondents more time to complete the survey.

Table 2-1: List of Invited Agencies

State	Agency	Position of Respondent
Alabama	Alabama Department of Transportation (ALDOT)	-
Alaska	Alaska Department of Transportation and Public Facilities	-
Arizona	Arizona Department of Transportation (ADOT)	Assistant State Engineer
Arkansas	Arkansas Department of Transportation	State ITS Engineer
California	California Department of Transportation (Caltrans)	-
Colorado	Colorado Department of Transportation	-
Connecticut	Connecticut Department of Transportation	-
Delaware	Delaware Department of Transportation (DelDOT)	Highway Safety Improvement Program (HSIP) Manager
Florida	Florida Department of Transportation (FDOT)	State Arterial Management Engineer
	Florida Department of Transportation (FDOT) / D1	TSM&O Program Engineer

Table 2-1, Continued: List of Invited Agencies

State	Agency	Position of Respondent
	Florida Department of Transportation (FDOT) / D2	TSM&O Program Manager
	Florida Department of Transportation (FDOT) / D3	Operations Manager
	Florida Department of Transportation (FDOT) / D4	TSM&O Program Engineer
	Florida Department of Transportation (FDOT) / D5	TSM&O Program Engineer
	Florida Department of Transportation (FDOT) / D6	TSM&O Program Engineer
	Florida Department of Transportation (FDOT) / D7	TSM&O Program Engineer
	Florida Turnpike Enterprise (FTE)	Assistant Traffic Operations Engineer
Georgia	Georgia Department of Transportation (GDOT)	Assistant State Traffic Engineer
Hawaii	Hawaii Department of Transportation (HDOT)	District Engineer
Idaho	Idaho Transportation Department (ITD)	-
Illinois	Illinois Department of Transportation (IDOT)	-
Indiana	Indiana Department of Transportation (INDOT)	-
Iowa	Iowa Department of Transportation	-
Kansas	Kansas Department of Transportation (KDOT)	State ITS Engineer
Kentucky	Kentucky Transportation Cabinet (KYTC)	-
Louisiana	Louisiana Department of Transportation & Development (LADOTD)	-
Maine	Maine Department of Transportation (MaineDOT)	State Traffic Engineer
Maryland	Maryland Department of Transportation (MDOT)	-
Massachusetts	Massachusetts Department of Transportation (MassDOT)	-
Michigan	Michigan Department of Transportation	ITS Engineer
Minnesota	Minnesota Department of Transportation (MnDOT)	TSM&O Director
Mississippi	Mississippi Department of Transportation (MDOT)	-
Missouri	Missouri Department of Transportation (MoDOT)	-
Montana	Montana Department of Transportation (MDT)	Maintenance Operations Manager
Nebraska	Nebraska Department of Transportation (NDOT)	Traffic Control Engineer
Nevada	Nevada Department of Transportation	-
New Hampshire	New Hampshire Department of Transportation	-
New Jersey	New Jersey Department of Transportation (NJDOT)	-
New Mexico	New Mexico Department of Transportation (NMDOT)	-
New York	New York State Department of Transportation (NYSDOT)	-
North Carolina	North Carolina Department of Transportation (NCDOT)	State Traffic Operations Engineer
North Dakota	North Dakota Department of Transportation (NDDOT)	-
Ohio	Ohio Department of Transportation (ODOT)	Traffic Management Administrator
Oklahoma	Oklahoma Department of Transportation (OKDOT)	-
Oregon	Oregon Department of Transportation	-
Pennsylvania	Pennsylvania Department of Transportation (PennDOT)	Chief of Traffic Operations
Rhode Island	Rhode Island Department of Transportation (RIDOT)	TMC Manager
South Carolina	South Carolina Department of Transportation (SCDOT)	Assistant State Traffic Management Engineer
South Dakota	South Dakota Department of Transportation (SDDOT)	-

Table 2-1, Continued: List of Invited Agencies

State	Agency	Position of Respondent
Tennessee	Tennessee Department of Transportation (TDOT)	-
Texas	Texas Department of Transportation (TxDOT)	Director, Traffic Management
Utah	Utah Department of Transportation (UDOT)	ITS Program Manager
Vermont	Vermont Agency of Transportation (VTrans)	State Traffic Engineer
Virginia	Virginia Department of Transportation (VDOT)	State Traffic Operations Manager
Washington	Washington State Department of Transportation (WSDOT)	Corridor Operations Manager
West Virginia	West Virginia Department of Transportation (WVDOT)	-
Wisconsin	Wisconsin Department of Transportation (WisDOT)	-
Wyoming	Wyoming Department of Transportation (WYDOT)	Maintenance Staff Engineer / Safety Management Engineer

Note: - stands for a non-responding agency.

A total of 27 state agencies and eight FDOT districts responded to the survey. The response rate was 54% and 100% for the nationwide and FDOT districtwide (including the FTE) surveys, respectively. Figure 2-2 presents the spatial distribution of the responding agencies.

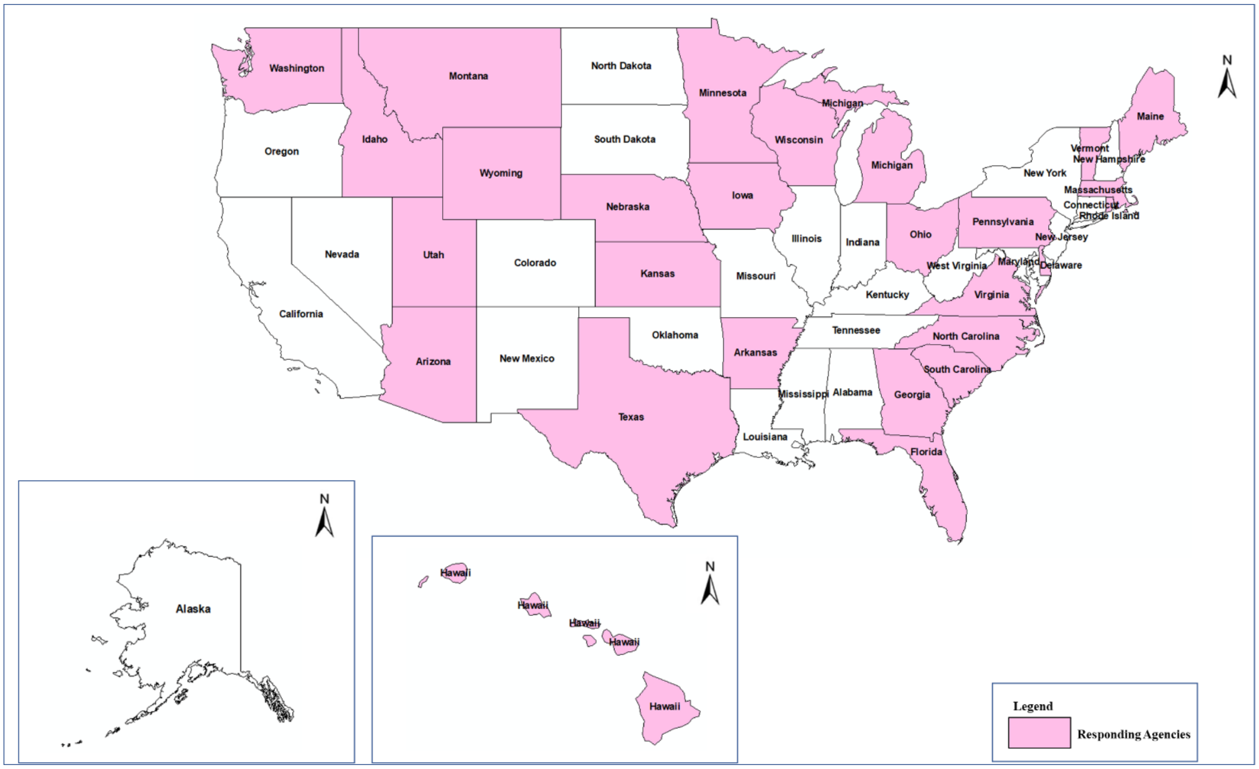

Figure 2-2: Spatial Distribution of Survey Agency Respondents

2.3 Nationwide Survey

The nationwide survey had five sets of questions:

- Policy and planning-related questions

- Infrastructure-related questions
- Technology-related questions
- Notification and coordination-related questions
- Data and documentation-related questions

2.3.1 Policy and Planning

2.3.1.1 Existence of Specific WWD Policy

The survey asked if the agency had a specific policy for addressing WWD incidents on freeways, and five respondents answered yes, 20 answered no, and two mentioned they were unsure. Among those who answered yes, one respondent mentioned that their agency notifies the police whenever a WWD system alarm goes off; they also notify vehicles on the freeway using Changeable Message Signs (CMSs). Figure 2-3 summarizes the state DOTs' responses to having the specific policies employed to address WWD incidents. However, most respondents (20) stated they do not have a specific policy for addressing WWD incidents on freeways

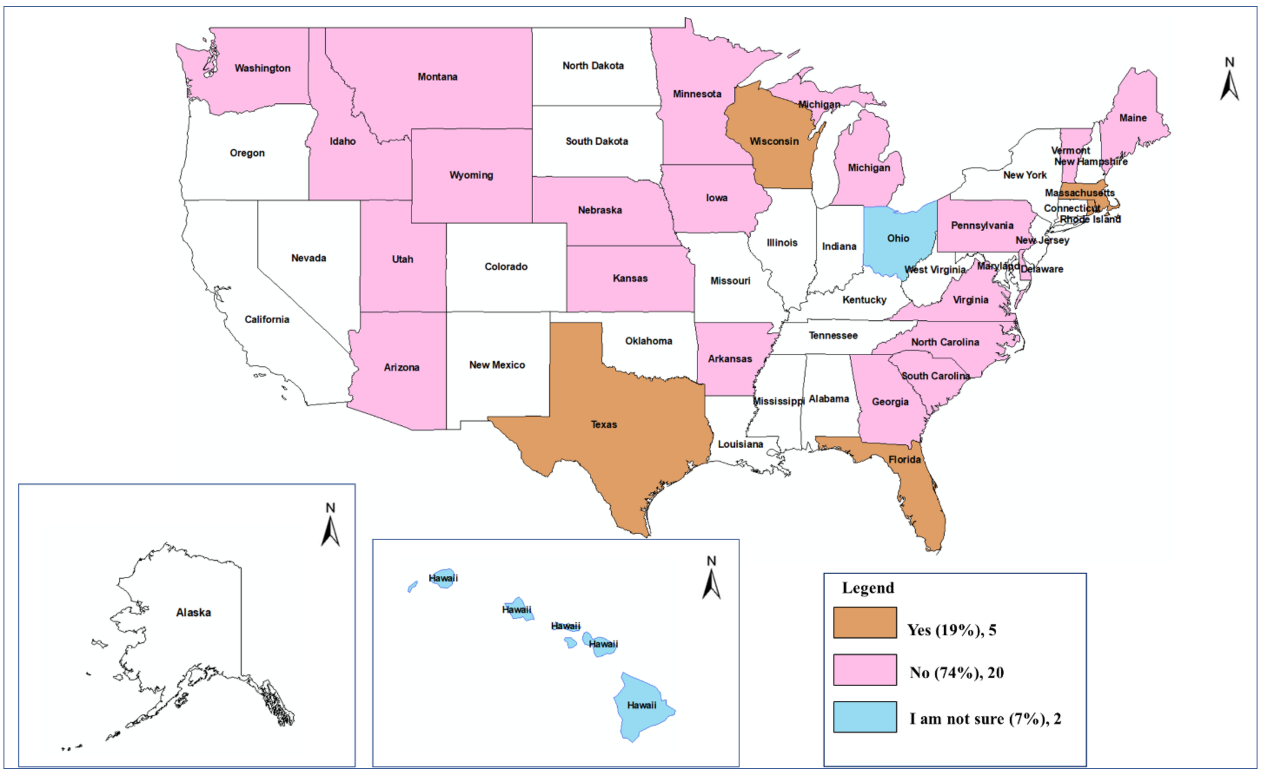

Figure 2-3: State DOTs with Specific WWD Policies

2.3.1.2 Existence of Specific WWD Response Plan

The question asked whether the agency has a specific response plan or procedures for intercepting wrong-way drivers on freeways in real time. The overview of the state DOTs' response on whether they have specific response plans to encounter the WWD events is summarized in Figure 2-4. The results showed that eight respondents answered "yes," 16 responded "no," and one was unsure.

The eight respondents who answered “yes” provided detailed descriptions of their response plan or procedures.

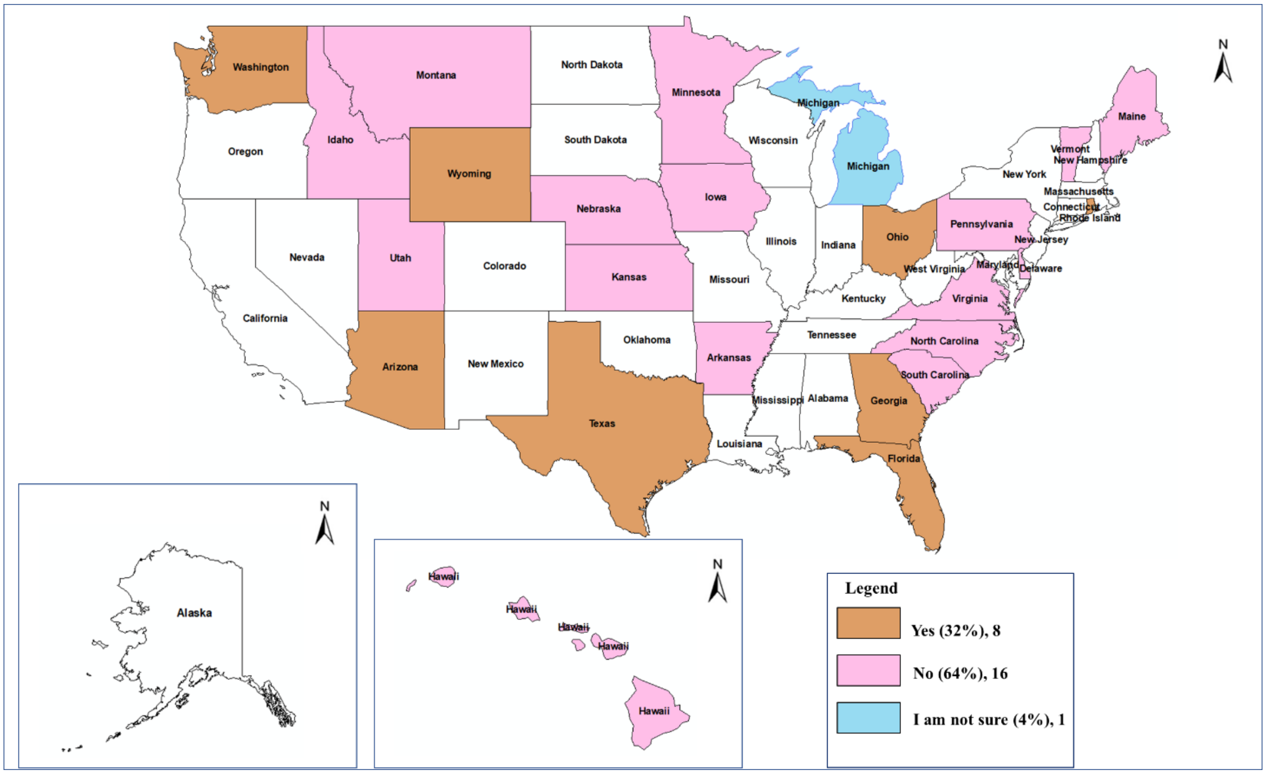

Figure 2-4: State DOTs with Specific WWD Response Plans or Procedures

Most agencies with a response plan use methods such as alerting law enforcement, notifying Transportation Management Center (TMC) operators, using Closed Circuit Television (CCTV) cameras to search for and confirm the WWD, posting DMS messaging where applicable, and disseminating information to responders. One respondent mentioned using Automatic Incident Detection (AID) cameras to detect wrong-way drivers and alert law enforcement. Most agencies surveyed do not have a response plan or procedures for intercepting wrong-way drivers on freeways in real time. The eight agencies with a response plan or procedures stated that they use various methods to intercept wrong-way drivers, including alerting law enforcement, using CCTV cameras, and posting messages on DMSs.

2.3.2 Infrastructure

2.3.2.1 Signing and Pavement Markings

The survey question asked respondents to select all types of signs and pavement markings their agency uses to prevent wrong-way drivers from entering the freeway. The response results are summarized in Figure 2-5. The results show that the most commonly used methods are supplemental signs (20 respondents), followed by lower mounting heights of “DO NOT ENTER” and “WRONG WAY” signs (16 respondents). Other commonly used methods include Wrong-Way pavement marking (15 respondents), red retroreflective strips on sign supports (14), oversized signs (13), and detection-triggered devices (12).

The less common methods among respondents were raised pavement markings (8 respondents) and retro-reflective delineators along off-ramps (8 respondents). Five and seven respondents mentioned the use of flashing beacons (not detection-based) and flashing light-emitting diodes (LEDs) around signs (not detection-based), respectively. Some unique methods were also mentioned by a few respondents (6) under the "Other" category, such as using automatic incident detection (AID) technology, straight-up green arrows at interchange traffic signal heads to emphasize the correct direction of travel, DO NOT ENTER, WRONG WAY static signage, and following the MUTCD guidelines. Only one respondent mentioned using directional rumble strips, and three mentioned passive warning systems. The results demonstrate that agencies use various methods to prevent WWD on freeways, sometimes combining or supplementing the previously mentioned countermeasures.

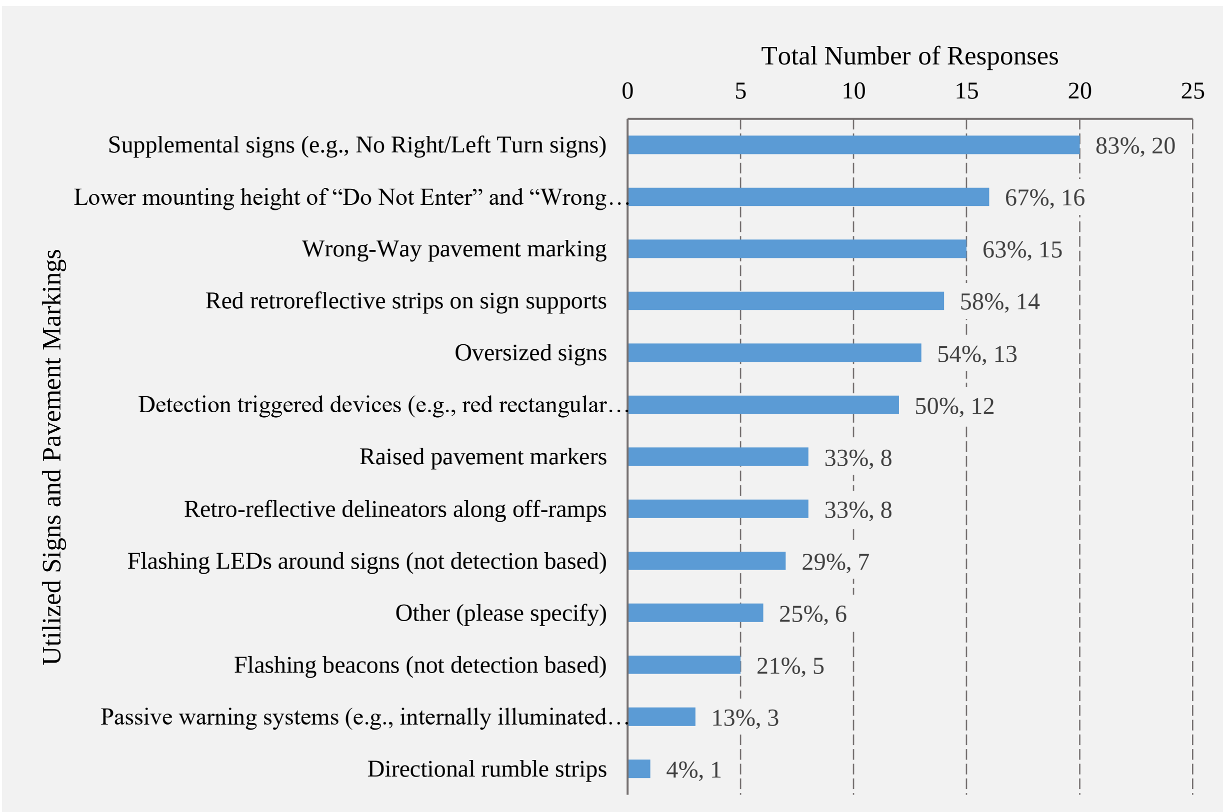

Figure 2-5: Types of Signs and Pavement Markings Used to Prevent WWD by State DOTs

2.3.2.2 Dynamic Message Signs - Content

The survey question aimed to identify the message(s) posted on DMS boards during an active WWD incident. Respondents provided various answers regarding the content displayed; the most common message displayed on DMS boards was some variation of "Wrong Way Driver Reported, Use Caution." Other responses included "Wrong Way Driver Detected, Use Caution," "Wrong Way Driver Ahead, Pull Over," and "Wrong Way Vehicle Use Caution." Several respondents stated that their agency does not display any information on DMS during such incidents. In contrast, others stated that their agency is currently exploring the possibility or is in the process of deploying this technology. One respondent mentioned that their agency determines the content of DMS based on a situational assessment.

It can be inferred from the responses that there is a need for more consistent and standardized approaches to alerting drivers about WWD incidents on freeways. The standard approach could include developing messaging and protocols for displaying information on DMS boards during active WWD incidents.

2.3.2.3 Dynamic Message Signs - Display Location

The responses to the question "How does your agency determine which DMSs shall display the warning message during an active WWD incident?" suggest that agencies use a wide variety of approaches to determine the radius/region of displaying the DMS message. Some agencies mentioned selecting the message board closest to the ramp or downstream of the wrong-way driver. Another respondent mentioned activating any DMS in the travel direction of the wrong-way driver or activating the DMSs associated with each WWD sign. One agency mentioned activating DMS for a distance of two signs when notified about a wrong-way driver. Another agency mentioned activating the DMS on potential impact routes that the WWD could have an impact on.

A few responding agencies indicated a case-by-case approach where activating or not activating DMS during WWD events depended on the nature of the incident. Some agencies stated that they do not currently activate DMS for WWD incidents. One agency mentioned using response plans via the advanced traffic management system (ATMS) for any incident. Another agency mentioned estimating the location and trying to display a WWD warning message on the DMS upstream of the wrong-way driver for the right-way drivers. The responses imply various approaches to determining which DMS should display the warning message during an active WWD incident. While some agencies use technology or specific criteria, others rely on their judgment and experience.

2.3.2.4 Dynamic Message Signs - Display Duration

The survey question asked respondents how long they typically post messages on DMSs during active WWD incidents on freeways. Two respondents specified a period for how long messages are posted, ranging from 10 to 20 minutes. Several respondents indicated that they post messages until the incident is resolved, the wrong-way driver is intercepted, or the driver is no longer on the given interstate system. Some respondents indicated they were not applicable or needed to check on this information. One respondent noted that they do not display information on the DMS regarding moving WWD vehicles. The responses obtained indicate no standardized approach to determining the display duration of DMSs during active WWD incidents on freeways. To determine this, agencies use criteria such as specified periods of time (per SOPs), incident resolution, and input from law enforcement or TMC operators.

2.3.3 Technology

2.3.3.1 WWD Detection Technologies

In this survey question, respondents were asked about the specific types of ITS technologies their agency uses to detect wrong-way drivers on freeways in real time. Figure 2-6 shows the survey results obtained from this question. The results indicate that CCTV (16 respondents) and video detection (12 respondents) are the most commonly used technologies. Compared to CCTV, video detection involves the automated detection of WWD vehicles using artificial intelligence or machine learning instead of having operators actively monitor the video feeds. Several respondents also mentioned radar (nine respondents) and thermal imaging/sensors (six respondents). Only two respondents reported using inductive loop detectors (ILDs), and none reported using magnetic sensors.

Additionally, a few respondents (4) mentioned using other types of ITS technologies that were not listed in the question, with three stating that their agency did not use any ITS technologies to detect wrong-way drivers and another one stating that their agency used only DO NOT ENTER and WRONG WAY static signage as the low population in their regions do not justify the installation and monitoring costs. The results suggest that CCTV and video detection are the most commonly used technologies for detecting wrong-way drivers in real time on freeways, followed by radar.

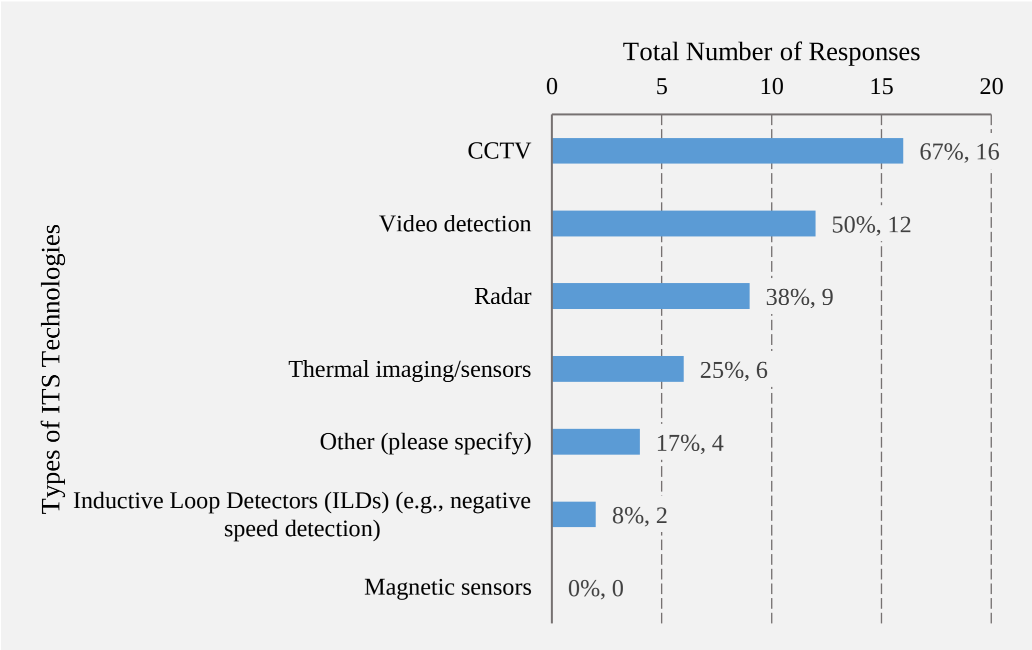

Figure 2-6: ITS Technologies Used by State DOTs to Detect WWD Incidents

2.3.3.2 WWD Trajectory Tracking Methods

The survey question aimed to understand how agencies track the trajectory of wrong-way drivers on freeways in real time. Participants were allowed to select multiple options from a given list. Results obtained from the survey responses for the methods are summarized in Figure 2-7. The results show that the most commonly used method to track the trajectory of WWD in real time is through TMC operators, chosen by 20 participants. Data from 911 calls or other emergency services were chosen by 18 participants, indicating that this method is also commonly used by agencies. ITS technologies, such as cameras and sensors, were the third most selected method (14 participants). Six participants selected “Other” and provided specific responses, including using Highway Patrol dispatch, dispatching law enforcement, and not having any method to track the trajectory of wrong-way drivers.

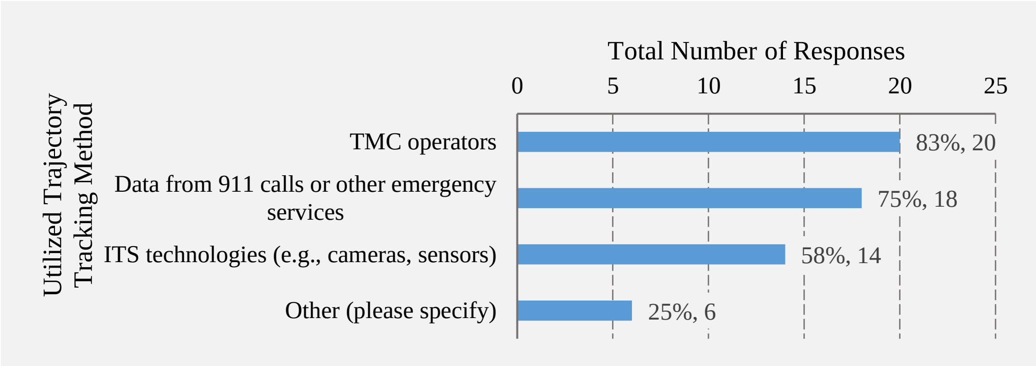

Figure 2-7: Methods Used by State DOTs to Track the Trajectory of WWD

2.3.3.3 Steps Adopted on WWD Detection

The survey question asked respondents about the steps their agency takes when a wrong-way driver is detected on the freeway. Figure 2-8 depicts the state DOTs’ responses on the steps they have adopted to deploy when a WWD event is detected. The results indicate the following:

- Dispatching law enforcement to the scene is the most common response, with 21 respondents reporting that their agency takes this step.
- Twelve respondents reported that their agency alerts right-way drivers on the freeway through DMSs.
- Only two respondents reported that their agency alerts right-way drivers through smartphone apps such as Google Maps, Waze, and Apple Maps.
- Four respondents provided other responses, one indicating that their wrong-way detection system is a pilot and has just begun, and the other stated they do not take steps that use ITS technologies.

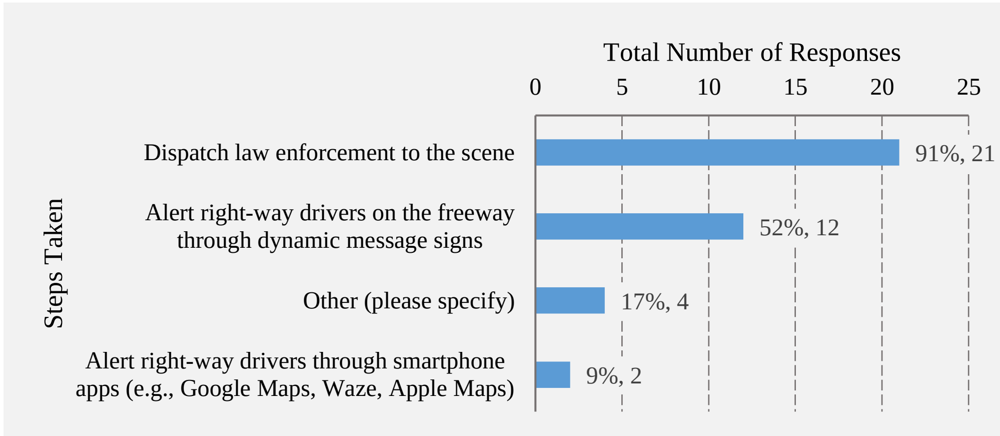

Figure 2-8: Steps Taken by State DOTs When a WWD is Detected

2.3.3.4 Evaluations of the Effectiveness of Strategies for Mitigating WWD Incidents

The survey question asked respondents whether their agency has conducted any studies or evaluations of the effectiveness of its policies, countermeasures, and response plans for addressing WWD incidents on freeways. Figure 2-9 presents the state DOTs' responses on whether they have ever evaluated the effectiveness of their WWD mitigation measures. The results indicate that seven out of 23 respondents (30%) answered "Yes," while 12 respondents (52%) answered "No." Four respondents (17%) were unsure. The seven respondents who answered "Yes" provided additional information about the studies or evaluations conducted by their agencies. One agency has released a request for proposals (RFP) to scan all possible WWD countermeasures.

In contrast, another agency mentioned that it assesses the effectiveness of its WWD countermeasures by analyzing video footage of corrected drivers. One agency cited a research project report by Finley et al. (2014) as the basis for its evaluations. Another respondent listed "List" as their agency's study or evaluation. Most respondents either answered "no" or "not sure," indicating that only a few state DOTs have conducted studies or evaluations of the effectiveness of their policies, countermeasures, and response plans for addressing WWD incidents on freeways.

Based on the results, it is implied that dispatching law enforcement to the scene is the most common step agencies take when a wrong-way driver is detected on the freeway. Alerting right-way drivers through DMS is also a standard method used. The use of smartphone apps is a less common method used by agencies.

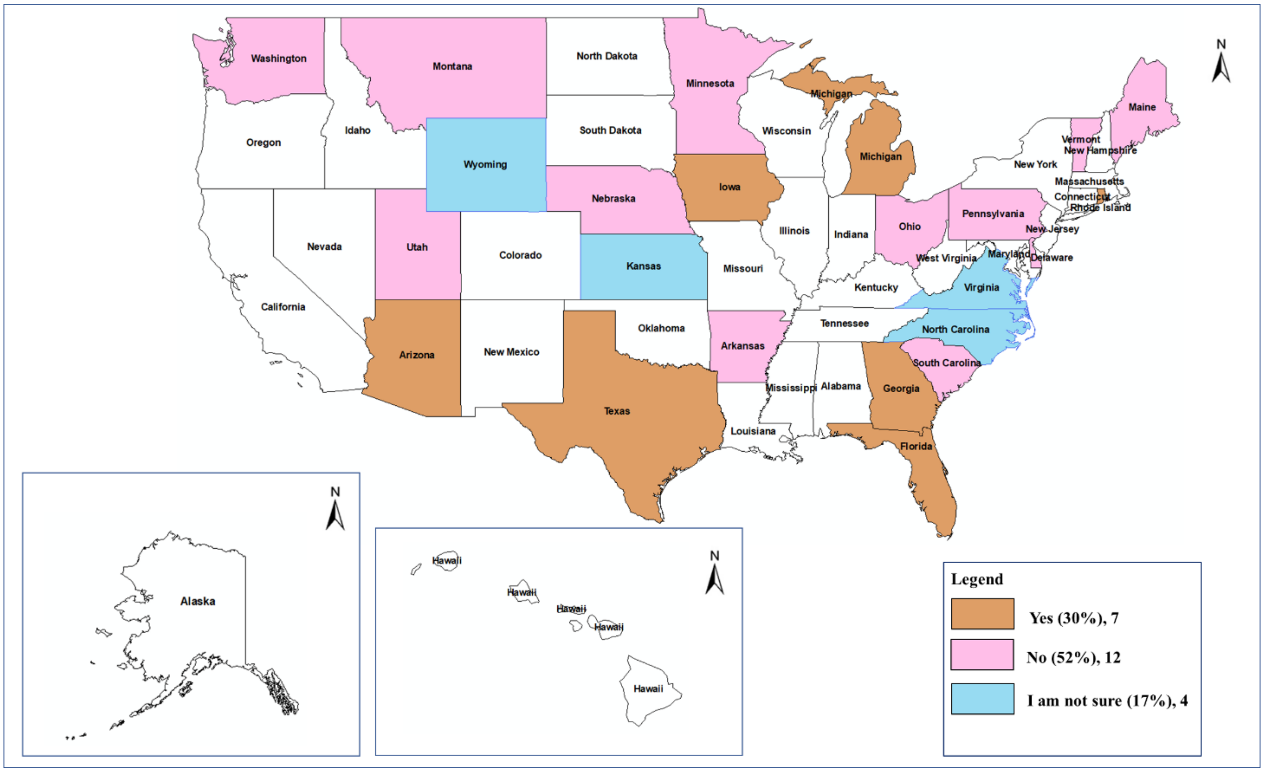

Figure 2-9: State DOTs with Previous Studies or Evaluations of the Effectiveness of WWD Policies, Countermeasures, and Response Plans

2.3.3.5 Future Testing of Technologies

The survey asked whether the respondent's agency plans to test new technologies to detect, prevent, or track WWD entries on freeways in the near future. The results indicate that 13 out of 23 respondents (57%) answered "Yes," while six respondents (26%) answered "No." Four respondents (19%) were unsure.

The 13 respondents who answered "Yes" provided additional information about the new technologies their agencies plan to test. One agency is currently working on connected vehicle applications, and another is looking to install new technologies that would use video analytics and automated DMS messaging in a metro area. Some respondents provided a specific technology being tested, such as a wrong-way detection system, sensor detection, or video analytics. One respondent mentioned that their agency continues reviewing new technologies and that testing will depend on funding or grant opportunities. These results are summarized in Figure 2-10.

One respondent mentioned researching and testing various "off-the-shelf" detection and alert systems and deciding to deploy a Carmanah system for broader deployment in different parts of Utah. The results indicate that most responding agencies (57%) will soon test new technologies to detect, prevent, or track WWD entries on freeways. The responses indicate a range of technologies being considered, including video analytics, sensor detection, and connected vehicle applications.

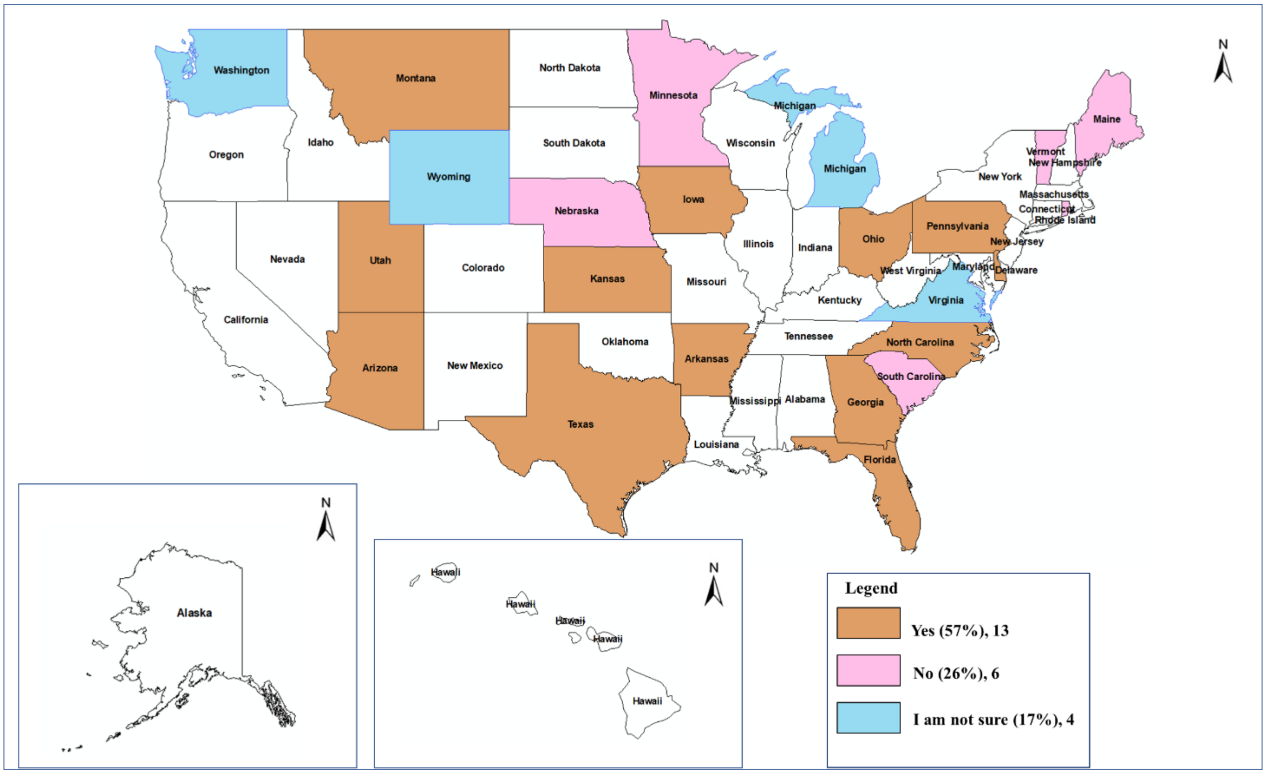

Figure 2-10: State DOTs Planning to Test New Technologies to Detect, Prevent, or Track WWD Entries

2.3.4 Notification and Coordination

2.3.4.1 Public and Media Real-Time Notification

The survey question aimed to identify how agencies notify the public and media in real time when a WWD incident occurs on freeways. Figure 2-11 gives a summary of the responses. The most popular method is dynamic (changeable) message signs, with 14 respondents selecting this option. On the other hand, social media (e.g., Twitter) was selected by only four respondents, while HAR releases and smartphone applications (e.g., Google Maps, Waze, Apple Maps) were each chosen by only one and two respondents, respectively.

Eleven respondents specified "Other" as a method used by their agency to notify the public and media in real time about a WWD incident on freeways. The responses are as follows:

- Nine respondents (39%) indicated their agency does not notify motorists of an active WWD vehicle. One of them added that when and if the WWD vehicle crashes, details of the incident are shared on the DMSs, Waze, on social media, and integrated public alert and warning system (IPAW).
- One respondent specified that their agency uses the MiDrive/511 website.
- One respondent indicated that their agency only activates real-time notification in coordination with law enforcement after confirming the incident.

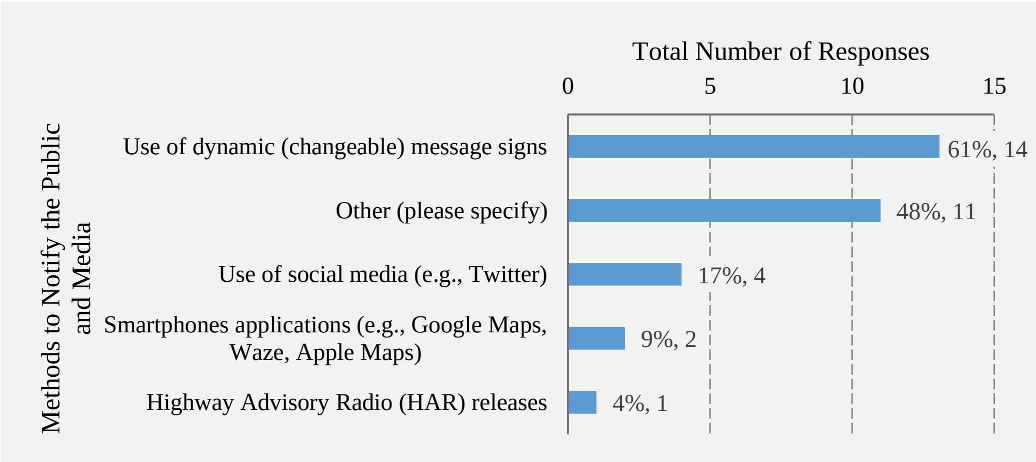

Figure 2-11: Methods Used by State DOTs to Notify the Public and Media in Real Time

DMSs are the most common method agencies use to notify the public and media in real time about a WWD incident on freeways. Social media and smartphone applications are less commonly used. Several of the responding agencies (39%) do not currently use any method to notify the public and media in real time.

2.3.4.2 Interagency Real-time Coordination

The survey question asked how different agencies coordinate in real time during a WWD incident on freeways. Some agencies use communication technology such as CCTV, DMS, radio, telephone, and shared video links to coordinate with law enforcement and emergency responders. For instance, one agency reported using ITS technologies such as CCTV and DMS to coordinate during a WWD incident. Another agency uses phone calls and radio to communicate with other agencies during an incident.

Other agencies are co-located with other agencies and organizations, which enables them to coordinate efficiently in the same physical space. For instance, one agency reported that the operation center is housed with other agencies and organizations, such as law enforcement and emergency responders. On the other hand, one agency recommends automated alerting or messaging to drivers and comments that traditional installations have only been installed at “hot spots.” The agency reported that most incidents happen so fast that hazardous driving scenarios run their course before its partners are notified.

Finally, some agencies rely on the appropriate law enforcement agencies for a coordinated response. For example, one agency reported that they contact the appropriate law enforcement for where the incident is located. The answers depict agencies' different coordination approaches during a WWD incident, such as communication technology, co-location with other agencies, automated alerting or messaging, and relying on law enforcement agencies.

2.3.5 Data and Documentation

2.3.5.1 WWD Incident Data Documentation

The survey question asked participants to select all information documented in a WWD incident on the freeway. The results show that the most commonly documented information is the location where the wrong-way driver entered the freeway (87% of the respondents) and the direction of travel of the wrong-way driver (83% of the respondents), followed closely by the outcome (78%). The final location of the wrong-way driver (70%) and the vehicle description (65%) were also frequently documented. Figure 2-12 outlines these responses.

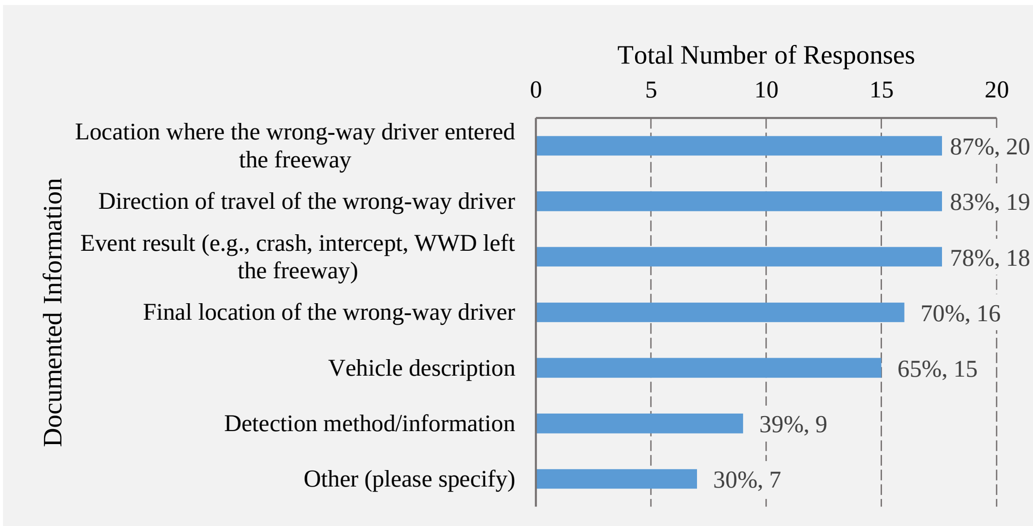

Figure 2-12: Documented Information by State DOTs in a WWD Incident

Less commonly documented information includes the detection method/information (39% of the respondents). Additionally, seven respondents selected "Other" and provided their responses. One respondent mentioned collecting response time, and two mentioned that the information is primarily captured in a crash report. At the same time, another said that there is no specific documentation process for this information. One other respondent entered "N/A" as a response. Lastly, one respondent mentioned that they record the date and time in addition to the information documented in a WWD incident.

2.3.5.2 WWD Data Collection and Analysis

The question asked respondents to select all types of data their agency collects and analyzes in WWD incidents on freeways. The response results for this survey question are summed up in Figure 2-13. Of the seven answer choices, the most commonly selected options were "Incident reports" and "WWD data," which were selected by 20 and 19 respondents, respectively. The third most selected option was "Reports from first responding agencies," which was selected by 13 respondents (57%).

Similarly, 12 respondents also selected "Data from detection and warning systems," and 11 respondents (48%) selected "Video recordings." Two of the respondents selected "Surveys of motorists” as a type of data that their agency collects and analyzes in WWD incidents on freeways. Among the four respondents who selected “Other,” one respondent specified that their agency does not collect any policy-specific data. Another responded that the agency analyzes the dashboard to identify hotspots, locations, and trends.

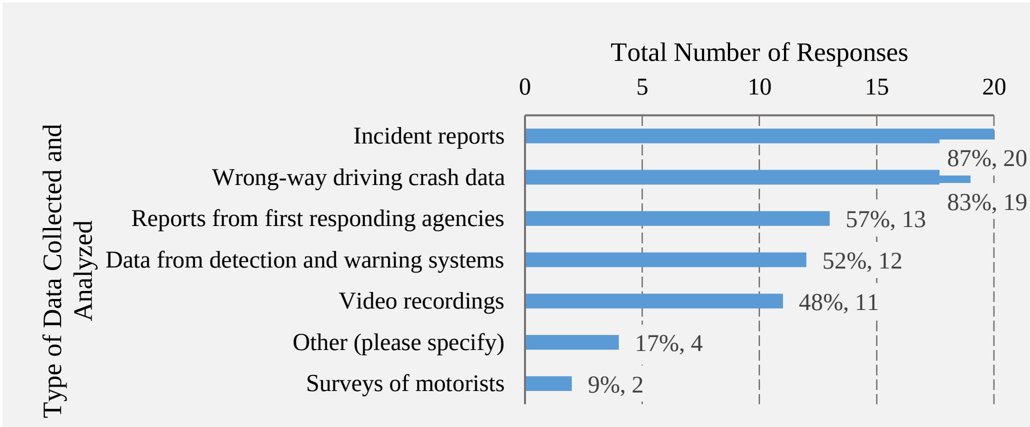

Figure 2-13: Types of Data Collected and Analyzed by State DOTs on a WWD Incident

Results suggest that the most common types of data collected and analyzed in WWD incidents on freeways are incident reports and WWD crash data, followed by reports from first responding agencies. Surveys of motorists are not widely analyzed for this purpose.

2.3.5.3 Evaluation Approaches of Countermeasures

The survey question asked respondents how their agency analyzes and evaluates the effectiveness of its WWD countermeasures on freeways. The most commonly selected approach was analyzing WWD incidents, with 18 respondents (78%) indicating that their agency uses this method. Analyzing crash data was also a commonly selected approach, with 17 respondents (74%) indicating that their agency uses this method. Evaluation of warning and detection systems was selected by 11 respondents (48%), and analysis of traffic flow data was selected by four respondents (17%). Only one respondent indicated that their agency conducts surveys of motorists to evaluate the effectiveness of their countermeasures. Three respondents indicated that they use public feedback as an evaluation approach.

Six respondents selected “Other” and provided additional information. One respondent indicated that their agency has only implemented countermeasures on selected on-ramps and has evaluated the number of incidents where drivers started going the wrong way but turned around. Another respondent indicated that their agency uses probe and event data for evaluation. Also, one respondent mentioned that this is an infrequent event, and another mentioned that they do not analyze the effectiveness of the countermeasures. Moreover, two respondents mentioned that they use detecting cameras to perform the evaluation. Another respondent indicated that their agency does not conduct formal evaluations. Figure 2-14 summarizes these responses.

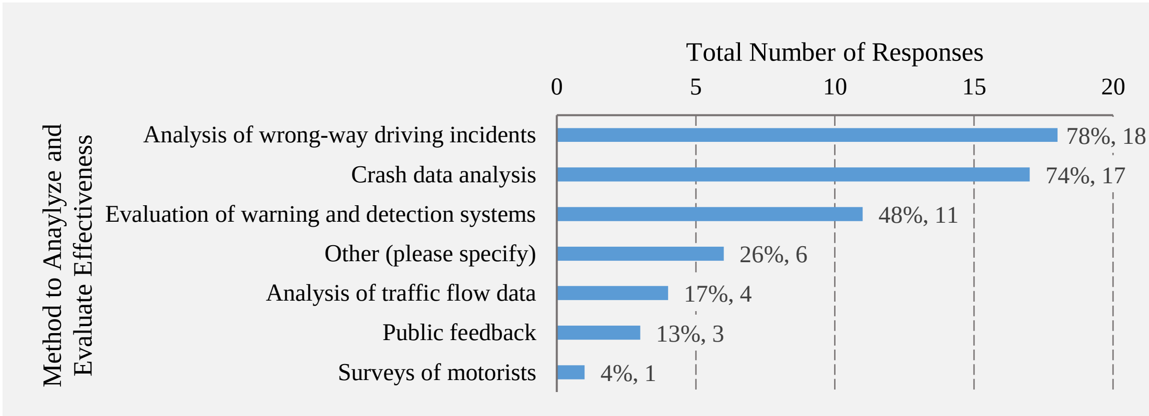

Figure 2-14: State DOTs' Methods to Analyze and Evaluate the Effectiveness of WWD Countermeasures

2.3.6 Nationwide Survey Summary

Overall, twenty-seven state agencies responded to the survey; the response rate was 54%. Some key findings from the state-of-the-practice survey include:

- A large majority of state DOTs do not have specific policies (74% of the responding states) or response plans (64% of the responding states).

- Among the responding states, supplemental signs (e.g., No Right/Left Turn signs) are the most common (83%) type of signing and pavement marking to prevent WWD incidents on freeways. Nationwide, the second most common approach is the use of lower mounting heights of "DO NOT ENTER" and "WRONG WAY" signs (67%).

- The DMS content displayed is a variation of the message "Wrong Way Driver Detected, Use Caution / Pull Over." Nationwide, some agencies responded that they do not display any information during WWD incidents.

- For the criteria to determine the spatial extent (i.e., the distance) to which the DMS are displayed nationally, the most common approach is using a distance-based criterion. However, it is worth mentioning that some agencies activate any DMS in the travel direction, and others activate DMS for a distance of two signs. One agency uses a case-by-case approach depending on the WWD incident.

- The responding agencies stated that they post messages for a set duration, ranging from 10 to 20 minutes. The message may also be posted until the incident is resolved, the wrong-way driver is intercepted, or the driver is no longer on the given interstate system.

- CCTV cameras are the most commonly used (67% of the responding states) ITS technology to detect wrong-way drivers on freeways in real time. The second most common approach is the use of video detection (50% of the responding states).

- Nationally, most agencies use TMC operators (83% of the responding states) and data from 911 calls or other emergency services (75% of the responding states). Some agencies in the U.S. do not have any method to track wrong-way drivers' trajectories.

- Nationally, dispatching law enforcement to the scene is the most common approach (91%), followed by alerting right-way drivers through DMS (52%) when a wrong-way driver is detected on the freeway.

- Nationally, a little over 50% of the responding states stated that they have not conducted studies or evaluations of the effectiveness of their policies, countermeasures, and response plans for addressing WWD incidents on freeways. Around one-third of the responding agencies reported that their agency had conducted such evaluations.

- There is an interest in testing new technologies to detect, prevent, or track WWD entries on freeways. Nationally, over half of the responding agencies (57%) plan to test new technologies, including video analytics, sensor detection, and connected vehicle applications.

- DMSs are the most commonly used method to notify the public and media in real time about WWD incidents (61% of the responding states). Newer technologies, such as social media and smartphone applications, are utilized less often. About 40% of the responding agencies stated that they do not currently use any method to notify the public and media in real time.

- Responses suggest that nationally, agencies use different methods to coordinate in real time during a WWD incident, such as communication technology, co-location with other agencies, automated alerting or messaging, and relying on law enforcement agencies.

- On a national level, the location where the WWD entered and the direction of travel was selected by 87% and 83% of the respondents as the most commonly documented information during a WWD event, respectively.

- Results suggest that nationally, the most common data collected and analyzed in WWD incidents on freeways are incident reports (87%) and WWD crash data (83%). It is a common practice to document data from detection and warning systems and reports from first-responding agencies. Surveys of motorists are not widely used nationally.

- Analyzing WWD incidents and crash data is commonly used for evaluating WWD countermeasures at the national level (78% and 74%, respectively). Evaluation of warning and detection systems is also common in the nationwide survey (48%). Additionally, some DOTs (17%) around the U.S. analyze traffic flow data to evaluate the implemented WWD countermeasures.

2.4 Florida Districtwide Survey

The Florida districtwide survey was prepared with the same five sets of questions as the nationwide survey elaborated on in the previous section. The questions were directed to the eight FDOT districts.

2.4.1 Policy and Planning

2.4.1.1 Existence of Specific WWD Policy

District-wise, from the responses to the question regarding the agency's policy for addressing WWD incidents on freeways, it can be observed D1, D2, D3, D6, D7, and the FTE answered "Yes," indicating that their agency has a specific policy in place for addressing such incidents. D5 answered "No," and D4 answered "I am not sure," indicating that their agency does not have a specific policy or that they may not be aware of it. Among the five respondents who answered yes, D1 provided a detailed policy for addressing WWD incidents, including utilizing ITS countermeasures and CCTV cameras to detect and manage incidents and a response plan that automatically activates signs within a radius of the incident. The policy also includes steps for confirming the direction of the wrong-way driver, broadcasting messages to Road Rangers, utilizing CCTV cameras, and notifying the public of a WWD incident.

D2 mentioned that their policy is defined in their SOPs. D3 described a comprehensive policy that immediately activates the WWD event and notifies all staff to locate the WWD via CCTV. Additionally, their policy involves posting WWD messages on DMS and notifying the Road Rangers and FHP. In a crash involving a wrong-way driver, a secondary event is created to manage the crash event. D6 procedure includes coordination with the Florida Highway Patrol, notification to Road Ranger personnel, dissemination of information via DMSs, and notifications to FDOT executive leadership and other FDOT District personnel. The FTE responded "yes," indicating that the agency has a specific policy in place for addressing such incidents. The policy included the steps to respond to WWD events as regulated by the FTE SOPs.

2.4.1.2 Existence of Specific WWD Response Plan

The survey question asked if agencies had specific response plans or procedures for intercepting wrong-way drivers on freeways in real time. Seven of the eight districts answered yes, while D6 answered no. The responses of those who answered yes were varied, with different strategies and procedures mentioned, such as alerting law enforcement, broadcasting messages to all road rangers, utilizing CCTV cameras, and deploying WWD equipment at various off-ramps. The survey results suggest that D1, D2, D3, D4, D5, D7, and the FTE have specific real-time response plans or procedures for intercepting wrong-way drivers on freeways. The responses provided by the respondents indicate that these plans typically involve immediate notification of law enforcement agencies and active search on CCTV cameras for validation.

2.4.2 Infrastructure

2.4.2.1 Signing and Pavement Markings

The survey question asked respondents to select all the types of signing and pavement markings their agency uses to prevent WWD on freeways. The most commonly selected types of signing and pavement markings were supplemental signs (selected by all the districts and the FTE) and detection-triggered devices (selected by D2, D3, D4, D5, D6, D7, and the FTE). Other frequently selected options included wrong-way pavement markings (D1, D4, D5, D6, D7, and the FTE), raised pavement markers (D1, D5, D6, and D7), Lower mounting height of “DO NOT ENTER” and “WRONG WAY” signs (D1, D4, D5, and the FTE), and red retroreflective strips on sign supports (D5, D6, D7, and the FTE). D4, D5, and D6 use oversized signs, while D1, D5, and D7 use flashing LEDs around signs.

The results indicate that agencies may use multiple types of signing and pavement markings to prevent WWD incidents on freeways. Supplemental signs and detection-triggered devices are most commonly used among FDOT districts. No agency in Florida uses directional rumble strips. Table 2-2 summarizes these results.

Table 2-2: Types of Signs and Pavement Markings Used by FDOT Districts to Prevent WWD Incidents on Freeways

District / Agency:		D1	D2	D3	D4	D5	D6	D7	FTE
Signing and Pavement Markings Used	**Oversized signs**				✔	✔	✔		
	Supplemental signs	✔	✔	✔	✔	✔	✔	✔	✔
	DO NOT ENTER and WRONG WAY signs	✔		✔	✔	✔	✔	✔	✔
	Red retroreflective strips			✔	✔	✔	✔	✔	✔
	Flashing LEDs around signs	✔		✔	✔	✔	✔	✔	✔
	Flashing beacons			✔	✔	✔	✔	✔	✔
	Raised pavement markers	✔		✔	✔	✔	✔	✔	✔
	Wrong-Way pavement marking	✔		✔	✔	✔	✔	✔	✔
	Directional rumble strips			✔	✔	✔	✔	✔	✔
	Retro-reflective delineators off-ramps			✔	✔	✔	✔	✔	✔
	Detection-triggered devices		✔	✔	✔	✔	✔	✔	✔
	Passive warning systems							✔	

Note: ✔ indicates the presence of WWD specific signing and pavement markings in a particular district or agency.

2.4.2.2 Dynamic Message Signs - Content

The survey question asked what content agencies display on DMSs during an active WWD incident to alert right-way drivers on freeways. The respondents described various messages their agencies display on DMSs during an active WWD incident. D2 stated that it uses a phased approach, with an initial "Wrong Way Driver Ahead" message followed by a caution message in the second phase. The caution messages include "Wrong Way Driver Alert | Use Extreme Caution," "Wrong Way Driver Ahead | Use Caution," and "Wrong Way Driver Reported | Use Caution."

2.4.2.3 Dynamic Message Signs – Display Location

The survey question asked how agencies determine which DMSs shall display the warning message during an active WWD incident. Different approaches were mentioned by the respondents. D1 and D5 stated that they display WWD warning messages on all DMSs within a 15-mile radius of detection, while FTE stated that it uses a 10-mile radius. D3 stated that they use a 50-mile radius to determine which DMS to display the warning message during WWD incident. D2 stated that they use geofencing in SunGuide^{TM}, a traffic management software system used by FDOT, to determine which DMSs to activate.

Most respondents mentioned using the distance-based criterion to determine which DMSs shall display the warning message. D6 mentioned they base their decision on the information available at the time of the incident, such as the known point of entry or the location of the wrong-way vehicle. The responses suggest that FDOT district agencies apply a combination of distance-based criteria and information available at the time of the incident to determine which DMS shall display the warning message.

2.4.2.4 Dynamic Message Signs – Display Duration

The survey question asked how long agencies usually post messages on DMSs during active WWD incidents on freeways. Responses varied in their specific timeframes. D1, D2, D3, D7, and the FTE post messages for a set duration, such as 10, 15, or 20 minutes, while D4, D5, and D6 display the messages until the incident is resolved or the wrong-way driver is intercepted. Results indicate that timeframes may vary from FDOT agency to agency and that decisions may be based on factors such as the likelihood of the wrong-way driver continuing on the freeway.

2.4.3 Technology

2.4.3.1 WWD Detection Technologies

The survey question asked the respondents to choose from several options regarding the specific type of ITS technologies that their agency uses to detect wrong-way drivers on freeways in real time. Table 2-3 summarizes the agencies' responses to this question. All agencies except D6 stated that they use CCTV cameras, while all agencies except D3 mentioned using thermal imaging/sensors to detect WWD incidents in real time. D2, D4, D6, D7, and the FTE selected radar detection each, while none of the respondents selected magnetic sensors. D6 selected "Other" and specified that detection devices are used on off-ramps, not freeways. Inductive loops are being used by D7 to detect WWD incidents. The results indicate that among the FDOT districts and the FTE, CCTV, and thermal imaging/sensors are the most commonly used technologies to detect wrong-way drivers in real time.

Table 2-3: Types of ITS Technologies Used to Detect WWD in Florida

District / Agency		D1	D2	D3	D4	D5	D6	D7	FTE
Types of ITS Technologies	CCTV	✔	✔	✔	✔	✔		✔	✔
	Video detection	✔			✔	✔		✔	✔
	Inductive Loop Detectors (ILDs)							✔	
	Magnetic sensors								
	Thermal imaging/sensors	✔	✔		✔	✔	✔	✔	✔
	Radar		✔		✔		✔	✔	✔
	Other						✔		

2.4.3.2 WWD Trajectory Tracking Methods

This question asked respondents how their agency tracks the real-time trajectory of wrong-way drivers on freeways. A majority of the agencies selected the three options: ITS technologies (all agencies except D3), data from 911 calls or other emergency services (all agencies except D3), and TMC operators (all agencies except D6). Results suggest that most agencies combine technologies and TMC operators to track the trajectory of wrong-way drivers in real time. None of the respondents selected the "Other" option. Table 2-4 gives an overview of the results.

Table 2-4: Methods Used by FDOT Districts to Track the Trajectory of Wrong-way Driver

District / Agency		D1	D2	D3	D4	D5	D6	D7	FTE
Trajectory Tracking Method	ITS technologies	✔	✔		✔	✔	✔	✔	✔
	Data from 911 calls or other emergency services	✔	✔		✔	✔	✔	✔	✔
	TMC operators	✔	✔	✔	✔	✔		✔	✔
	Other								

2.4.3.3 Steps Adopted on WWD Detection

The survey question asked about the steps they take when a WWD event is detected on the freeway and provided three answer options to choose from and an "Other" option. The responses to this question are outlined in Table 2-5. All the districts and the FTE selected the option to alert right-way drivers on the freeway through DMSs when a wrong-way driver is detected. Dispatching law enforcement to the scene was selected by all agencies except D4, and D4 selected the option to alert right-way drivers through smartphone apps.

D4, D6, and the FTE selected the “Other” option, indicating that their agency dispatches road rangers and advises FHP or alerts service patrol via HAR. Results indicate that when a wrong-way driver is detected on the freeway, FDOT district agencies commonly alert right-way drivers through DMS and dispatch law enforcement to the scene. In Florida, there is limited use of smartphone apps to alert right-way drivers when a wrong-way driver is detected.

Table 2-5: Steps Taken by FDOT Districts When a Wrong-way Driver is Detected

District / Agency		D1	D2	D3	D4	D5	D6	D7	FTE
Steps Taken	Alert right-way drivers on the freeway through dynamic message signs	✔	✔	✔	✔	✔	✔	✔	✔
	Alert right-way drivers through smartphone apps				✔				
	Dispatch law enforcement to the scene	✔	✔	✔		✔	✔	✔	✔
	Other				✔		✔		✔

2.4.3.4 Evaluations of the Effectiveness of Strategies for Mitigating WWD Incidents

The survey question asked respondents whether their agency has conducted any studies or evaluations of the effectiveness of its policies, countermeasures, and response plans for addressing WWD incidents on freeways. Six FDOT districts and the FTE responded to this question. D1, D3, D7 and the FTE reported that their agency had conducted studies or evaluations. D2 reported that their agency had not conducted any evaluations. D4 and D6 were unsure if their agency had conducted any such evaluations.

D1 provided a specific contact person within their agency to provide more information. D7 mentioned evaluating the number of WWD incidents and analyzing WWD correction on off-ramps by drivers as a result of the WWD detection devices on the off-ramps. D3 mentioned using after-action reviews and data comparisons to evaluate the effectiveness of their policies, countermeasures, and response plans. Finally, the FTE indicated that the agency had conducted WWD studies and evaluations in two phases since 2014.

2.4.3.5 Future Testing of Technologies

The survey question asked whether the FDOT district agencies plan to test new technologies to detect, prevent, or track WWD entries on freeways in the near future. All the districts and the FTE answered “Yes,” indicating that they all plan to test new technologies. The agencies also provided additional information on the agency's planned tests of new technologies. The technologies mentioned by the respondents include MVDS (Mainline Vehicle Detection System) for main-line interstate detection, LiDAR and Video Analytics, Artificial Intelligence (AI), and illuminated pavement markers.

D3 mentioned that technology changes daily, and continued review and deployment of new solutions is always considered. All the FDOT districts are interested in implementing new technologies to detect, prevent, or track WWD entries on freeways in the near future, considering both advanced and traditional solutions to address this issue.

2.4.4 Notification and Coordination

2.4.4.1 Public and Media Real-Time Notification

This survey question aimed to identify the methods the FDOT districts and the FTE used to notify the public and media in real time when a WWD incident occurs on freeways. All eight respondents selected DMSs to notify the public and media in real time about a WWD incident on freeways. D3 selected the option to use social media (e.g., Twitter) and smartphone applications (e.g., Google Maps, Waze, Apple Maps). The FTE selected the option for HAR releases, and no respondents chose "Other." Table 2-6 recapitulates the responses to this survey question.

Table 2-6: Methods Used by FDOT Districts to Notify the Public and Media in Real Time

District / Agency		D1	D2	D3	D4	D5	D6	D7	FTE
Methods to Notify the Public and Media	**Use of DMSs**	✔	✔	✔	✔	✔	✔	✔	✔
	Use of social media			✔					
	HAR releases								✔
	Smartphones applications			✔					
	Other								

2.4.4.2 Interagency Real-Time Coordination

The survey question asked FDOT districts how they coordinate in real time with other agencies and organizations during a WWD incident on freeways. The respondents described several methods their agencies use to coordinate in real time during a WWD incident on freeways. These methods include telephone, computer, radio, dispatch, shared video via Teams/Mutual link, and email. D1 mentioned that their agency uses the SOP language that has been previously established.

D2, D5, D6, D7, and the FTE mentioned that they coordinate with the following agencies and organizations during a WWD incident: law enforcement, emergency responders, transportation agencies, and service patrol personnel. D2 mentioned that their agency's RTMC is co-located with the Florida Highway Patrol and the local sheriff's office in Jacksonville, which may facilitate coordination during an incident. Responses suggest that agencies use different communication methods (i.e., telephone, computer, radio, Microsoft Teams) to coordinate in real time during a WWD incident and work closely with other organizations to respond effectively to an incident.

2.4.5 Data and Documentation

2.4.5.1 WWD Incident Data Documentation

The survey question asked participants to select the information documented in a WWD incident on the freeway. The responses to this survey question are summarized in Table 2-7. All the districts and the FTE documented the direction of travel of the wrong-way driver and the event's result in a WWD incident on the freeway. Additionally, the final location of the wrong-way driver, the location where the wrong-way driver entered the freeway, and the detection method/information were also documented by D1, D2, D4, D6, D7, and the FTE. Note that D5 didn't respond to this question. D1, D2, D4, D7, and the FTE mentioned that they document the vehicle description. Three agencies, D4, D6, and D7, mentioned "Other" as an option and provided the following responses: "Only if the information is available" (D4), "If found on camera, then will note in the incident report" (D7), and "Point of entry is tough to obtain" (D6).

Table 2-7: Documented Information by FDOT Districts in a WWD Incident

District / Agency		D1	D2	D3	D4	D5	D6	FTE
Documented Information	**Final location of the wrong-way driver**	✔	✔		✔	✔	✔	✔
	Location where the wrong-way driver entered the freeway	✔	✔	✔	✔		✔	✔
	Direction of travel of the wrong-way driver	✔	✔	✔	✔	✔	✔	✔
	Vehicle description	✔	✔		✔		✔	✔
	Detection method/information	✔	✔		✔	✔	✔	✔
	Event result	✔	✔	✔	✔	✔	✔	✔

2.4.5.2 WWD Data Collected and Analyzed

The survey question asked respondents to select all types of data their agency collects and analyzes in WWD incidents on freeways. All the districts and the FTE indicated that their agency collects and analyzes incident reports and WWD crash data. All the agencies except D3 reported collecting and analyzing data from detection and warning systems and reports from first-responding agencies. No respondents reported collecting and analyzing video recordings or surveys of motorists. Note that D5 did not respond to this question. These response results are outlined in Table 2-8.

Table 2-8: Types of Data Collected and Analyzed by FDOT Districts in WWD Incidents

District / Agency		D1	D2	D3	D4	D6	D7	FTE
Type of Data Collected and Analyzed	Incident reports	✔	✔	✔	✔	✔	✔	✔
	Data from detection and warning systems	✔	✔		✔	✔	✔	✔
	Video recordings							
	Reports from first responding agencies	✔	✔		✔	✔	✔	✔
	Surveys of motorists							
	WWD crash data	✔	✔	✔	✔	✔	✔	✔
	Other							

2.4.5.3 Evaluation Approaches of Countermeasures

The survey question aimed to gather information on the methods used by FDOT districts to evaluate the effectiveness of their WWD countermeasures on freeways. Table 2-9 summarizes the response results to this survey question. The most frequently chosen responses were crash data analysis (chosen by all agencies except D4), evaluation of warning and detection systems (chosen by all agencies except D3), and analysis of WWD incidents (chosen by all agencies except D2). D6 selected "Other," indicating that they are still in the initial stages of deployment. The FTE reported using public feedback as a means to evaluate the countermeasures. None of the respondents reported using Surveys of motorists to evaluate their countermeasures.

Table 2-9: Methods Used by FDOT Districts to Analyze and Evaluate the Effectiveness of WWD Countermeasures

District / Agency		D1	D2	D3	D4	D5	D6	D7	FTE
Method to Analyze and Evaluate Effectiveness	Crash data analysis	✔	✔	✔		✔	✔	✔	✔
	Public feedback								✔
	Evaluation of warning and detection systems	✔	✔		✔	✔	✔	✔	✔
	Analysis of WWD incidents	✔		✔	✔	✔	✔	✔	✔
	Surveys of motorists								
	Analysis of traffic flow data								
	Other						✔		

2.4.6 Florida Statewide Survey Summary

Eight FDOT district agencies responded to the survey. Some of the key findings include:

- A significant number of FDOT districts have specific WWD policies and response plans in place.
- Supplemental signs (e.g., No Right/Left Turn signs) are the most commonly used type of signing and pavement marking to prevent WWD incidents on freeways. The second most frequently used method in Florida is detection-triggered devices.
- The DMS content displayed is a variation of the phased message "Wrong Way Driver Detected, Use Caution / Pull Over."
- For the criteria to determine the extent to which the DMSs are displayed, in Florida, the most common approach is using a distance-based criterion. In Florida, agencies may choose a radius of 10-50 miles.
- In Florida, agencies post messages for a set duration, ranging from 10 to 20 minutes. The message may also be posted until the incident is resolved, the wrong-way driver is intercepted, or the driver is no longer on the given interstate system.
- CCTV cameras are the most commonly used ITS technology to detect wrong-way drivers on freeways in real time. Thermal imaging/sensors are used at the same scale as CCTV cameras in Florida. Magnetic sensors are not used in Florida.
- FDOT districts utilize ITS technologies, data from 911 calls or other emergency services, and TMC operators to track wrong-way drivers in real time.
- FDOT districts primarily post DMS to alert right-way drivers, followed by dispatching law enforcement to the scene when a wrong-way driver is detected.
- Four FDOT districts have evaluated the effectiveness of their policies, countermeasures, and response plans for addressing WWD incidents on freeways.
- In Florida, there is an interest in testing new technologies to detect, prevent, or track WWD entries on freeways. All FDOT districts stated that they plan to test new technologies, including MVDS (Mainline Vehicle Detection System), LiDAR and video analytics, AI, and illuminated pavement markers.
- DMSs are the most commonly used ITS devices to notify the public and media in real time about WWD incidents in Florida. Newer technology, such as social media and smartphone applications, is utilized less often.

- Responses suggest that in Florida, agencies use different methods to coordinate in real time during a WWD incident, such as communication technology, co-location with other agencies, automated alerting or messaging, and relying on law enforcement agencies.

- It can be inferred from the results that in Florida, the direction of travel of the wrong-way driver and the event result is the most commonly documented information.
- Results suggest that in Florida, the most common data collected and analyzed in WWD incidents on freeways are incident reports and WWD crash data. It is a common practice to document data from detection and warning systems and reports from first-responding agencies in Florida. Surveys of motorists are not widely used in Florida.

- Analyzing WWD incidents and crash data is commonly used for evaluating WWD countermeasures by FDOT districts. Evaluation of warning and detection systems is also a common approach.

2.5 Summary

This chapter presents the findings on the current state-of-the-practice on countermeasures and response plans or procedures for responding to WWD incidents on freeways. The objectives of the state-of-practice survey include identifying nationwide best practices in responding to WWD events on freeways and evaluating the effectiveness of existing WWD response plans and WWD DMS messaging. The goal is to comprehensively evaluate the FDOT's strategic response plan to WWD events on freeways. The chapter involved surveying state DOTs and FDOT districts to obtain information on existing policies and response plans or procedures for responding to WWD events on freeways. Twenty-seven state DOT agencies and eight FDOT district agencies responded to the survey; the response rate was 54% (national) and 100% (Florida). Some of the key findings include:

- It can be observed that there is a notable difference between nationwide and FDOT districtwide results regarding the existence of both specific policies and response plans for addressing WWD incidents on freeways. A large majority of state DOTs do not have specific policies or response plans; on the other hand, a majority of the FDOT districts have specific WWD policies and response plans in place. The results suggest that the FDOT may have a more active plan for addressing freeway WWD incidents.

- Both nationally and in Florida, supplemental signs (e.g., No Right/Left Turn signs) are the most commonly used type of signing and pavement marking to prevent WWD incidents on freeways. Nationwide, the second most common approach is the use of lower mounting heights of "DO NOT ENTER" and "WRONG WAY" signs. However, the second most frequently used method in Florida is detection-triggered devices.

- For the DMS's content, national and FDOT districtwide results were similar. The content displayed is a variation of the phased message "Wrong Way Driver Detected, Use Caution / Pull Over." Nationwide, some agencies responded that they do not display any information during a WWD incident.

- For the criteria to determine the extent to which the WWD message on the DMS is displayed, nationally and in Florida, the most common approach is using a distance-based criterion. However, it is worth mentioning that some national agencies activate any DMS in the travel direction, and others activate DMS for a distance of two signs. Others may use a case-by-case approach. In Florida, FDOT districts may choose a radius of 10-50 miles.

- Both nationally and in Florida, FDOT districts post messages for a set duration, ranging from 10 to 20 minutes. The message may also be posted until the incident is resolved, the wrong-way driver is intercepted, or the driver is no longer on the given interstate system.

- Both nationally and in Florida, CCTV cameras are the most commonly used ITS technology to detect wrong-way drivers on freeways in real time. Nationwide, the second most frequently used approach is video detection. However, thermal imaging/sensors are used at the same scale as CCTV cameras in Florida. Magnetic sensors are not used in any of the cases.

- FDOT districts utilize ITS technologies, data from 911 calls or other emergency services, and TMC operators to track wrong-way drivers in real time. Nationally, most agencies use TMC operators and data from 911 calls or other emergency services. Some agencies in the U.S. do not have any method to track WW drivers' trajectories.

- Nationally, dispatching law enforcement to the scene is the most common approach, followed by alerting right-way drivers through DMS when a wrong-way driver is detected on the freeway. On the other hand, FDOT districts primarily post DMS to alert right-way drivers, followed by dispatching law enforcement to the scene when a WWD is detected.

- Nationally, over 50% of the responding states have not evaluated the effectiveness of their policies, countermeasures, and response plans for addressing WWD incidents on freeways. Around one-third of the respondents reported that their agency had conducted such evaluations. In Florida, out of the seven respondents, four reported that their agency had conducted evaluations. Results suggest that further studies and evaluations may be needed to determine the most effective strategies.

- Results indicate that both nationally and FDOT districtwide, there is an interest in testing new technologies to detect, prevent, or track WWD entries on freeways. All FDOT districts plan to test new technologies, including MVDS (Mainline Vehicle Detection System), LiDAR and video analytics, AI, and illuminated pavement markers.

- DMSs are the most commonly used method to notify the public and media in real time about WWD incidents, both on a national scale and in Florida. Newer technology, such as social media and smartphone applications, is utilized less often. About 40% of the responding agencies nationwide do not currently use any method to notify the public and media in real time.

- Responses suggest that nationally and in Florida, agencies use different methods to coordinate in real time during a WWD incident, such as communication technology, co-location with other agencies, automated alerting or messaging, and relying on law enforcement agencies.

- It can be inferred from the results that in Florida, the direction of travel of the wrong-way driver and the WWD incident outcome is the most commonly documented information. At a national level, the location where the WWD entered and the direction of travel was selected by most of the respondents.

- Results suggest that nationally and in Florida, the most common data collected and analyzed in WWD incidents on freeways are incident reports and WWD crash data. It is a common practice to document data from detection and warning systems and reports from first-responding agencies. Surveys of motorists are not widely used either nationally or in Florida.

- Analyzing WWD incidents and crash data is commonly used for evaluating WWD countermeasures by state DOTs and in Florida. Evaluation of warning and detection systems is also a common approach, but it was found to be more predominant in Florida.

CHAPTER 3
FDOT'S WWD RESPONSE REVIEW

This chapter discusses the FDOT district's state-of-the-practice in responding to WWD events. The review evaluates each district's current WWD response plans to document their effectiveness. The chapter identifies the deviations observed from the existing SOPs while responding to the WWD events in each district. The chapter also provides recommendations on the response plans. Additionally, it documents the most effective approaches and valuable knowledge gained and offers insights into the standard procedures for promptly and effectively addressing WWD occurrences in real time. The assessment in this chapter will aid in comprehending the present status of how WWD events are dealt with. A list of the files needed to conduct the review includes:

- FDOT Districts' SOPs
- SunGuide™ Event Chronology of the WWD Events for the years 2018-2022

3.1 Existing Practices

WWD events are responded to by the districts' RTMCs. RTMCs use SunGuide™ software to receive WWD alerts and document the detected WWD events. FDOT districts use detection technologies such as TrafficVision or Wrong Way Vehicle Detection System (WWVDS) and Law Enforcement Officers (LEOs) to detect WWD events. All districts use DMSs to alert right-way drivers during WWD events. WWD events are tracked and located using CCTVs with the help of RRSP and LEOs.

3.1.1 WWD Detection

D1 uses ITS technologies where deployed to detect WWD events. The ITS technologies deployed in D1 include TrafficVision and WWVDS. Otherwise, RRSP and FHP are used to report the detected/observed WWD events to the RTMC. D2 also uses RRSP, FHP, and technologies such as the WWVDS and CCTVs to notify the RTMC about the detected WWD event.

D3 uses FHP, RRSP, and LEOs as notifying agencies. D4 uses FHP, WWVDS, or CCTV to detect WWD events. D5 and Central Florida Expressway Authority (CFX) detect WWD events using the Incident Detection Subsystem (IDS) or receive WWD alerts and calls from external sources, including LEO, RRSP, and FHP.

D6 mainly uses FHP and RRSP to receive WWD alerts but sometimes uses technologies such as Vehicle Alert and CCTV to detect WWD events. D7 uses LEO, CCTV, and IDS to detect and notify the RTMC about WWD events. Florida Turnpike Enterprise (FTE) uses FHP, WWVDS, and radar vehicle detection devices to detect and alert the RTMC to WWD events.

3.1.2 WWD Tracking

All FDOT districts, FTE, and CFX, use DMS to alert right-way drivers during WWD events. D1, D2, D3, D4, D5, FTE, and CFX provide a certain radius within which DMSs should be turned on during WWD events, while D6 and D7 do not. The details of the DMS activations are discussed in the following subsections.

In addition to DMSs, FTE uses appropriate HAR stations to warn the public about an active WWD event. Also, all the districts use CCTV cameras to track the confirmed wrong-way driver with the help of RRSP, FHP, and LEOs. WWD event is tracked until the vehicle is stopped, rectifies itself, or results in a crash. Sometimes, a minimum time is set to try and locate the WWD vehicle, after which, even if not found, it is assumed not a danger anymore to the moving traffic. At the end of a WWD event, email communications were necessitated to managers and other appropriate personnel for D2, D3, D6, D7, and the FTE.

3.1.3 DMS Activation

Each FDOT district has different protocols for DMS activation. For D1, the operator first has to create the event in the system, and then automatically, the DMSs within the appropriate (15-mile) radius are activated to display the WWD alert messaging. In D2 (without the WWD vendor vehicle alarm system), the operator manually creates the WWD event in the system and selects the appropriate radius around the event (i.e., 15 miles) for all DMSs to display the WWD messaging. D3 operates as D2 for events reported by FHP or LEO and operates as D1 for events detected via IDS. D4 operates as D1.

D5 and CFX operate as D1 if notified by IDS about the WWD event or as D2 when alerted by external sources (FHP, RRSP, LEO, etc.). D6 operates as D1. Regarding D7, the operator chooses the device-linking approach to select the DMSs to be activated after recording the WWD event in the system. FTE operates as D2. For some locations in D2 with the WWD vendor vehicle alarm system, DMSs are activated automatically once the detectors pick up a wrong-way driver. Therefore, for all districts except some locations in D2, DMSs are activated after an initial input from the RTMC operator.

When the incident is reported by sources other than TrafficVision, D1 operators may activate the signs before confirming the presence of WWD events. If the WWD event is detected by the TrafficVision technology, then it has to be confirmed that it is not a false alarm before the appropriate DMSs are activated. In D2, the signs are activated before the confirmation of the WWD event. Also, in D3, D4, and D6, DMSs are activated just after the event has been reported or detected before being confirmed.

In D5 and CFX, the WWD event has to be confirmed before the DMSs are activated. D7 depends on whether the WWD event has been detected by IDS or reported by LEO. For WWD events detected by IDS, the events have to be confirmed before the signs are activated. LEO/CCTV-reported events do not have to be confirmed before activating the DMSs. The WWD events reported by FHP dispatch do not have to be confirmed before activating DMSs. For FTE locations with WWD vendor vehicle alarm systems, the events must be confirmed first before appropriate DMSs are activated.

3.1.4 Closing the WWD Event

After responding to a WWD event, the event has to be closed for documentation purposes. The event is closed when the vehicle is stopped, rectifies itself, results in a crash, or after the SOP-required minimum time (set to attempt to find the WWD vehicle). Unless the WWD event ends up being a false alarm, all districts close out a WWD event after the response efforts. For D1, when WWD events are notified by agencies other than TrafficVision, false alarm events have to be set as "False Alarm" and not closed at the end of events. According to the SOP for D1, closing false alarm events impacts reporting and creates the need for tedious sorting of events. D7 specifically requires the event to be closed in the end, even if it was a false alarm. Other districts required the events to be closed in the end but did not specifically say whether it was wrong to close the false alarm events or not. Table 3-1 outlines the existing practices used by the FDOT districts, FTE, and CFX when responding to WWD events.

Table 3-1: Existing Practices

District	Detection	Tracking	DMS Activation	Closing
D1	ITS, RRSP, & FHP	CCTV, RRSP, FHP, & LEO	RTMC Operator	"False alarm" or "Closed"
D2	RRSP, FHP, Vehicle Alert, & CCTV	CCTV, RRSP, FHP, & LEO	Automatically or by RTMC Operator	"Closed"
D3	FHP, RRSP, & LEO	CCTV, RRSP, FHP, & LEO	RTMC Operator	"Closed"
D4	FHP, WWEDS, & CCTV	CCTV, RRSP, FHP, & LEO	RTMC Operator	"Closed"
D5	IDS, LEO, RRSP, & FHP	CCTV, RRSP, FHP, & LEO	RTMC Operator	"Closed"
D6	FHP, RRSP Vehicle Alert, & CCTV	CCTV, RRSP, FHP, & LEO	RTMC Operator	"Closed"
D7	LEO, CCTV, & IDS	CCTV, RRSP, FHP, & LEO	RTMC Operator	Must be "Closed"
FTE	FHP, WWD vendor vehicle alarm system, & radar vehicle detection devices	CCTV, RRSP, FHP, & LEO	RTMC Operator	"Closed"
CFX	IDS, LEO, RRSP, & FHP	CCTV, RRSP, FHP, & LEO	RTMC Operator	"Closed"

3.2 Data

WWD events and DMS locations in each district, FTE, and CFX were needed to analyze the spatial relationship between the WWD events and the DMSs. Location data for the DMS and WWD events was requested and used to identify all the DMSs within a certain radius (SOP-related) around a particular WWD event. This check was used to confirm whether the SOP-related radius that DMSs should be activated is met when responding to a WWD event. Except for D6 and D7, all FDOT districts' SOPs required DMS within a certain SOP-specified radius referenced to the WWD event to be activated when the event is detected, reported, or confirmed.

3.2.1 Standard Operating Procedures (SOPs)

The SOPs include specific guidelines for responding to WWD events prepared for each district, FTE, and CFX. While the SOPs in two regions might be similar, no two have the same procedures. The SOPs guide the RTMC operators on steps to follow after detecting or receiving a WWD alert. The steps start with how to document the detected/reported event, track the wrong-way driver, who to communicate with, whether and how to use the DMSs, and how to close the WWD event.

Different from other districts, D1 has two SOPs guiding the response to WWD events. One of the guidelines is supposed to be followed during responding to WWD events notified by TrafficVision technology. Another guideline is used when WWD events are detected/reported by other notifying agencies (i.e., not TrafficVision). Each of the remaining districts, FTE, and CFX has one document for SOPs. The details of the steps provided by the SOPs are summarized in Section 3.3.

3.2.2 Wrong-Way Driving Events Sampling

Each of the FDOT districts had a list of events filtered from 2018 to 2022. A total of 12,029 WWD events were detected in the eight FDOT districts and CFX during the analysis period. Due to time and resource constraints, event sampling was found to be a feasible approach. Depending on the number of recorded WWD events in each district, a portion of the events was randomly sampled to get a representative fraction of all events. Equations 3-1 and 3-2 depict the statistically significant sample representing the finite number of WWD events in each district at a 95% confidence level (CL).

$$n = (N \times X) / (X + N - 1) \quad (3\text{-}1)$$

$$X = Z_{\alpha/2}^{2} \times p \times (1-p) / MOE^{2} \quad (3\text{-}2)$$

Where,

Z_{α} = critical value of the normal distribution evaluated at a 95% CL,
MOE = the margin of error (0.05),
p = the sample proportion, and
N = the population size.

For this analysis, the sample proportion (p) was assumed to be 0.95, indicating that in a district, the guidelines are either followed thoroughly with very few deviations or the opposite with systematic deviations. This means that either 95% of responded WWD events are assumed to be responded to without SOP deviations or vice-versa. The worst-case scenario is assumed to be when operators repeat the same kind of deviation over and over again (i.e., systematic deviation). Table 3-2 summarizes the number of WWD events that were sampled from all WWD events between 2018 and 2022 and reviewed for each district, FTE, and CFX.

Table 3-2: Reviewed Sample Size of WWD Events for Each District, FTE, and CFX

District	Sampled WWD Events	Total WWD Events Reported/Detected
D1	51	553 (166 from January 2022)
D2	52	152
D3	62	370
D4	65	534
D5	72	2,588
D6	51	266 (51 from January 2022)
D7	72	3,046
FTE	64	466
CFX	72	4,054

3.3 Review of WWD Events

The reviewing task started with studying and understanding the SOPs provided by each FDOT district, FTE, and CFX. The guidelines provided by the districts varied in different degrees across regions, with some variations being minor and others more significant. A representative sample of WWD events generated, as explained in Section 3.2, was reviewed for each district. The timeline of WWD event response was analyzed from the chronology of events file. The analysis indicated to what extent the response process followed the guidelines. Figure 3-1 summarizes the effort used to review the WWD response plans.

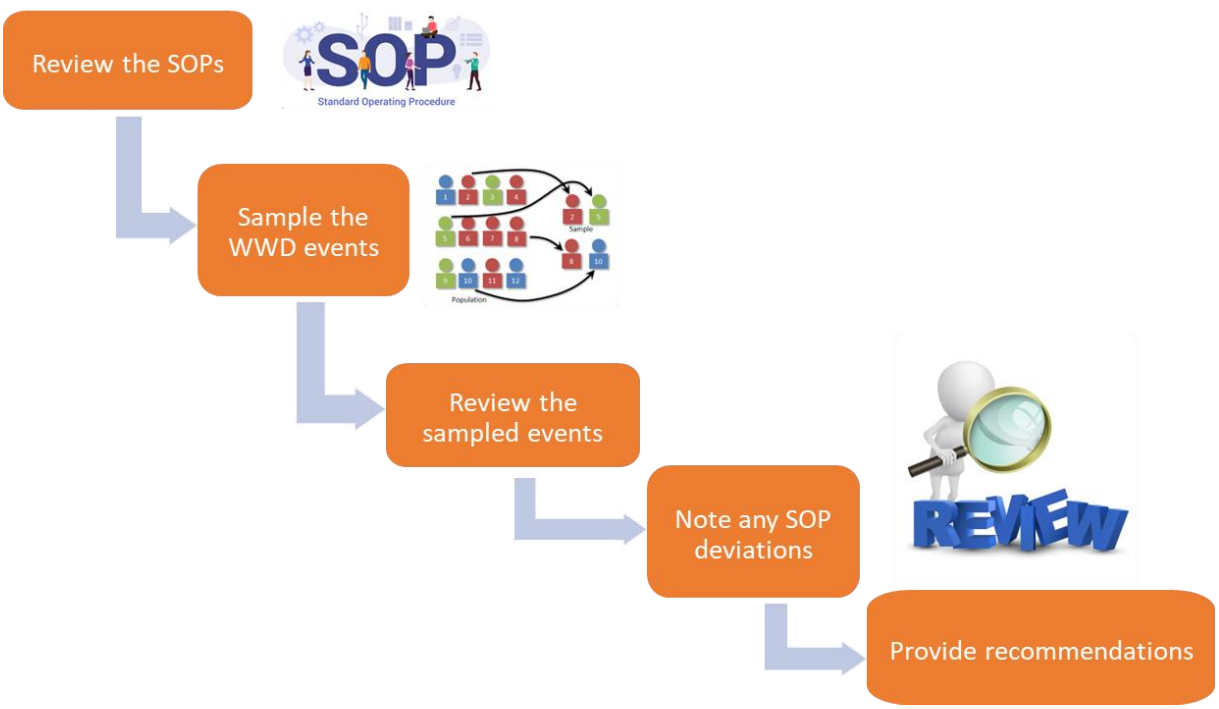

Figure 3-1: WWD Events Reviewing Process

For some districts (D6 and D7), it was possible to know all the deviated guidelines from the SOPs just by analyzing the chronology of the WWD events. But, for other districts, the guidelines specified a particular radius around the WWD event where the DMSs shall be switched on when the event is detected/reported.

To assess whether the DMSs were activated within the designated radius (specified in SOPs) around detected/reported WWD events, the spatial join analysis tool in ArcGIS was employed. This analysis involved utilizing WWD event and DMS location data, represented by latitude and longitude coordinates. These coordinates were input into ArcGIS as *x* and *y* data, with latitude assigned to *y* and longitude to *x*. The resulting coordinates were displayed and exported to create shapefiles. Through a spatial join operation, the attributes of the generated shapefiles were linked, with the WWD event locations serving as the target/reference and the DMS locations as the joined feature. The resulting table combined the attributes of the DMS shapefiles with those of the WWD events. This allowed for a comprehensive association between each WWD event and the corresponding DMSs located within the specified radius outlined in the SOP. Figure 3-2 provides a visual representation from ArcGIS, highlighting the inputs utilized in the Spatial Join tool for the analysis of the WWD event-DMS radius review. The WWD event-DMS radius review is elaborated in detail in Section 3.3.1.

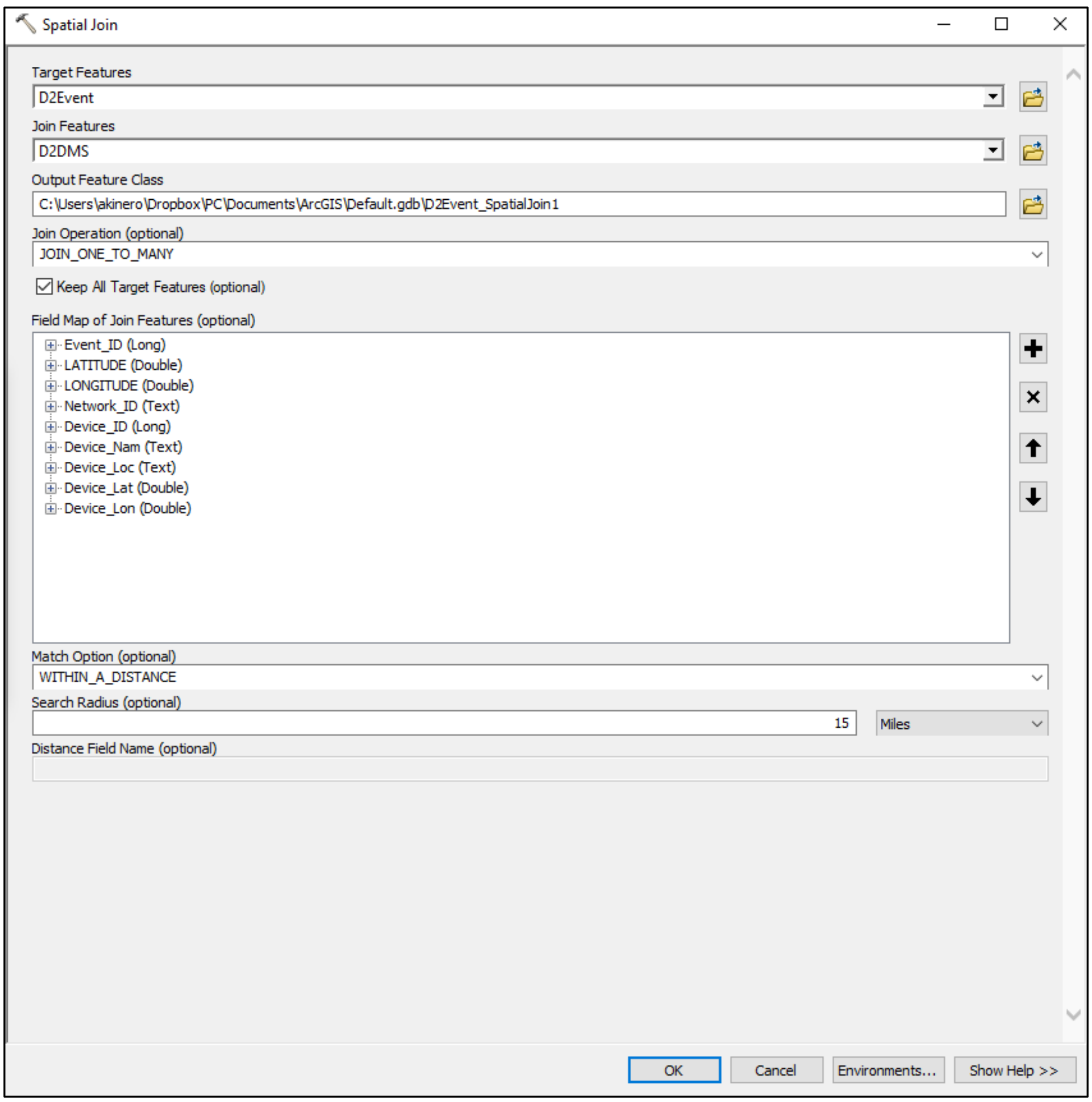

Figure 3-2: Spatial Join Analysis for WWD Event-DMS Radius Review

3.3.1 District One (D1)

A total of 51 WWD events out of 166 from D1 were reviewed. Since the District's SOP (D1-SOP) was updated in December 2021, the WWD events studied were the ones from January 2022. The reviewing process was done in two parts. The first part was to analyze the chronology of events and observe if all the steps (except the DMS within the required radius) in the SOP were followed. The second part focused on determining (using Spatial Join in ArcGIS) if the DMSs within the 15-mile radius (as per D1-SOP) of the event were activated as part of the event response.

In the first part of the review, 20 WWD events were responded to without deviating from the D1-SOP. For the second part, in 27 WWD events, all the DMS within the 15-mile radius of the event were activated in response to the WWD event. Out of the 20 WWD events from which SOP guidelines were completely followed in the first part, only eight events involved activating all DMSs within the required radius during the event responses.

The common deviations encountered during the reviewing process were:

- Closing the response plan before the minimum required amount of time to attempt to locate the WWD event (15 minutes per D1-SOP)
- Put the event status to "closed" instead of "false alarm," as instructed in the SOP for events that are not found after 15 minutes.
- Not turning on all the DMSs within the required radius.

Another deviation that appeared only in one WWD event included not notifying the FHP and RRSP during the WWD event response. The sampled WWD events in D1 are shown in Figure 3-3.

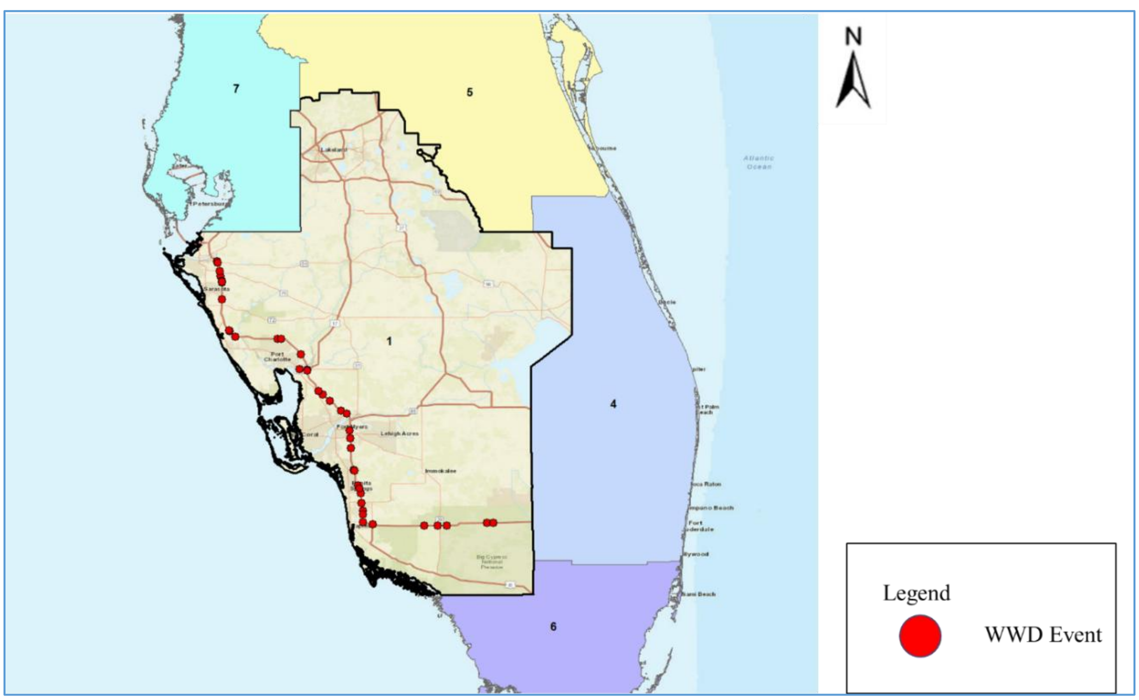

Figure 3-3: Sampled WWD Events in D1

Figure 3-4 illustrates an example of one of the WWD events in D1, surrounded by the DMSs within a 15-mile radius. In the attribute table generated after the spatial join analysis, every sampled event was linked to the DMSs within a radius of 15 miles. The table was then checked and compared to the DMSs shown in the chronology of events file. The event chronology files showed the time stamps while responding to the WWD event. If one or more of the DMSs within the D1-SOP required radius (15 miles) was not seen in the time stamps, then it was considered as an SOP deviation in responding to the WWD event. This check was done for all districts whose SOPs specified a certain radius for DMSs to be activated around a WWD event.

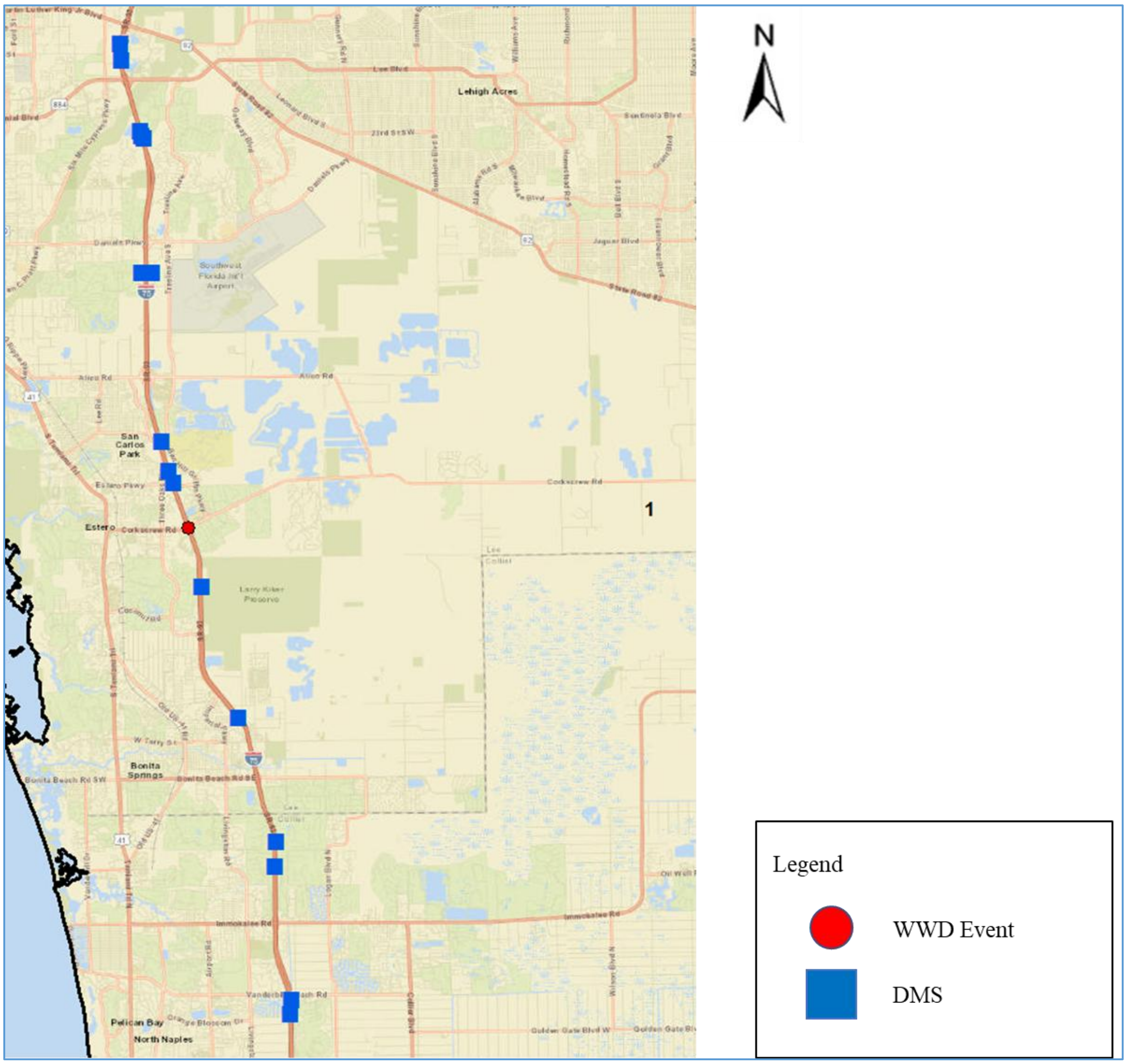

Figure 3-4: An Example of a WWD Event in D1 with DMSs within a 15-Mile Radius

3.3.2 District Two (D2)

A total of 52 WWD events out of 152 from D2 were reviewed. The TAPCO system detected two events among the sampled WWD events. Similar to the WWD events in D1, the reviewing process was done in two parts. The first part was to analyze the chronology of events and observe if all the steps (except checking the DMS within the required radius) in the district's SOP (D2-SOP) were followed. The second was by analyzing (through spatial join) if the DMS within the 15-mile radius (as per SOP) of the event were all activated to display the specified WWD message during the event response. In the first part of reviewing, 32 WWD events were responded to without deviating from the D2-SOP. For the second part, no WWD events response involved turning on all the DMS within the 15-mile radius required.

The common deviations identified in D2 were:

- Closing the response plan before the minimum required amount of time to attempt to locate the WWD event (10 minutes per D2-SOP)
- Not activating all DMSs within the required radius during WWD incidents (15 miles per D2-SOP)

There were two events notified by the TAPCO system, and they were automatically responded to without deviating from D2-SOP. Figure 3-5 illustrates the sampled WWD events in D2.

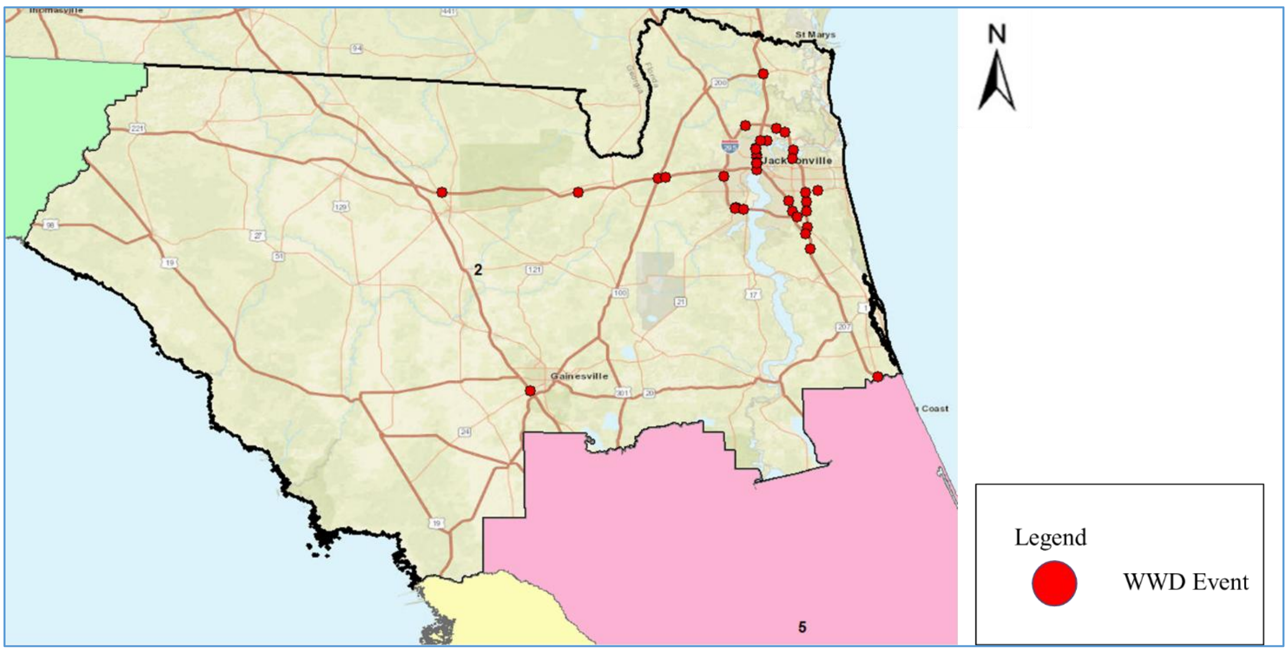

Figure 3-5: Sampled WWD Events in D2

3.3.3 District Three (D3)

Out of the 370 WWD events in D3, a total of 62 events were reviewed. In D3, the review process was divided into two parts. The first part involved analyzing the sequence of events and checking if all the required steps in the district's standard operating procedure (D3-SOP) were followed, excluding the activation of DMS within the specified radius. The second part involved analyzing whether the DMS within a 10-mile radius of the event were all activated during the response, using spatial join. In the initial review, all WWD events deviated from one or more of the D3-SOP guidelines during event response. In the second part, 51 of the responses to WWD events included activating all the DMS within the required 10-mile radius.

The common deviations noted in D3 are:

- Most DMS posts did not use the exact text required by D3-SOP
- The RRSP were not notified about wrong-way drivers during the incidents
- ITS and RTMC managers were not notified and contacted once the WWD event had been confirmed or was resolved

Other deviations, such as not activating any DMS at all during the WWD event response, were also seen a few times. The sampled WWD events from D3 are depicted in Figure 3-6.

Figure 3-6: Sampled WWD Events in D3

3.3.4 District Four (D4)

In D4, 65 WWD events out of 534 were reviewed. Similar to D1, D2, and D3 districts, the reviewing process was done in two parts (SOP guidelines and DMS radius review). While reviewing the district's SOP (D4-SOP) guidelines, WWD event responses to six events followed the D4-SOP completely.

The most common deviations in responding to the WWD events for D4 include:

- Not notifying the RRSP during the incidents
- Most DMS posts did not use the exact text required by D4-SOP

Other SOP deviations noticed in this district include not notifying FHP when the event is detected by CCTV or WWVDS, and not indicating any effort to locate the WWD on CCTV in the chronology of events. For some events, the status of the event just started with "active" instead of "unconfirmed," as stated in the D4-SOP. Moreover, it was shown that the wrong-way driver was tracked for some events, but it was not indicated how the tracking was done.

Also, while reviewing whether the DMS within the required radius (10 miles as per D4-SOP) were all switched on during responding to WWD events, 58 events responses did not meet this requirement. In Figure 3-7, the sampled WWD events from D4 are displayed.

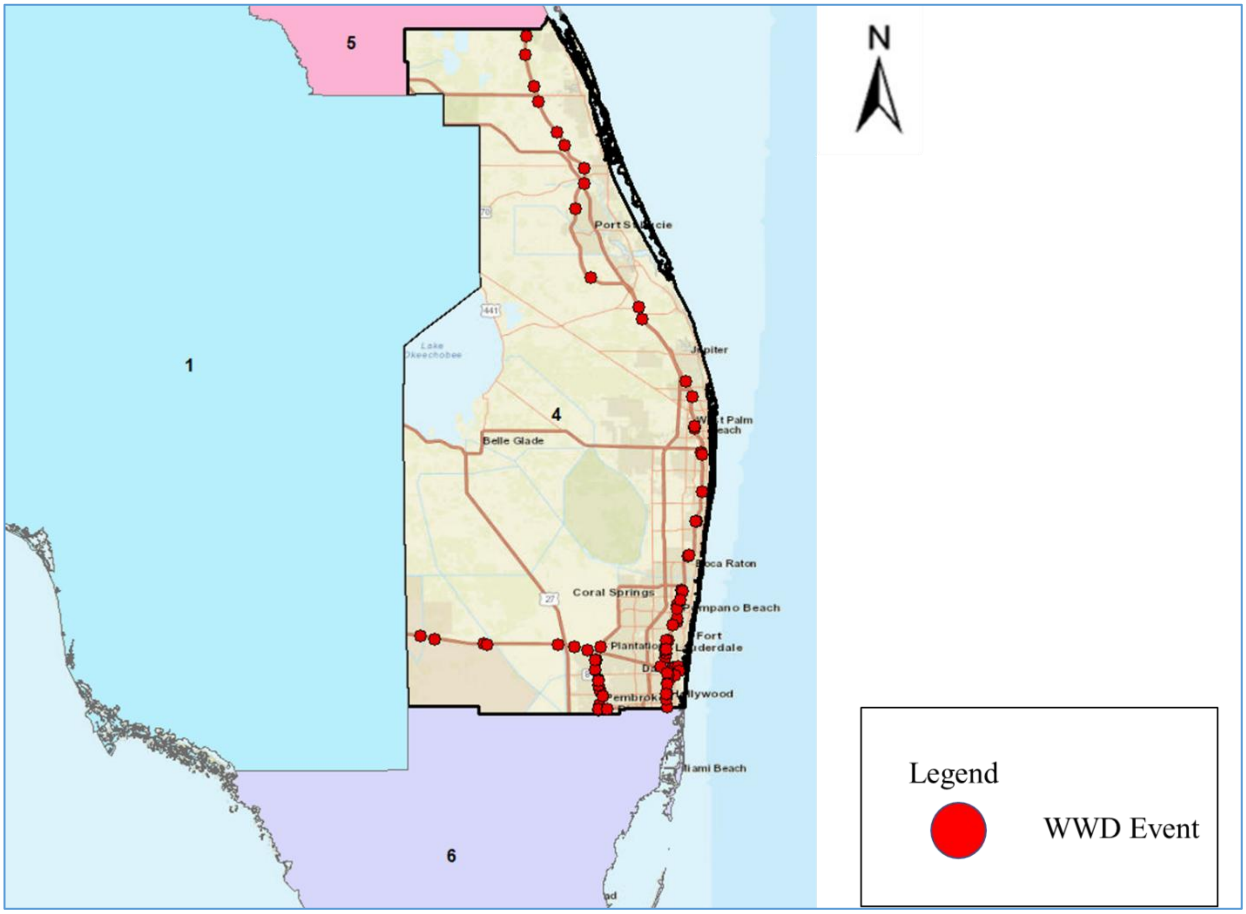

Figure 3-7: Sampled WWD Events in D4

3.3.5 District Five (D5)

In D5, 72 WWD events out of 2,588 were sampled and reviewed. Same as in D1, D2, D3, and D4, the reviewing task was done in two parts for this district. For the first part of reviewing (without considering which DMSs are switched on), about 92% of the WWD events (66) were responded to as per the district's SOP (D5-SOP). Only six events included an SOP deviation in which the responses were closed before the required time (15 minutes) to try and locate the wrong-way driver specified by D5-SOP.

D5-SOP did not require any response if the event is a false alarm, involves maintenance, includes pedestrians, is a vehicle backing up, or is an emergency vehicle. Most of the events in D5 involved these kinds of events, which did not require any response. Among the reviewed, five events (7%) were false alarms. Some were just test events on the facilities.

Events that required response plans (20) were extracted and checked for the DMS radius requirement (15 miles per D5-SOP). All 20 events had one or more DMSs not switched on in the required radius during a WWD event response. The representation of the sampled WWD events in D5 can be observed in Figure 3-8.

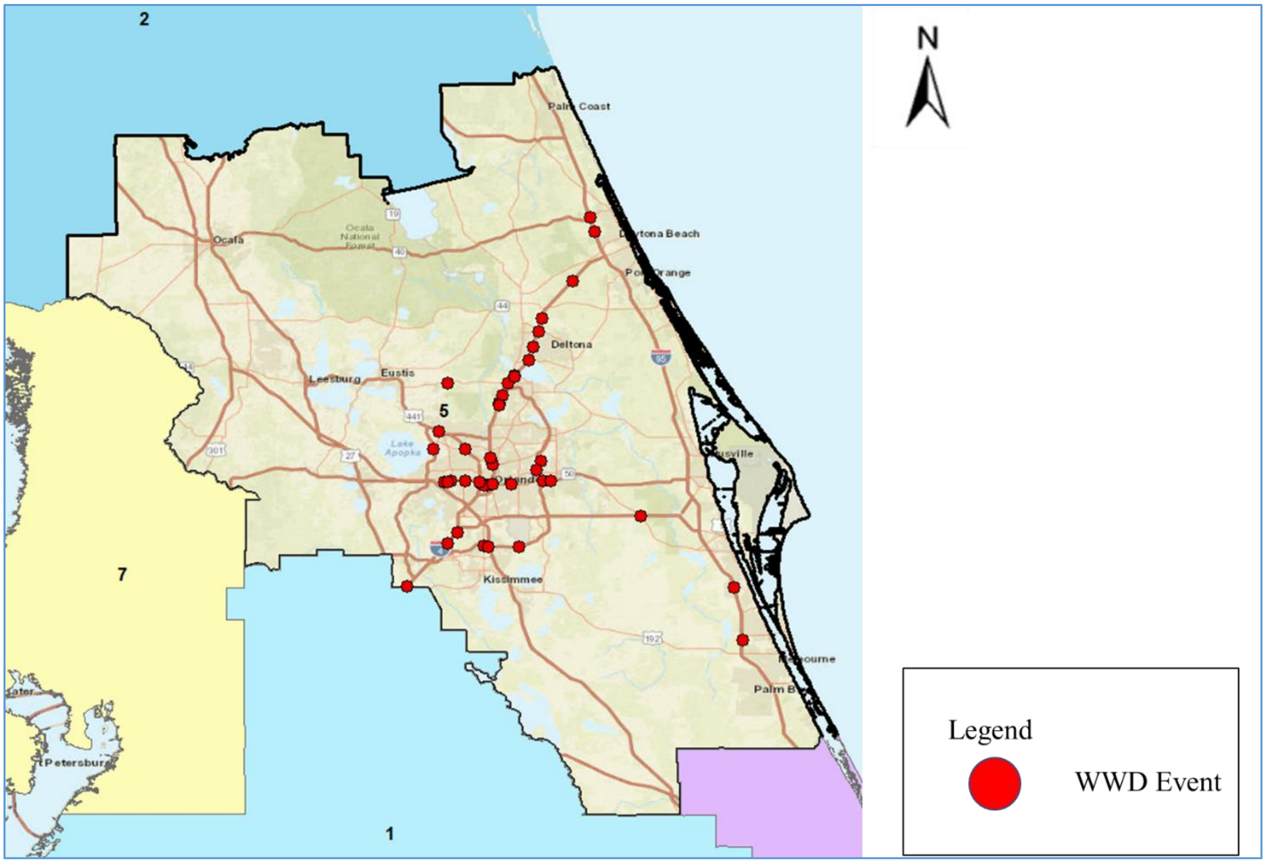

Figure 3-8: Sampled WWD Events in D5

3.3.6 District Six (D6)

A total of 51 events out of 266 WWD events were reviewed for D6. The SOP for this district was updated in November 2021, and so the reviewed events were those from 2022. Compared to the previously reviewed districts, the DMS activation radius around WWD events was not analyzed. This is because the D6-SOP did not specify a specific radius for the DMS to be switched on; instead, it just required the DMS on the facility (and arterial roadways connected to it) that a WWD event has been detected to be put on at the time of an event.

D6 followed the D6-SOP effectively when responding to 47 (92%) of the sampled WWD events. In four of the remaining events, some of the D6-SOP guidelines were not followed. While responding to three WWD events, RRSP was not notified. Notifying the RRSP is one of the requirements for the D6-SOP. Another requirement in the SOP was to put the status for all events not reported by RRSP or CCTV as "unconfirmed." This requirement was not met when responding to one of the WWD events. Figure 3-9 shows the sampled events from D6.

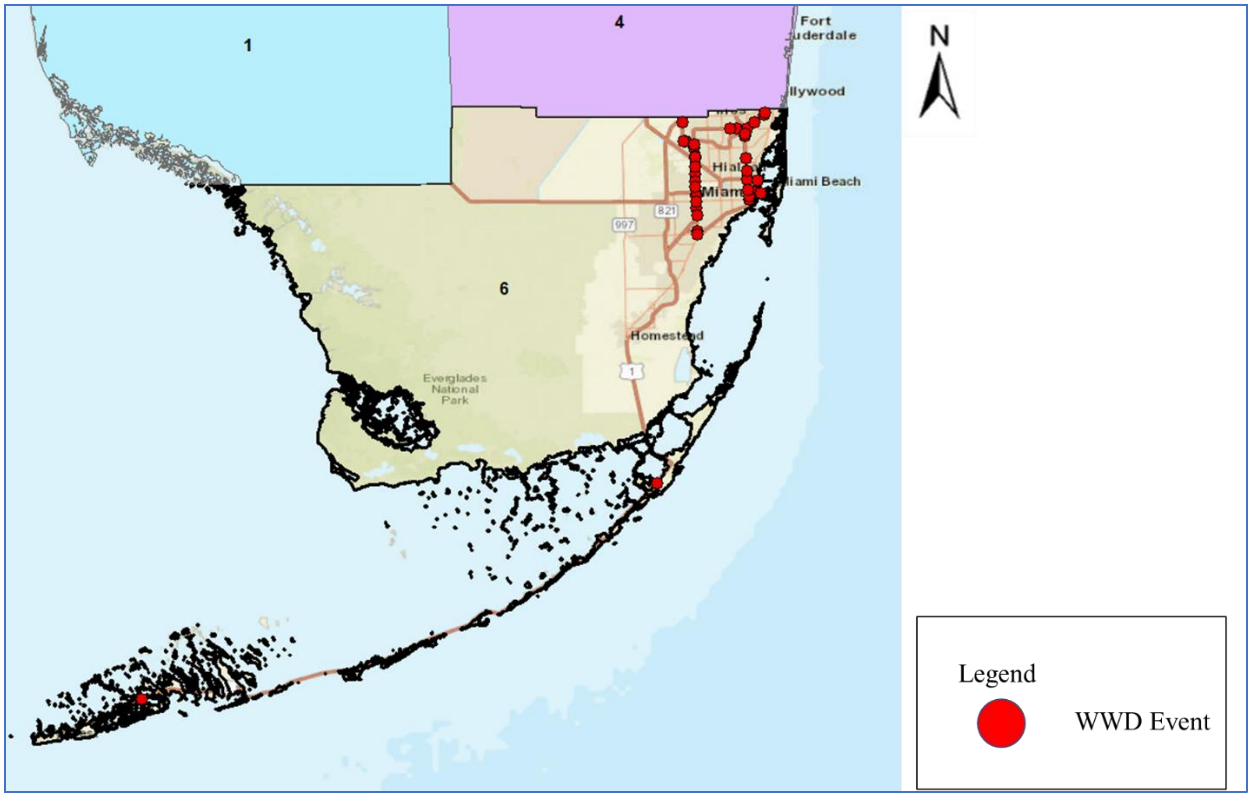

Figure 3-9: Sampled WWD Events in D6

3.3.7 District Seven (D7)

Among the 3,046 WWD events recorded in D7, a total of 72 events were reviewed. The analysis did not include checking the DMS within the activation radius of incidents. This omission was due to the fact that the D7-SOP did not specify the radius for activating the DMS. Figure 3-10 shows the sampled events from D7.

D7 completely adhered to the D7-SOP in response to 33 out of the sampled WWD events. Most of these events were false alarms and test events that did not require any response. In the remaining events that required responses, one or more of the following D7-SOP guidelines were not followed:

- Not notifying the RRSP or FHP about wrong-way drivers during the incidents
- Not switching on DMSs during a WWD event

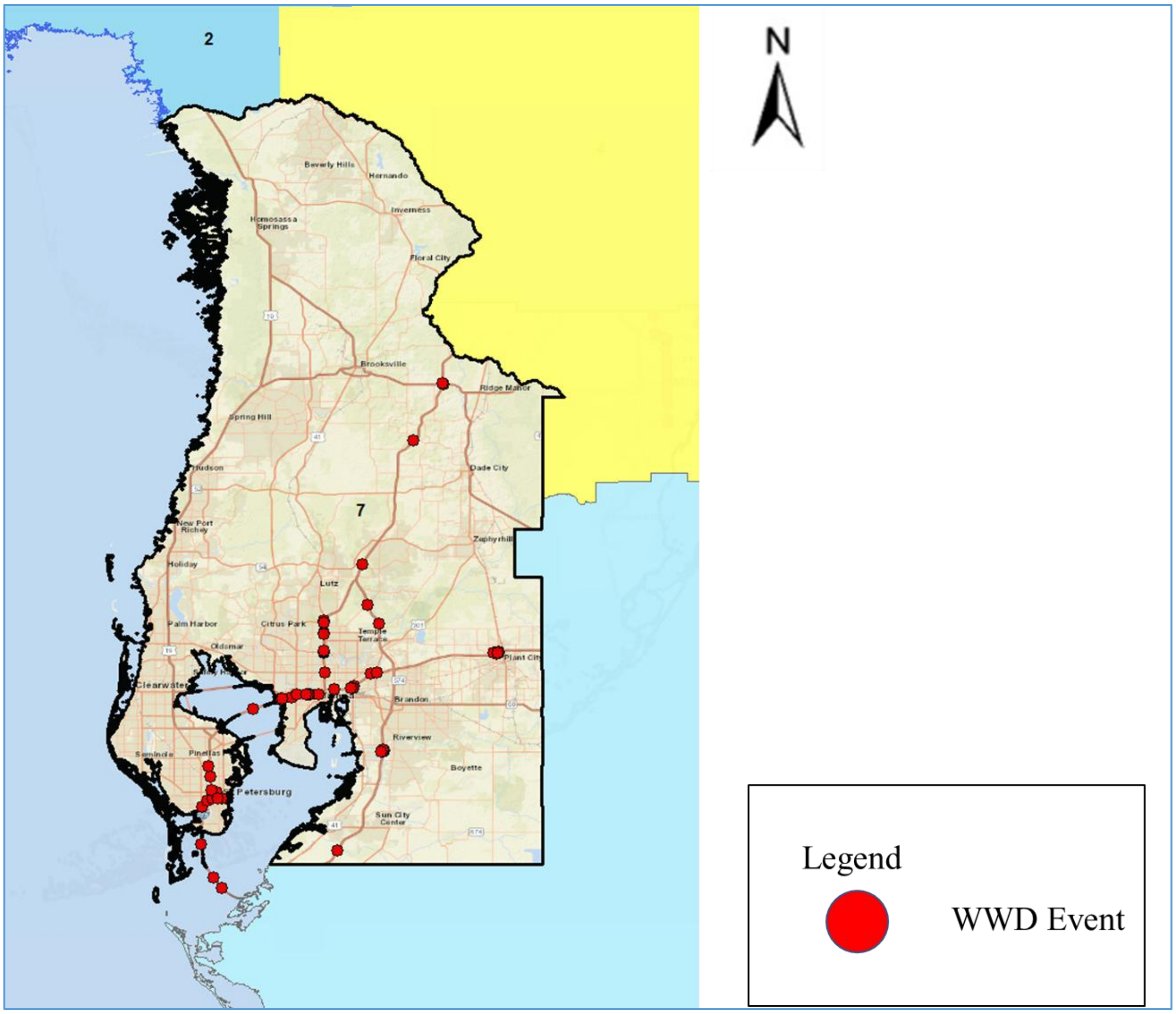

Figure 3-10: Sampled WWD Events in D7

3.3.8 Florida Turnpike Enterprise (FTE)

For the FTE, there were two guidelines to be followed: one for the WWD events before July 2019 and one for the events recorded after July 2019. A total of 64 events out of 466 WWD events were sampled and reviewed. The reviewing task was done in two parts. For the first part of reviewing (without considering which DMS are switched on), none of the WWD events were responded to as per the FTE-SOP.

The most common SOP deviations observed in the first part are:

- Not notifying RRSP of the wrong-way driver's location
- Not using the exact text required by FTE-SOP when displaying a DMS warning message
- Not activating any DMS during a WWD event
- Not activating the appropriate HAR stations during an incident to broadcast and alert drivers on WWD events

For the second part of the review, all events had one or more DMS not switched on within the required 10-mile radius during a WWD event response. Figure 3-11 showcases the WWD events that were explicitly sampled from the FTE.

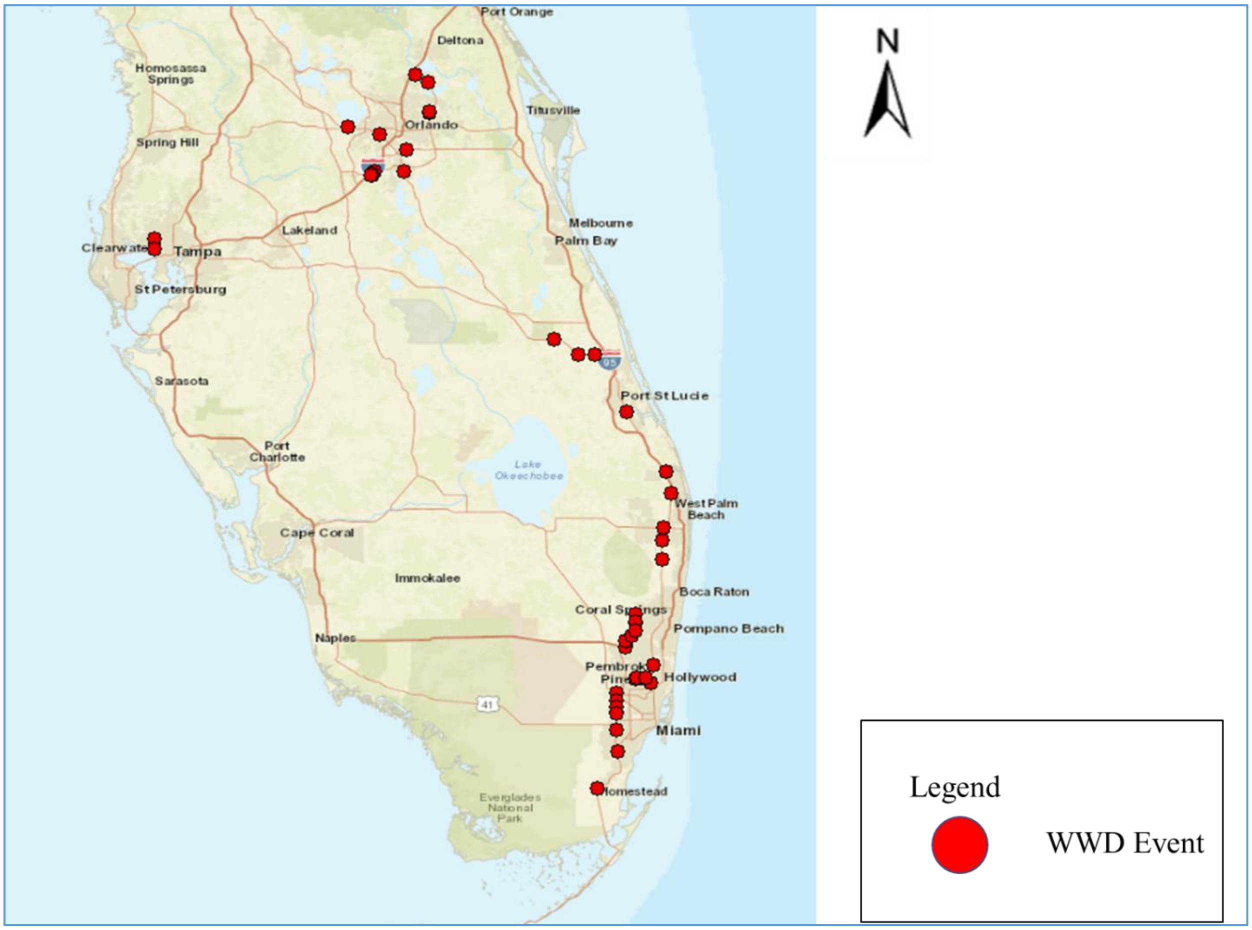

Figure 3-11: Sampled WWD Events in the FTE

3.3.9 Central Florida Expressway Authority (CFX)

For CFX, 72 events were sampled out of 4,054 WWD events and reviewed. Like most of the FDOT districts, CFX WWD events were reviewed in two parts. During the initial phase of the review, the analysis was conducted without taking into account which DMSs were activated. For 62 events, the CFX-SOP did not necessitate the implementation of a response plan. This was mainly due to false alarms and situations like pedestrians. The CFX-SOP guidelines stated that no action was required from the RTMC operators on such events. In the remaining ten events, all of them were responded to with two common deviations from CFX-SOP:

- Not notifying RRSP of the wrong-way driver's location
- Not activating any DMS during a WWD event

The second part of the review aimed to ensure all the DMSs within the required radius of the WWD event (15 miles per CFX-SOP) were switched on. Only those sampled events which required a response plan were reviewed. All reviewed events had one or more DMSs that were not switched on during the WWD event. Figure 3-12 exhibits the sampled WWD events that were examined in the CFX.

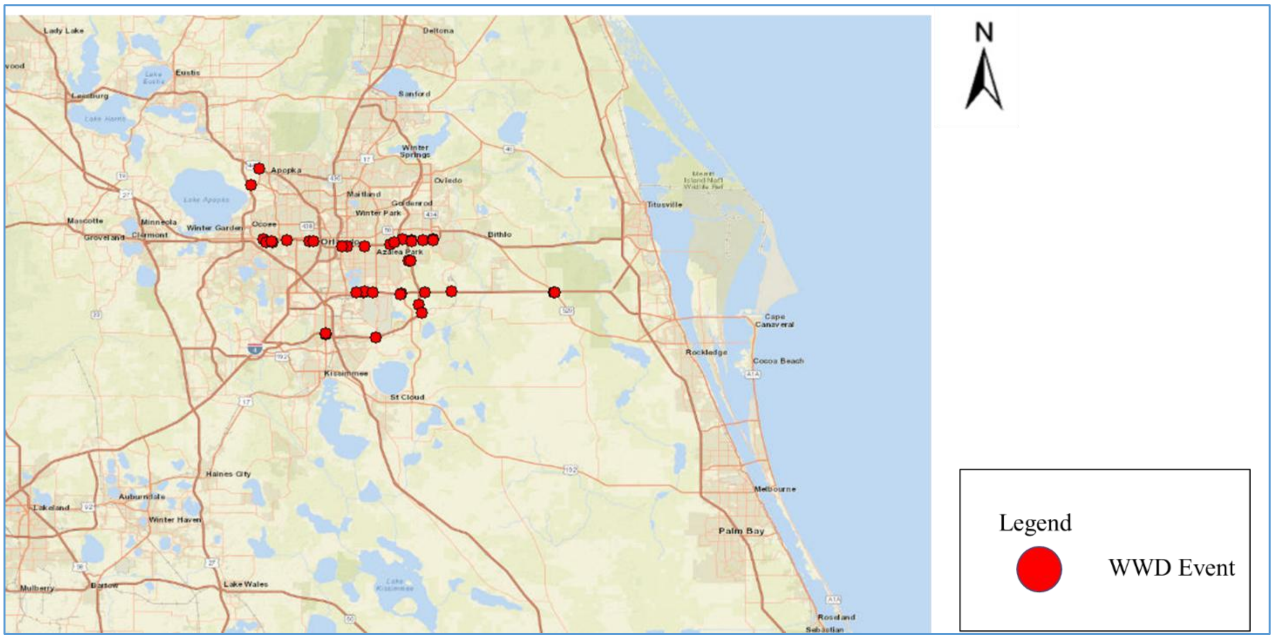

Figure 3-12: Sampled WWD Events in the CFX

3.4 False Alarms

Different FDOT districts have different definitions of a false alarm. Most definitions include the false positive detection of a WWD event. False positive is when a WWD event is detected or reported while actually there was no WWD movement. Some districts include other scenarios, such as maintenance activities or pedestrians as false alarms. Also, some districts considered an event a false alarm if the wrong-way driver/vehicle is not found after a specified amount of time. Table 3-3 summarizes the FDOT districts, what they consider false alarms, and the percentage of false alarms in the reviewed WWD events.

Table 3-3: Definition of False Alarms

District	False Alarm Definition	Percentage of False Alarms
D1	• When a reported WWD cannot be found or confirmed after 15 minutes. • No apparent cause for the alarm or when poor video quality or incorrect camera position causes the alarm.	59% (30/51)
D2	• Pictures from the WWD vendor vehicle alarm system show no WWD vehicle. • Emergency personnel, maintenance crews, and construction vehicles.	4% (2/52)
D3	No apparent definition	N/A
D4	No apparent definition	N/A
D5	Any alarm that does not appear to have impacted visibly. This could be wind, rain, detection of vehicles on side roads, etc.	7% (5/72)
D6	No apparent definition	N/A
D7	False positives, authorized vehicles, incompliant vehicles (vehicles detected on opposite ramps, backed up and self-corrected vehicles), non-vehicles (bicycles and pedestrians), and test events	44% (32/72)
FTE	• WWD vehicle is not found in 15 minutes. • Maintenance/construction type vehicle. • No vehicles are found on cameras.	0%
CFX	Any alarm that does not appear to have impacted visibly. This could be wind, rain, detection of vehicles on side roads, etc.	14% (10/72)

3.5 Summary

A total of 561 WWD events from the FDOT districts, FTE, and CFX from 2018 to 2022 were sampled and reviewed. In responding to some WWD events, the agencies deviated from following their guidelines to varying extents. Most of the deviations were not critical. However, some deviations may increase the probability of a WWD event progressing into a crash due to the inability to intercept or the driver to perform corrective action during the WWD event response. The following deviations could increase the WWD crash probability:

- Failure to notify appropriate agencies, such as FHP, RRSP, or LEOs, during a WWD event
- Closing the response plan before the minimum required amount of time to attempt to locate the WWD event
- Failure to activate some or all of the DMSs within the WWD focus area (SOP-defined radius around WWD events)

In FTE, for some WWD events, it was stated that the reason they could not switch some DMSs was that the required message required by FTE-SOP could not fit the specific signs. D5 indicated in the chronology of WWD response that some of their DMSs were not working properly during the WWD event. D5 also had the issue of not adding some DMSs to the response plan because the D5-SOP suggested message did not fit on the sign. These DMS issues might not be stated in the WWD events chronologies for other districts, but they could be the case for them as well. Table 3-4 summarizes the percentage of the sampled WWD events that involved activating all DMSs within the SOP-recommended radii when responding to the events.

Table 3-4: Responded WWD Events with the Recommended DMS Activation Radius

District	Events with 100% DMS Radius Activation
D1	53% (27/51)
D2	0% (0/52)
D3	82% (51/62)
D4	11% (7/65)
D5	0% (0/21)
FTE	0% (0/64)
CFX	0% (0/10)

Note: The SOPs for D6 and D7 did not specify the radius of DMS activation.

The research team believes the provided recommendations in this chapter will help handle the WWD events well when they occur. Districts should strive as much as possible to respond to the events as per the guidelines provided in their SOPs. The following measures should be advocated by the FDOT districts, FTE, and CFX when responding to WWD events:

- Notifying the appropriate officers could increase the probability of intercepting the wrong-way driver and preventing the aftermath of WWD crashes.
- A thorough check should be done for as long as possible before confirming that the WWD vehicle has not been found. Giving up too early on finding the vehicle could also result in WWD crashes, which could have been prevented had the search effort been continued.
- All the DMSs within the required radius (by the SOPs) should be switched on during WWD events to warn the right-way drivers about the oncoming wrong-way driver. The alert will make the right-way drivers more careful and increase the chances of avoiding the wrong-way drivers in the worst-case scenario that they come in their way.
- The DMSs should be used not only on the link where a WWD movement has been detected but also on connecting roadway facilities. The suggested setting is because the WWD drivers may move from one facility to another unknowingly or in an attempt to rectify their WWD movement.
- Districts should consider replacing, maintaining, and testing the existing DMSs to be able to display the required messages during WWD events. Alternatively, in cases where the required messages cannot fit specific DMSs, districts should explore alternatives to communicate the necessary information. The options may involve revisiting the messaging format to convey important messages effectively without adjusting the size of the signs.
- All districts should maintain comprehensive and accurate chronologies of WWD events, including any issues encountered with DMSs. By documenting such challenges, districts can identify recurring problems and develop strategies to address them systematically.
- Districts should foster a culture of continuous improvement by regularly reviewing and updating their WWD response protocols. By learning from past experiences and incorporating best practices, districts can enhance their overall response capabilities.

- Regular training sessions should be conducted for personnel involved in WWD response to reinforce adherence to guidelines and SOPs. Training should focus on effective communication, proper utilization of DMSs, and understanding the criticality of interception in preventing crashes and ensuring public safety.

- Districts should be encouraged to collaborate and share insights, challenges, and best practices related to WWD events. Establishing a platform for sharing lessons learned and innovative approaches can lead to collective improvements across all districts.

- Periodic audits and assessments of WWD response activities should be implemented to identify any systemic issues. The audits could also help evaluate compliance with guidelines and measure the effectiveness of implemented measures. These evaluations will help identify areas for improvement and ensure ongoing adherence to best practices.

Generally, SOP guidelines should be followed thoroughly for safety purposes and consistency in documentation purposes when responding to WWD events. By implementing these recommendations, districts can enhance their response capabilities, reduce risks associated with WWD events, and improve public safety.

CHAPTER 4
REAL-WORLD TRAFFIC DATA ANALYSIS

This chapter investigates how drivers respond to DMS related to WWD events (WWD-related DMS). DMSs are electronic signs that can be programmed and are typically positioned along highways (Edara et al., 2011). Their primary purpose is to relay real-time information about various traffic conditions, including unusual events such as adverse weather, construction, road closures, detours, and roadway incidents. These messages are designed to influence driver behavior by providing real-time traffic-related information to alert and caution drivers, regulate traffic flow, and manage congestion on the road. In Florida, DMSs convey messages such as "WRONG WAY DRIVER USE EXTREME CAUTION" during active WWD incidents. Figure 4-1 shows an example of a WWD message on a DMS.

Figure 4-1: WWD Message Example on a DMS

The research team analyzed traffic data to quantitatively evaluate driver responses, focusing on adjustments in speed and lane usage in response to WWD-related DMS messages. Various data sources were utilized for this analysis, including:

- Detector data from the Regional Integrated Transportation Information System (RITIS) - the detector data included traffic speed and lane use data linked with WWD DMS activation.
- SunGuide™ incident data - the WWD incident response chronology data showed the DMSs activated and the activation time while responding to WWD events. The chronology from SunGuide™ also revealed the WWD message logs and the changes in the DMS messages.
- DMS location data – the location data showed the coordinates of the DMSs activated during each WWD event response.

4.1 Data Collection

The analysis was based on speed and lane use data collected during WWD DMS activations. DMS location data were used to plot 925 DMSs from the FDOT Districts, Florida Turnpike Enterprise (FTE), and Central Florida Expressway Authority (CFX) in ArcGIS. Florida freeway detectors' inventory file, which consists of each detector's coordinates, was downloaded from RITIS. The detectors were also plotted in ArcGIS and spatially joined with the DMSs to obtain all DMSs with detectors within 1000 ft. The 1000 ft distance was used considering the sight distance of drivers. The aim was to collect traffic behavioral changes near the DMSs caused by the WWD messages on the signs. A total of 299 DMSs with detectors within 1000 ft were studied to analyze their activation impact during WWD events. In RITIS data, the lower lane number means it is relatively on the left side (i.e., faster lane), and the higher lane number means it is relatively on the right side of the road (i.e., slower lane). For example, in a freeway segment with four lanes (Figure 4-2), Lane 1 is the lane on the left-most side of the road (i.e., fast lane), while Lane 4 is on the right-most side of the road (i.e., slow lane).

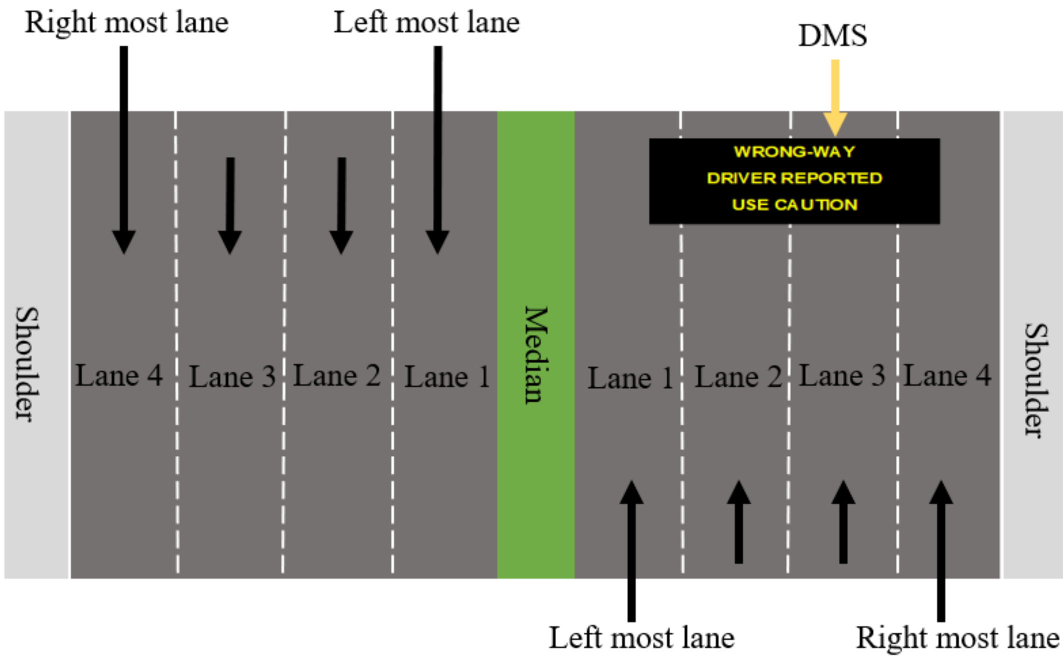

Figure 4-2: Freeway Segment with Four Lanes in Each Approach

4.2 Lane Speed Changes

One of the behaviors that was examined was traffic speed changes before and during WWD DMS activation. The aim was to analyze the traffic behavioral patterns caused by the DMSs. The evaluation was conducted within freeway lanes and along the entire freeway segments to determine lane speed changes and overall speed changes in freeway segments triggered by the WWD DMS message. Defining an observable speed change can be subjective, and therefore, for this study, considerable speed changes are the ones that are statistically significant. RITIS traffic speed data were collected for one or more detectors within 1000 ft of the DMSs. The detector data analyzed were in the same roadway approach as the DMSs.

For each DMS, traffic speed data from the proximity detectors was first collected for a period during which a WWD DMS message was activated. For example, if the chronology of WWD events shows that the WWD DMS message was displayed from 1500 to 1515 (15 minutes), then the detector speed data was extracted from 1500 to 1515. To analyze the traffic speed behavioral change in response to the message, traffic speed before the WWD DMS message also had to be analyzed. Hence, the detector speed data was also extracted from 1445 to 1500 (15 minutes before the DMS activation). The mean speeds obtained in the two periods were then analyzed to determine whether the traffic speed changed and how significant the change was. Equation 4-1 illustrates the lane speed change analysis.

$$Z_\alpha = \frac{\mu_2 - \mu_1}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} \quad (4\text{-}1)$$

Where,

Z_α = critical value of the normal distribution evaluated at a 95% CL,
μ_2 = lane traffic mean speed before DMS activation,
μ_1 = lane traffic mean speed during DMS activation,
S_2 = lane speed standard deviation before DMS activation,
S_1 = lane speed standard deviation during DMS activation,
n_1 = number of speed data points returned from RITIS detector data extraction during DMS activation (i.e., speed readings used to calculate μ_1), and
n_2 = number of speed data points returned from RITIS detector data extraction before DMS activation (i.e., speed readings used to calculate μ_2).

The null hypothesis, alternative hypothesis, and the z-statistic used for lane speed change analysis are illustrated below:

- Null hypothesis (H_0): the difference in the means of lane traffic speeds when WWD messages are displayed on DMSs and before DMS activation is zero (i.e., H_0: $\mu_1 = \mu_2$).
- Alternative hypothesis (H_a): the average lane speeds before WWD messages are displayed are greater than the average lane speeds during DMS activations at a 95% CL (i.e., H_a: $\mu_2 > \mu_1$).
- The z-statistic value greater than 1.645 indicates a statistically significant reduction in lane traffic speeds.

The following subsections (Sections 4.2.1 through 4.2.8) describe the traffic speed change results obtained in each studied freeway segment lane associated with the WWD DMS activation. The analysis was done in D1-7 and the FTE. Most detectors around the CFX's DMSs were dormant at the time of DMS activations, and hence, CFX was not analyzed.

All the DMS analyzed had a WWD alert activation of more than 10 minutes. RITIS detectors can collect speed data up to 3 data points per minute (every 20 seconds). Therefore, since the WWD-related DMS studied were activated for at least 10 minutes and hence involved at least 30 data points, z-statistics was suitable and appropriate to use (Abebe, 2019). Tables 4-1 through 4-8 summarize the lane speed changes in the FDOT Districts 1-7 and FTE triggered by the WWD DMS activations, respectively. Note that in each district, the number of speed change detector readings decreased as the number of lanes increased. This is because in a district, all freeways have at least two lanes, but fewer have, say, six lanes in each approach. Therefore, all studied WWD incidents will have Lane 1 speed change readings, but fewer events will have Lane 6 speed change readings. A few exceptions occurred when there were no detector lane readings for some lanes. Since speed change analysis was conducted in multiple WWD-related DMS activation events, the False Discovery Rate method was used to adjust the significance level for analysis. The significance level is adjusted to avoid the chances of having at least one false positive in significant speed change with an increased number of tests (Storey, 2002) in different WWD-related DMS activations.

4.2.1 District One (D1)

A total of 27 DMSs in D1 were analyzed. The speed change in response to a WWD DMS was analyzed for each DMS (detector speed change reading). The analysis of traffic speed change in D1 showed the following trends, as summarized in Table 4-1:

- For Lane 1, among the 26 speed change readings analyzed, 73.1% showed a reduction in speed during the DMS activation period. At 95% CL, 26.9% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 2, among the 27 speed change readings analyzed, 81.5% showed a reduction in speed during the DMS activation period. At 95% CL, 14.8% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 3, among the 25 speed change readings analyzed, 88.0% showed a reduction in speed during the DMS activation period. At 95% CL, 28.0% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 4, among the two speed change readings analyzed, all showed a reduction in speed during the DMS activation period. At 95% CL, all WWD events involved significant reductions in traffic speed when DMSs were activated.

Table 4-1: Lane Speed Change Readings During WWD DMS Activation in D1

Lane #	Total Detector Readings	Events with Speed Reduction (ESR)	% ESR	Events with Significant Speed Reduction (at 95% CL) (ESSR)	% ESSR
1	26	19	73.1%	7	26.9%
2	27	22	81.5%	4	14.8%
3	25	22	88.0%	7	28.0%
4	2	2	100.0%	2	100.0%

4.2.2 District Two (D2)

In D2, a total of 63 DMSs were analyzed. The analysis of traffic speed change in the district revealed the following patterns, as summarized in Table 4-2:

- For Lane 1, among the 63 speed change readings analyzed, 76.2% showed a reduction in speed during the DMS activation period. At 95% CL, 27.0% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 2, among the 62 speed change readings analyzed, 66.1% showed a reduction in speed during the DMS activation period. At 95% CL, 19.4% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 3, among the 47 speed change readings analyzed, 70.2% showed a reduction in speed during the DMS activation period. At 95% CL, 19.1% of WWD events involved significant reductions in traffic speed when DMSs were activated.

- For Lane 4, among the nine speed change readings analyzed, 33.3% showed a reduction in speed during the DMS activation period. At 95% CL, 11.1% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 5, among the three speed change readings analyzed, 66.7% showed a reduction in speed during the DMS activation period. At 95% CL, none of the WWD events involved significant reductions in traffic speed when DMSs were activated.

Table 4-2: Lane Speed Change Readings During WWD DMS Activations in D2

Lane #	Total Detector Readings	ESR	% ESR	ESSR	% ESSR
1	63	48	76.2%	17	27.0%
2	62	41	66.1%	12	19.4%
3	47	33	70.2%	9	19.1%
4	9	3	33.3%	1	11.1%
5	3	2	66.7%	0	0.0%

Note: ESR = Events with Speed Reduction; ESSR = Events with Significant Speed Reduction.

4.2.3 District Three (D3)

In D3, a total of 11 DMSs were analyzed. The analysis of traffic speed change in the district revealed the following patterns, as summarized in Table 4-3:

- For Lane 1, among the 11 speed change readings analyzed, 63.3% showed a reduction in speed during the DMS activation period. At 95% CL, 36.4% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 2, among the 11 speed change readings analyzed, 81.8% showed a reduction in speed during the DMS activation period. At 95% CL, 54.5% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 3, among the five speed change readings analyzed, 60.0% showed a reduction in speed during the DMS activation period. At 95% CL, 20.0% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 4, only one speed change reading was analyzed. The one WWD event did not involve a reduction in speed during the DMS activation period.

Table 4-3: Lane Speed Change Readings During WWD DMS Activations in D3

Lane #	Total Detector Readings	ESR	% ESR	ESSR	% ESSR
1	11	7	63.6%	4	36.4%
2	11	9	81.8%	6	54.5%
3	5	3	60.0%	1	20.0%
4	1	0	0.0%	0	0.0%

Note: ESR = Events with Speed Reduction; ESSR = Events with Significant Speed Reduction.

4.2.4 District Four (D4)

In D4, a total of 45 DMSs were analyzed. The analysis of traffic speed change in the district revealed the following patterns, as summarized in Table 4-4:

- For Lane 1, among the 42 speed change readings analyzed, 71.4% showed a reduction in speed during the DMS activation period. At 95% CL, 14.3% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 2, among the 45 speed change readings analyzed, 84.4% showed a reduction in speed during the DMS activation period. At 95% CL, 13.3% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 3, among the 37 speed change readings analyzed, 81.1% showed a reduction in speed during the DMS activation period. At 95% CL, 29.7% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 4, among the 33 speed change readings analyzed, 66.7% showed a reduction in speed during the DMS activation period. At 95% CL, 21.2% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 5, among the 17 speed change readings analyzed, 58.8% showed a reduction in speed during the DMS activation period. At 95% CL, 17.6% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 6, among the six speed change readings analyzed, 83.3% showed a reduction in speed during the DMS activation period. At 95% CL, 16.7% of WWD events involved significant reductions in traffic speed when DMSs were activated.

Table 4-4: Lane Speed Change Readings During WWD DMS Activations in D4

Lane #	Total Detector Readings	ESR	% ESR	ESSR	% ESSR
1	42	30	71.4%	6	14.3%
2	45	38	84.4%	6	13.3%
3	37	30	81.1%	11	29.7%
4	33	22	66.7%	7	21.2%
5	17	10	58.8%	3	17.6%
6	6	5	83.3%	1	16.7%

Note: ESR = Events with Speed Reduction**;** ESSR = Events with Significant Speed Reduction.

4.2.5 District Five (D5)

In D5, a total of eight DMSs were analyzed. The analysis of traffic speed change in the district revealed the following patterns, as summarized in Table 4-5:

- For Lane 1, among the eight speed change readings analyzed, 75.0% showed a reduction in speed during the DMS activation period. At 95% CL, 25.0% of WWD events involved significant reductions in traffic speed when DMSs were activated.

- For Lane 2, among the eight speed change readings analyzed, 87.5% showed a reduction in speed during the DMS activation period. At 95% CL, 12.5% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 3, among the seven speed change readings analyzed, 71.4% showed a reduction in speed during the DMS activation period. At 95% CL, 42.9% of WWD events involved significant reductions in traffic speed when DMSs were activated.

Table 4-5: Lane Speed Change Readings During WWD DMS Activations in D5

Lane #	Total Detector Readings	ESR	% ESR	ESSR	% ESSR
1	8	6	75.0%	2	25.0%
2	8	7	87.5%	1	12.5%
3	7	5	71.4%	3	42.9%

Note: ESR = Events with Speed Reduction; ESSR = Events with Significant Speed Reduction.

4.2.6 District Six (D6)

In D6, a total of 32 DMSs were analyzed. The analysis of traffic speed change in the district showed the following patterns, as summarized in Table 4-6:

- For Lane 1, among the 29 speed change readings analyzed, 55.2% showed a reduction in speed during the DMS activation period. At 95% CL, 13.8% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 2, among the 30 speed change readings analyzed, 50.0% showed a reduction in speed during the DMS activation period. At 95% CL, 10.0% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 3, among the 22 speed change readings analyzed, 54.6% showed a reduction in speed during the DMS activation period. At 95% CL, none of the WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 4, among the 15 speed change readings analyzed, 60.0% showed a reduction in speed during the DMS activation period. At 95% CL, 6.7% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 5, among the eight speed change readings analyzed, 62.5% showed a reduction in speed during the DMS activation period. At 95% CL, none of the WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 6, only three speed change readings were analyzed. The three WWD events did not involve a reduction in speed during the DMS activation period.

Table 4-6: Lane Speed Change Readings During WWD DMS Activations in D6

Lane #	Total Detector Readings	ESR	% ESR	ESSR	% ESSR
1	29	16	55.2%	4	13.8%
2	30	15	50.0%	3	10.0%
3	22	12	54.6%	0	0.0%
4	15	9	60.0%	1	6.7%
5	8	5	62.5%	0	0.0%
6	3	0	0.0%	0	0.0%

Note: ESR = Events with Speed Reduction; ESSR = Events with Significant Speed Reduction.

4.2.7 District Seven (D7)

In D7, a total of 82 DMSs were analyzed. The analysis of traffic speed change in the district showed the following patterns, as summarized in Table 4-7:

- For Lane 1, among the 82 speed change readings analyzed, 69.5% showed a reduction in speed during the DMS activation period. At 95% CL, 31.7% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 2, among the 82 speed change readings analyzed, 68.3% showed a reduction in speed during the DMS activation period. At 95% CL, 23.2% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 3, among the 68 speed change readings analyzed, 58.8% showed a reduction in speed during the DMS activation period. At 95% CL, 10.3% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 4, among the 30 speed change readings analyzed, 60.0% showed a reduction in speed during the DMS activation period. At 95% CL, 6.7% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 5, among the seven speed change readings analyzed, 71.4% showed a reduction in speed during the DMS activation period. At 95% CL, 14.3% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 6, among the three speed change readings analyzed, 33.3% showed a reduction in speed during the DMS activation period. At 95% CL, 33.3% of WWD events involved significant reductions in traffic speed when DMSs were activated.

Table 4-7: Lane Speed Change Readings During WWD DMS Activations in D7

Lane #	Total Detector Readings	ESR	% ESR	ESSR	% ESSR
1	82	57	69.5%	26	31.7%
2	82	56	68.3%	19	23.2%
3	68	40	58.8%	7	10.3%
4	30	18	60.0%	2	6.7%
5	7	5	71.4%	1	14.3%
6	3	1	33.3%	1	33.3%

Note: ESR = Events with Speed Reduction; ESSR = Events with Significant Speed Reduction.

4.2.8 FTE

Along the Turnpike, a total of 31 DMSs were analyzed. The analysis of traffic speed change in the district showed the following patterns, as summarized in Table 4-8:

- For Lane 1, among the 29 speed change readings analyzed, 79.3% showed a reduction in speed during the DMS activation period. At 95% CL, 24.1% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 2, among the 30 speed change readings analyzed, 93.3% showed a reduction in speed during the DMS activation period. At 95% CL, 23.3% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 3, among the 15 speed change readings analyzed, 53.3% showed a reduction in speed during the DMS activation period. At 95% CL, 20.0% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 4, among the eight speed change readings analyzed, 75.0% showed a reduction in speed during the DMS activation period. At 95% CL, 25.0% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- For Lane 5, among the four speed change readings analyzed, 25.0% showed a reduction in speed during the DMS activation period. At 95% CL, none of the WWD events involved significant reductions in traffic speed when DMSs were activated.

Table 4-8: Lane Speed Change Readings During WWD DMS Activations in FTE

Lane #	Total Detector Readings	ESR	% ESR	ESSR	% ESSR
1	29	23	79.3%	7	24.1%
2	30	28	93.3%	7	23.3%
3	15	8	53.3%	3	20.0%
4	8	6	75.0%	2	25.0%
5	4	1	25.0%	0	0.0%

Note: ESR = Events with Speed Reduction; ESSR = Events with Significant Speed Reduction.

4.3 Segment Speed Changes

Lastly, freeway segments consisting of multiple lanes were analyzed to assess the segment traffic speed-changing patterns during WWD DMS activations. The mean of the mean speed in all segment lanes was calculated to get the segment mean speed before and during DMS activation. It was then analyzed whether segment-wise traffic speed changed and the significance of the change. Equations 4-2 through 4-4 summarize the process of this analysis.

$$\mu_S = \frac{\mu_{l1} + \mu_{l2} + \cdots \mu_{ln}}{n_l} \tag{4-2}$$

$$S_S = \sqrt{\frac{1}{{n_l}^2}\left({s_{l1}}^2 + {s_{l2}}^2 + \cdots {s_{ln}}^2\right)} \tag{4-3}$$

$$Z_\alpha = \frac{\mu_{S2} - \mu_{S1}}{\sqrt{\frac{{S_{S1}}^2}{n_1} + \frac{{S_{S2}}^2}{n_2}}} \tag{4-4}$$

where,

Z_α	=	critical value of the normal distribution evaluated at a 95% CL,
μ_S	=	mean speed along the freeway segment,
μ_{S1}	=	mean speed along the freeway segment during DMS activation,
μ_{S2}	=	mean speed along the freeway segment before DMS activation,
μ_{li}	=	lane mean speeds in the freeway segment analyzed,
n_l or n	=	number of lanes in the freeway segment analyzed,
S_S	=	freeway segment speed standard deviation,
S_{S1}	=	freeway segment speed standard deviation during DMS activation,
S_{S2}	=	freeway segment speed standard deviation before DMS activation,
s_{li}	=	standard deviation of lane speeds in the freeway segment analyzed,
n_1	=	number of detector speed readings during DMS activation, and
n_2	=	number of detector speed readings before DMS activation.

The null hypothesis, alternative hypothesis, and the z-statistic used for freeway segment speed change analysis are illustrated below:

- Null hypothesis (H_o): the difference in the means of traffic speeds when WWD messages are displayed on DMSs and before DMS activation is zero (i.e., H_o: $\mu_{S2} = \mu_{S1}$).
- Alternative hypothesis (H_a): the average speeds before DMS activation are greater than the average speeds when WWD messages are displayed at a 95% CL(i.e., H_a: $\mu_{S2} > \mu_{S1}$).
- The z-statistic value greater than 1.645 indicates a statistically significant reduction in freeway segment traffic speeds.

Analyzing the segment speed changes across various districts during the WWD events with DMS activations yielded the following noteworthy insights:

- In D1, among the 27 speed change readings analyzed, 85.2% showed a reduction in speed during the DMS activation period. At 95% CL, 33.3% of WWD events involved significant reductions in traffic speed when DMSs were activated.

- In D2, among the 63 speed change readings analyzed, 73.0% showed a reduction in speed during the DMS activation period. At 95% CL, 38.1% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- In D3, among the 11 speed change readings analyzed, 72.7% showed a reduction in speed during the DMS activation period. At 95% CL, 54.5% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- In D4, among the 45 speed change readings analyzed, 84.4% showed a reduction in speed during the DMS activation period. At 95% CL, 24.4% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- In D5, among the eight speed change readings analyzed, 87.5% showed a reduction in speed during the DMS activation period. At 95% CL, 50.0% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- In D6, among the 32 speed change readings analyzed, 59.4% showed a reduction in speed during the DMS activation period. At 95% CL, 15.6% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- In D7, among the 82 speed change readings analyzed, 67.1% showed a reduction in speed during the DMS activation period. At 95% CL, 26.8% of WWD events involved significant reductions in traffic speed when DMSs were activated.
- Along the Turnpike, among the 31 speed change readings analyzed, 83.9% showed a reduction in speed during the DMS activation period. At 95% CL, 25.8% of WWD events involved significant reductions in traffic speed when DMSs were activated.

Collectively, across all districts and FTE, there were a total of 299 speed change readings, with 222 events (74.2%) demonstrating traffic speed reductions during WWD DMS activations. At 95% CL, 89 events (29.8%) exhibited significant speed reductions during DMS activations. Figure 4-3 summarizes the segment speed changes in each district, summarizing the number and percentage of WWD events that involved traffic speed reductions during DMS activations.

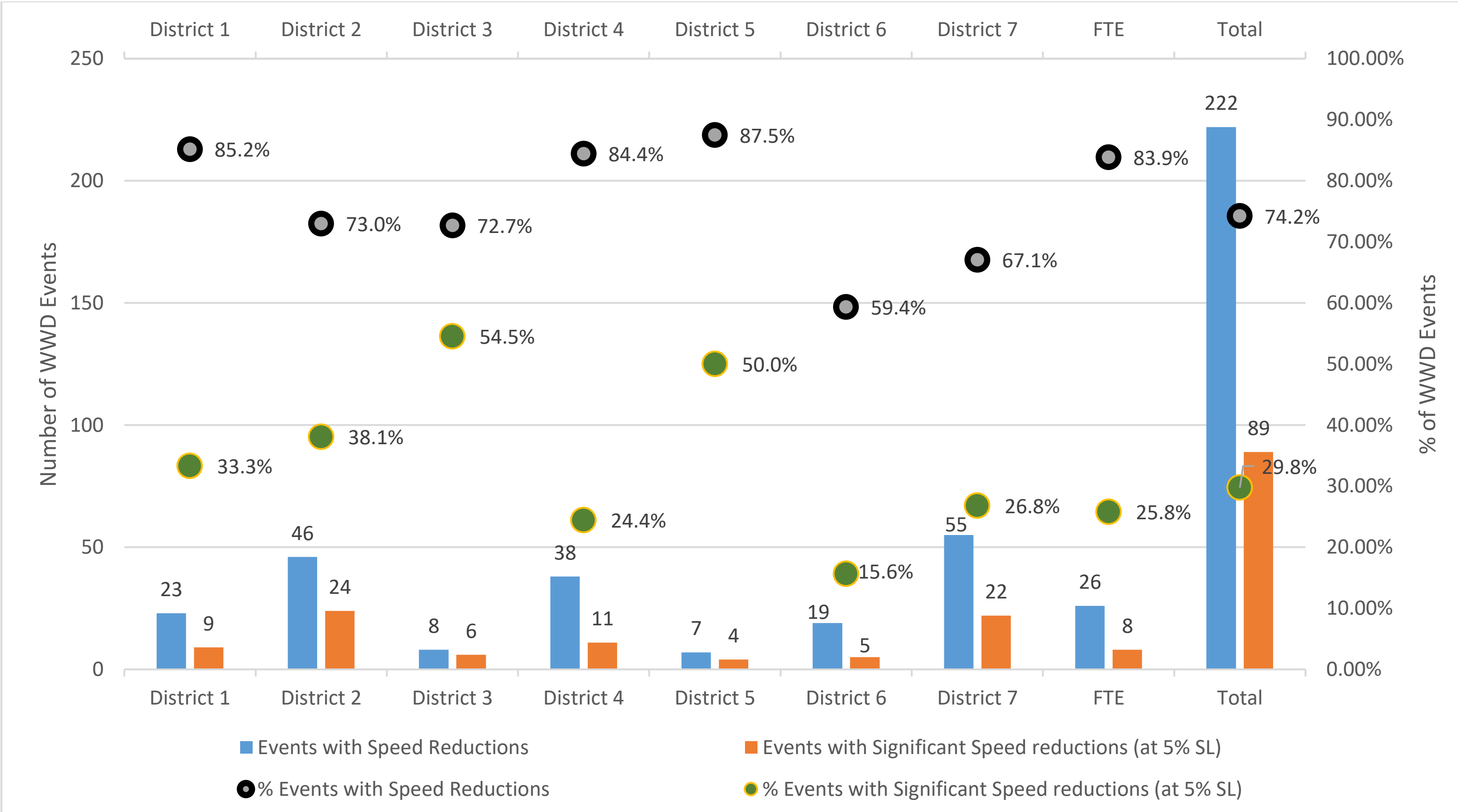

Figure 4-3: Segment Speed Changes in Each District and Aggregate Speed Changes in All Districts

Overall, for all the FDOT districts and the FTE, the traffic speed before and during DMS activation was 68.8 mph and 67.2 mph, respectively. Table 4-9 shows the values of overall mean traffic speeds, standard deviations, and the z-statistic for the difference in mean speeds before and during DMS activations. The null hypothesis here is that the mean traffic speed before and after the WWD-related DMS activation is the same. The alternative hypothesis is that the mean speed before DMS activation is greater than the one before activation. The z-statistic of the difference was found to be 1.906 (>1.645), indicating a significant overall speed reduction during the DMS activations at 95% CL. Therefore, for the DMSs analyzed, DMS activations during WWD events caused overall traffic speed reduction on the freeways.

Table 4-9: Overall Difference Between Traffic Mean Speeds Before and During DMS Activations

	Traffic Speed Before DMS Activation (mph)	Traffic Speed During DMS Activation (mph)
Mean	68.8	67.2
Standard Deviation	9.8	11.3
Observations	299	299
z-statistic	**1.906**	
p-value, one-tail	**0.028**	
z-critical, one-tail	**1.645**	

4.4 Lane Use

Another part of the analysis of real-world traffic behavioral change linked with WWD DMS activations focused on lane distribution changes. The same 299 DMSs used in analyzing traffic speed change behavior during WWD events were used to analyze the traffic lane use behavior. Four DMSs involved detector readings with only one lane segment, and therefore, lane use could not be analyzed for these DMSs. For each DMS, traffic volume data from the nearest upstream detectors was first collected for a period that a WWD DMS message was activated and for the same period before activation. The proportions of lane traffic volumes within freeway segments (i.e., lane proportions) were analyzed to observe the changes in lane usage between the fast (i.e., left) and slow (i.e., right) lanes before and during the WWD DMS activations. It was then examined whether there was a traffic shift from the fast lanes moving to slow lanes during the display of WWD messages on the DMSs. For safety reasons, traffic is expected to shift from fast lanes to slow lanes during WWD DMS activations.

This analysis examined the lane proportion changes between fast and slow lanes and whether the changes were significant. Specifically, it was analyzed whether the traffic lane volumes are increasing in the slow lanes or decreasing in the fast lanes and the significance of the change.

Z-statistics was used to examine the significance of the lane use changes linked with WWD DMS activations. The proportions were obtained from the ratio of the traffic volume detector readings in each lane to the sum of traffic lane volumes. Equations 4-5 and 4-6 illustrate the significance test of lane use changes.

$$Z_\alpha = \frac{P_2 - P_1}{\sqrt{P(1-P)(\frac{1}{n_1}+\frac{1}{n_2})}} \qquad (4\text{-}5)$$

$$P = \frac{X_1 + X_2}{n_1 + n_2} \qquad (4\text{-}6)$$

where,

Z_α = critical value of the normal distribution evaluated at a 95% or 90% CL,
P_2 = lane proportions during DMS activation,
P_1 = lane proportions before DMS activation,
n_1 = freeway segment traffic volume before DMS activation,
n_2 = freeway segment traffic volume during DMS activation,
X_1 = specific lane volume before DMS activation, and
X_2 = specific lane volume during DMS activation.

The null hypothesis, alternative hypothesis, and the z-statistic used for lane proportion changes analysis are illustrated below:

- The null hypothesis for fast lanes (H_o): the difference in the lane proportions when WWD messages are displayed and before that is zero (i.e., H_o: $P_2 = P_1$).
- The alternative hypothesis for fast lanes (H_a): the lane proportions when WWD messages are displayed are less than the proportions before DMS activation at a 95% or 90% CL(i.e., H_a: $P_2 < P_1$).
- The z-statistic value less than -1.645 (95% CL) or -1.283 (90% CL) indicates a significant change in the fast lane usage.
- The null hypothesis for slow lanes (H_o): the difference in the lane proportions when WWD messages are displayed and before that is zero (i.e., H_o: $P_2 = P_1$).
- The alternative hypothesis for slow lanes (H_a): the lane proportions when WWD messages are displayed are greater than the proportions before DMS activations at a 95% or 90% CL(i.e., H_a: $P_2 > P_1$).
- The z-statistic value greater than 1.645 (95% CL) or 1.283 (90% CL) indicates a significant change in the slow lane usage.

This analysis was performed in different segments depending on their total number of lanes. The analyzed DMSs in the districts had the number of lanes ranging from 2 to 6 lanes per direction. Some districts had all of these segments for the analyzed DMSs, while some did not. Similar to the traffic speed change analysis, this analysis observed the lane proportion changes per every WWD DMS activation studied. The lane change movements were observed through lane distribution changes before and during DMS activations in response to WWD events (lane proportion change reading). The False Discovery Rate approach was used to adjust the significance level in the lane use analysis for the same reason that it was used in the speed change analysis.

4.4.1 Two-Lane Segments

Two-lane segments were the studied freeway segments with two lanes in a single approach. The focus is on analyzing the traffic shift from Lane 1 (the faster left lane) to Lane 2 (the slower right lane). Table 4-10 summarizes traffic lane proportion changes for 2-lane freeway segments analyzed in FDOT districts and FTE. The following patterns were observed:

- Among the two lane proportion change readings in D1, all involved traffic shifting from Lane 1 to Lane 2 on WWD DMS activations. At 95% CL, none of the WWD events were associated with statistically significant lane changes during WWD DMS activations. On the other hand, at 90% CL, 50% of events involved significant lane changes after activating DMSs.
- Among the 15 lane proportion change readings in D2, 4% involved traffic shifting from Lane 1 to Lane 2 on WWD DMS activations. At both 95% CL and 90% CL, 6.7% of the WWD events were associated with statistically significant lane changes during WWD DMS activations.
- Among the six lane proportion change readings in D3, 5% involved traffic shifting from Lane 1 to Lane 2 on WWD DMS activations. At both 95% CL and 90% CL, none of the WWD events were associated with statistically significant lane changes during WWD DMS activations.
- Among the seven lane proportion change readings in D4, 57.1% involved traffic shifting from Lane 1 to Lane 2 on WWD DMS activations. At both 95% CL and 90% CL, 14.3% of the WWD events were associated with statistically significant lane changes during WWD DMS activations.
- Only one lane proportion change reading was registered in D5. The WWD event associated with the reading did not involve traffic shifting from Lane 1 to Lane 2 on WWD DMS activations.
- Among the six lane proportion change readings in D6, 50% involved traffic shifting from Lane 1 to Lane 2 on WWD DMS activations. At 95% CL, none of the WWD events was associated with statistically significant lane changes during WWD DMS activations. On the other hand, at 90% CL, 25.0% of events involved significant lane movements after activating DMSs.
- Among the 14 lane proportion change readings in D7, 57.1% involved traffic shifting from Lane 1 to Lane 2 on WWD DMS activations. At 95% CL, 14.3% of the WWD events were associated with statistically significant lane changes during WWD DMS activations. On the other hand, at 90% CL, 28.6% of events involved significant lane movements after activating DMSs.
- Among the 15 lane proportion change readings in the FTE, 66.7% involved traffic shifting from Lane 1 to Lane 2 on WWD DMS activations. At 95% CL, 6.7% of the WWD events were associated with statistically significant lane changes during WWD DMS activations. On the other hand, at 90% CL, 13.3% of events involved significant lane movements after activating DMSs.
- Across all districts and agencies, 55.9% of WWD events were linked to traffic lane changes to slower lanes (from Lane 1 to Lane 2), with 7.4% associated with significant changes at 95% CL and 16.2% within the 90% CL.

Table 4-10: Traffic Lanes Proportion Changes for 2-Lane Freeway Segments

District	Total Lane Proportion Change Readings (TLPCR)	# Shifting from Lane 1 (NSL1) to 2	% NSL1	# Significant Shifting from Lane 1 (NSSL1) to 2	% NSSL1
D1	2	2	100.0	0[a], 1[b]	0.0[a], 50.0[b]
D2	15	6	40.0	1[a], 1[b]	6.7[a], 6.7[b]
D3	6	3	50.0	0[a], 0[b]	0.0[a], 0.0[b]
D4	7	4	57.1	1[a], 1[b]	14.3[a], 14.3[b]
D5	1	1	100.0	0[a], 0[b]	0.0[a], 0.0[b]
D6	8	4	50.0	0[a], 2[b]	0.0[a], 25.0[b]
D7	14	8	57.1	2[a], 4[b]	14.3[a], 28.6[b]
FTE	15	10	66.7	1[a], 2[b]	6.7[a], 13.3[b]
Total	68	38	55.9	5[a], 11[b]	7.4[a], 16.2[b]

Note: # = Number of lane proportion change readings; a = 95% CL; b = 90% CL.

4.4.2 Three-Lane Segments

Three-lane segments were the analyzed freeway segments with three lanes in a single approach. For these segments, the aim was to examine the traffic shift from Lane 1 and the traffic migration to Lane 3 during WWD DMS activations. Table 4-11 summarizes traffic lane proportion changes for three-lane freeway segments analyzed in FDOT districts and FTE. In summary, the key findings are as follows:

- Among the 24 lane proportion change readings in D1**,**
  - Lane 1: 54.2% shifting, 4.2% significant shifting at 95% CL, and 8.3% significant shifting at 90% CL
  - Lane 3: 58.3% migrating, 0% significant migrating at 95% CL, and 8.3% significant migrating at 90% CL
- Among the 38 lane proportion change readings in D2**,**
  - Lane 1: 52.6% shifting, 5.3% significant shifting at 95% CL, and 7.9% significant shifting at 90% CL
  - Lane 3: 36.8% migrating, 5.3% significant migrating at 95% CL, and 5.3% significant migrating at 90% CL
- Among the four lane proportion change readings in D3**,**
  - Lane 1: 50.0% shifting, 0.0% significant shifting at 95% CL, and 0.0% significant shifting at 90% CL
  - Lane 3: 25.0% migrating, 0.0% significant migrating at 95% CL, and 25.0% significant migrating at 90% CL
- Among the six lane proportion change readings in D4**,**
  - Lane 1: 50.0% shifting, 16.7% significant shifting at 95% CL, and 16.7% significant shifting at 90% CL
  - Lane 3: 16.7% migrating, 0.0% significant migrating at 95% CL, and 0.0% significant migrating at 90% CL
- Among the seven lane proportion change readings in D5**,**

    - Lane 1: 57.1% shifting, 0.0% significant shifting at 95% CL, and 0.0% significant shifting at 90% CL
    - Lane 3: 71.4% migrating, 0.0% significant migrating at 95% CL, and 0.0% significant migrating at 25% CL
- Among the eight lane proportion change readings in D6**,**
    - Lane 1: 62.5% shifting, 12.5% significant shifting at 95% CL, and 12.5% significant shifting at 90% CL
    - Lane 3: 62.5% migrating, 0.0% significant migrating at 95% CL, and 12.5% significant migrating at 90% CL
- Among the 38 lane proportion change readings in D7**,**
    - Lane 1: 55.3% shifting, 5.3% significant shifting at 95% CL, and 10.5% significant shifting at 90% CL
    - Lane 3: 55.3% migrating, 2.6% significant migrating at 95% CL, and 10.5% significant migrating at 90% CL
- Among the eight lane proportion change readings in the FTE**,**
    - Lane 1: 62.5% shifting, 12.5% significant shifting at 95% CL, and 25.0% significant shifting at 90% CL
    - Lane 3: 62.5% migrating, 12.5% significant migrating at 95% CL, and 25.0% significant migrating at 90% CL
- Overall, among the 133 lane proportion change readings across all districts and FTE**,**
    - Lane 1: 54.9% shifting, 6.0% significant shifting at 95% CL, and 17.8% significant shifting at 90% CL
    - Lane 3: 66.0% migrating, 3.0% significant migrating at 95% CL, and 9.0% significant migrating at 90% CL

Table 4-11: Traffic Lanes Proportion Changes for 3-Lane Freeway Segments

Left Lanes (LL)					
District	TLPCR	NSL1	% NSL1	NSSL1	% NSSL1
D1	24	13	54.2	1[a], 2[b]	4.2[a], 8.3[b]
D2	38	20	52.6	2[a], 3[b]	5.3[a], 7.9[b]
D3	4	2	50.0	0[a], 0[b]	0.0[a], 0.0[b]
D4	6	3	50.0	1[a], 1[b]	16.7[a], 16.7[b]
D5	7	4	57.1	0[a], 0[b]	0.0[a], 0.0[b]
D6	8	5	62.5	1[a], 1[b]	12.5[a], 12.5[b]
D7	38	21	55.3	2[a], 4[b]	5.3[a], 10.5[b]
FTE	8	5	62.5	1[a], 2[b]	12.5[a], 25.0[b]
Total	133	73	54.9	8[a], 13[b]	6.0[a], 17.8[b]
Right lanes (RL)					
District	TLPCR	# Moving to Lane 3 (NML3)	% NML3	# Significant Moving to Lane 3 (NSML3)	% NSML3
D1	24	14	58.3	0[a], 2[b]	0.0[a], 8.3[b]
D2	38	14	36.8	2[a], 2[b]	5.3[a], 5.3[b]
D3	4	1	25.00	0[a], 1[b]	0.0[a], 25.0[b]
D4	6	1	16.7	0[a], 0[b]	0.0[a], 0.0[b]
D5	7	5	71.4	0[a], 0[b]	0.0[a], 0.0[b]
D6	8	5	62.5	0[a], 1[b]	0.0[a], 12.5[b]
D7	38	21	55.3	1[a], 4[b]	2.6[a], 10.5[b]
FTE	8	5	62.5	1[a], 2[b]	12.5[a], 25.0[b]
Total	133	66	49.6	4[a], 12[b]	3.0[a], 9.0[b]

Note: # = Number of lane proportion change readings; a = 95% CL, and b = 90% CL; NML = Number of WWD Events Involving Moving to the Lane; NSL = Number of WWD Events Involving Shifting from the Lane; NSML = Number of WWD Events Involving Significant Moving to the Lane; NSSL = Number of WWD Events Involving Significant Shifting from the Lane; TLPCR = Total Lane Proportion Change Readings.

4.4.3 Four-Lane Segments

Four-lane segments were the analyzed freeway segments with four lanes in a single approach. In these segments, the task was to examine the traffic shift from the left lanes (Lane 1 and Lane 2) and the traffic migration to the right lanes (Lane 3 and Lane 4) during WWD DMS activations. Table 4-12 summarizes traffic lane proportion changes for 4-lane freeway segments analyzed in FDOT districts and FTE. In summary, the findings are as follows:

- Only one lane proportion change reading was analyzed in D1**,** and it revealed that
    - Lane 1: 0.0% shifting
    - Lane 2: 0.0% shifting
    - Lane 3: 0.0% migrating
    - Lane 4: 100.0% migrating, 0.0% significant migrating
- Among the six lane proportion change readings in D2**,**

- Lane 1: 66.7% shifting, 16.7% significant shifting at 95% CL, and 33.3% significant shifting at 90% CL
    - Lane 2: 50.0% shifting, 0.0% significant shifting
    - Lane 3: 50.0% migrating, 16.7% significant migrating at 95% CL, 16.7% significant migrating at 90% CL
    - Lane 4: 66.7% migrating, 0.0% significant migrating
- Only one lane proportion change reading was analyzed in D3**,** and it revealed that
    - Lane 1: 100.0% shifting, 0.0% significant shifting at 95% CL, 100.0% significant shifting at 90% CL
    - Lane 2: 0.0% shifting
    - Lane 3: 100.0% migrating, 0.0% significant migrating
    - Lane 4: 0.0% migrating
- Among the 16 lane proportion change readings in D4**,**
    - Lane 1: 56.3% shifting, 0.0% significant shifting at 95% CL, 12.5% significant shifting at 90% CL
    - Lane 2: 56.3% shifting, 0.0% significant shifting
    - Lane 3: 25.0% migrating, 0.0% significant migrating at 95% CL, 6.3% significant migrating at 90% CL
    - Lane 4: 62.5% migrating, 0.0% significant migrating at 95% CL, 12.5% significant migrating at 90% CL
- Among the eight lane proportion change readings in D6**,**
    - Lane 1: 37.5% shifting, 0.0% significant shifting
    - Lane 2: 37.5% shifting, 0.0% significant shifting
    - Lane 3: 37.5% migrating, 12.5% significant migrating at 95% CL, 12.5% significant migrating at 90% CL
    - Lane 4: 25.0% migrating, 0.0% significant migrating at 95% CL, 12.5% significant migrating at 90% CL
- Among the 23 lane proportion change readings in D7**,**
    - Lane 1: 60.9% shifting, 0.0% significant shifting at 95% CL, 17.4% significant shifting at 90% CL
    - Lane 2: 43.5% shifting, 0.0% significant shifting
    - Lane 3: 52.2% migrating, 0.0% significant migrating
    - Lane 4: 52.2% migrating, 8.7% significant migrating at 95% CL, 13.0% significant migrating at 90% CL
- Among the four lane proportion change readings in the FTE**,**
    - Lane 1: 0.0% shifting
    - Lane 2: 75.0% shifting, 0.0% significant shifting
    - Lane 3: 50.0% migrating, 0.0% significant migrating
    - Lane 4: 50.0% migrating, 0.0% significant migrating
- Overall, among the 59 lane proportion change readings across the districts and FTE**,**
    - Lane 1: 52.5% shifting, 1.7% significant shifting at 95% CL, 15.3% significant shifting at 90% CL
    - Lane 2: 47.5% shifting, 0.0% significant shifting
    - Lane 3: 42.4% migrating, 3.4% significant migrating at 95% CL, 5.1% significant migrating at 90% CL

- Lane 4: 52.5% migrating, 3.4% significant migrating at 95% CL, 10.2% significant migrating at 90% CL

Table 4-12: Traffic Lanes Proportion Changes for 4-Lane Freeway Segments

Left Lanes									
District	TLPCR	NSL1	% NSL1	NSSL1	% NSSL1	NSL 2	% NSL 2	NSSL2	% NSSL 2
D1	1	0	0.0	0[a], 0[b]	0.0[a], 0.0[b]	0	0.0	0[a], 0[b]	0.0[a], 0.0[b]
D2	6	4	66.7	1[a], 2[b]	16.7[a], 33.3[b]	3	50.0	0[a], 0[b]	0.0[a], 0.0[b]
D3	1	1	100.0	0[a], 1[b]	0.0[a], 100.0[b]	0	0.0	0[a], 0[b]	0.0[a], 0.0[b]
D4	16	9	56.3	0[a], 2[b]	0.0[a], 12.5[b]	9	56.3	0[a], 0[b]	0.0[a], 0.0[b]
D6	8	3	37.5	0[a], 0[b]	0.0[a], 0.0[b]	3	37.5	0[a], 0[b]	0.0[a], 0.0[b]
D7	23	14	60.9	0[a], 4[b]	0.0[a], 17.4[b]	10	43.5	0[a], 0[b]	0.0[a], 0.0[b]
FTE	4	0	0.0	0[a], 0[b]	0.0[a], 0.0[b]	3	75.0	0[a], 0[b]	0.0[a], 0.0[b]
Total	59	31	52.5	1[a], 9[b]	1.7[a], 15.3[b]	28	47.5	0[a], 0[b]	0.0[a], 0.0[b]
Right Lanes									
District	TLPCR	NML 3	% NML3	NSML3	% NSML 3	# NML 4	% NML4	NSML4	% NSML 4
D1	1	0	0.0	0[a], 0[b]	0.0[a], 0.0[b]	1	100.0	0[a], 0[b]	0.0[a], 0.0[b]
D2	6	3	50.0	1[a], 1[b]	16.7[a], 16.7[b]	4	66.7	0[a], 0[b]	0.0[a], 0.0[b]
D3	1	1	100.0	0[a], 0[b]	0.0[a], 0.0[b]	0	0.0	0[a], 0[b]	0.0[a], 0.0[b]
D4	16	4	25.0	0[a], 1[b]	0.0[a], 6.3[b]	10	62.5	0[a], 2[b]	0.0[a], 12.5[b]
D6	8	3	37.5	1[a], 1[b]	12.5[a], 12.5[b]	2	25.0	0[a], 1[b]	0.0[a], 12.5[b]
D7	23	12	52.2	0[a], 0[b]	0.0[a], 0.0[b]	12	52.2	2[a], 3[b]	8.7[a], 13.0[b]
FTE	4	2	50.0	0[a], 0[b]	0.0[a], 0.0[b]	2	50.0	0[a], 0[b]	0.0[a], 0.0[b]
Total	59	25	42.4	2[a], 3[b]	3.4[a], 5.1[b]	31	52.5	2[a], 6[b]	3.4[a], 10.2[b]

Note: # = Number of lane proportion change readings; a = 95% CL, and b = 90% CL; NML = Number of WWD Events Involving Moving to the Lane; NSL = Number of WWD Events Involving Shifting from the Lane; NSML = Number of WWD Events Involving Significant Moving to the Lane; NSSL = Number of WWD Events Involving Significant Shifting from the Lane; TLPCR = Total Lane Proportion Change Readings.

4.4.4 Five-Lane Segments

Five-lane segments were the analyzed freeway segments with five lanes in a single approach. In these segments, the task was to examine the traffic shift from the left lanes (Lane 1 and Lane 2) and the traffic migration to the right lanes (Lane 4 and Lane 5) during WWD DMS activations. Table 4-13 summarizes traffic lane proportion changes for 5-lane freeway segments analyzed in FDOT districts and FTE. Here is a summarized overview of the table:

- Among the three lane proportion change readings in D2**,**
  - Lane 1: 66.7% shifting, 0.0% significant shifting
  - Lane 2: 33.3% shifting, 0.0% significant shifting
  - Lane 4: 33.3% migrating, 0.0% significant migrating
  - Lane 5: 100.0% migrating, 0.0% significant migrating
- Among the 11 lane proportion change readings in D4**,**

    - Lane 1: 45.5% shifting, 9.1% significant shifting at 95% CL, 9.1% significant shifting at 90% CL
    - Lane 2: 36.4% shifting, 9.1% significant shifting at 95% CL, 9.1% significant shifting at 90% CL
    - Lane 4: 54.6% migrating, 9.1% significant migrating at 95% CL, 9.1% significant migrating at 90% CL
    - Lane 5: 45.5% migrating, 0.0% significant migrating
- Among the three lane proportion change readings in D6**,**
    - Lane 1: 100.0% shifting, 0.0% significant shifting
    - Lane 2: 33.3% shifting, 0.0% significant shifting
    - Lane 4: 0.0% migrating
    - Lane 5: 100.0% migrating, 0.0% significant migrating
- Among the four lane proportion change readings in D7**,**
    - Lane 1: 75.0% shifting, 25.0% significant shifting at 95% CL, 25.0% significant shifting at 90% CL
    - Lane 2: 75.0% shifting, 0.0% significant shifting at 95% CL, 25.0% significant shifting at 90% CL
    - Lane 4: 75.0% migrating, 0.0% significant migrating
    - Lane 5: 50.0% migrating, 0.0% significant migrating
- Among the three lane proportion change readings in the FTE**,**
    - Lane 1: 33.3% shifting, 0.0% significant shifting
    - Lane 2: 100.0% shifting, 0.0% significant shifting
    - Lane 4: 33.3% migrating, 0.0% significant migrating
    - Lane 5: 66.7% migrating, 0% significant migrating at 95% CL, 33.3% significant migrating at 90% CL
- Overall, among the 24 lane proportion change readings across the districts and FTE**,**
    - Lane 1: 58.3% shifting, 8.3% significant shifting at 95% CL, 8.3% significant shifting at 90% CL
    - Lane 2: 50.0% shifting, 4.2% significant shifting at 95% CL, 8.3% significant shifting at 90% CL
    - Lane 4: 45.8% migrating, 4.2% significant migrating at 95% CL, 4.2% significant migrating at 90% CL
    - Lane 4: 62.5% migrating, 0.0% significant migrating at 95% CL, 4.2% significant migrating at 90% CL

Table 4-13: Traffic Lanes Proportion Changes for 5-Lane Freeway Segments

Left Lanes									
District	TLPCR	NSL1	% NSL1	NSSL1	% NSSL1	NSL2	% NSL2	NSSL2	% NSSL2
D2	3	2	66.7	0[a],0[b]	0.0[a],0.0[b]	1	33.3	0[a],0[b]	0.0[a],0.0[b]
D4	11	5	45.5	1[a],1[b]	9.1[a],9.1[b]	4	36.4	1[a],1[b]	9.1[a],9.1[b]
D6	3	3	100.0	0[a],0[b]	0.0[a],0.0[b]	1	33.3	0[a],0[b]	0.0[a],0.0[b]
D7	4	3	75.0	1[a],1[b]	25.0[a],25.0[b]	3	75.0	0[a],1[b]	0.0[a],25.0[b]
FTE	3	1	33.3	0[a],0[b]	0.0[a],0.0[b]	3	100.0	0[a],0[b]	0.0[a],0.0[b]
Total	24	14	58.3	2[a],2[b]	8.3[a],8.3[b]	12	50.0	1[a],2[b]	4.2[a],8.3[b]

Right Lanes									
District	TLPCR	# NML 4	% NML 4	NSML 4	% NSML 4	NML 5	% NML 5	NSML 5	% NSML 5
D2	3	1	33.3	0[a],0[b]	0.0[a],0.0[b]	3	100.0	0[a],0[b]	0.0[a],0.0[b]
D4	11	6	54.6	1[a],1[b]	9.1[a],9.1[b]	5	45.45	0[a],0[b]	0.0[a],0.0[b]
D6	3	0	0.0	0[a],0[b]	0.0[a],0.0[b]	3	100.0	0[a],0[b]	0.0[a],0.0[b]
D7	4	3	75.0	0[a],0[b]	0.0[a],0.0[b]	2	50.0	0[a],0[b]	0.0[a],0.0[b]
FTE	3	1	33.3	0[a],0[b]	0.0[a],0.0[b]	2	66.7	0[a],1[b]	0.0[a],33.3[b]
Total	24	11	45.8	1[a],1[b]	4.2[a],4.2[b]	15	62.5	0[a],1[b]	0.0[a],4.2[b]

Note: # = Number of lane proportion change readings; a = 95% CL, and b = 90% CL; NML = Number of WWD Events Involving Moving to the Lane; NSL = Number of WWD Events Involving Shifting from the Lane; NSML = Number of WWD Events Involving Significant Moving to the Lane; NSSL = Number of WWD Events Involving Significant Shifting from the Lane; TLPCR = Total Lane Proportion Change Readings.

4.4.5 Six-Lane Segments

Six-lane segments were the analyzed freeway segments with six lanes in a single approach. In these segments, the task was to examine the traffic shift from the left lanes (Lane 1 and Lane 2) and the traffic migration to the right lanes (Lane 5 and Lane 6) during WWD DMS activations. Table 4-14 summarizes traffic lane proportion changes for 6-lane freeway segments analyzed in FDOT districts and FTE. In summary, the findings show the following patterns:

- Among the five lane proportion change readings in D4**,**
    - Lane 1: 60.0% shifting, 0.0% significant shifting
    - Lane 2: 40.0% shifting, 0.0% significant shifting
    - Lane 5: 40.0% migrating, 20.0% significant migrating at 95% CL, 20.0% significant migrating at 90% CL
    - Lane 6: 60.0% migrating, 0.0% significant migrating, 20.0% significant migrating at 90% CL
- Among the three lane proportion change readings in D6**,**
    - Lane 1: 66.7% shifting, 0.0% significant shifting
    - Lane 2: 66.7% shifting, 0.0% significant shifting at 95% CL, 33.3% significant shifting at 90% CL
    - Lane 5: 33.3% migrating, 0.0% significant migrating

- Lane 6: 66.7% migrating, 0.0% significant migrating, 33.3% significant migrating at 90% CL
- Among the three lane proportion change readings in D7**,**
    - Lane 1: 100.0% shifting, 0.0% significant shifting, 33.3% significant shifting at 90% CL
    - Lane 2: 33.3% shifting, 0.0% significant shifting
    - Lane 5: 33.3% migrating, 0.0% significant migrating
    - Lane 6: 66.7% migrating, 33.3% significant migrating, 33.3% significant migrating at 90% CL
- Overall, among the 11 lane proportion change readings across the three districts**,**
    - Lane 1: 72.7% shifting, 0.0% significant shifting at 95% CL, 9.1% significant shifting at 90% CL
    - Lane 2: 45.5% shifting, 0.0% significant shifting at 95% CL, 9.1% significant shifting at 90% CL
    - Lane 5: 36.4% migrating, 9.1% significant migrating at 95% CL, 9.1% significant migrating at 90% CL
    - Lane 6: 63.6% migrating, 9.1% significant migrating at 95% CL, 27.3% significant migrating at 90% CL

Table 4-14: Traffic Lanes Proportion Changes for 6-Lane Freeway Segments

Left Lanes									
District	TLPCR	NSL1	% NSL1	NSSL 1	% NSSL 1	NSL2	% NSL2	NSSL 2	% NSSL2
D4	5	3	60.0	0^a, 0^b	0.0^a,0.0^b	2	40.0	0^a, 0^b	0.0^a,0.0^b
D6	3	2	66.7	0^a, 0^b	0.0^a,0.0^b	2	66.7	0^a, 1^b	0^a, 33.3^b
D7	3	3	100.0	0^a, 1^b	0.0^a, 33.3^b	1	33.3	0^a, 0^b	0.0^a,0.0^b
Total	11	8	72.7	0^a, 1^b	0.0^a, 9.1^b	5	45.5	0^a, 1^b	0^a, 9.1^b
Right Lanes									
District	TLPCR	NML5	% NML5	#NSML5	% NSML5	NML6	% NML6	NSML6	% NSML6
D4	5	2	40.0	1^a, 1^b	20.0^a, 20.0^b	3	60.00	0^a, 1^b	0.0^a, 20.0^b
D6	3	1	33.3	0^a, 0^b	0.0^a,0.0^b	2	66.67	0^a, 1^b	0^a, 33.3^b
D7	3	1	33.3	0^a, 0^b	0.0^a,0.0^b	2	66.67	1^a, 1^b	33.3^a, 33.3^b
Total	11	4	36.4	1^a, 1^b	9.1^a, 9.1^b	7	63.64	1^a, 3^b	9.1^a, 27.3^b

Note: # = Number of lane proportion change readings; a = 95% CL, and b = 90% CL; NML = Number of WWD Events Involving Moving to the Lane; NSL = Number of WWD Events Involving Shifting from the Lane; NSML = Number of WWD Events Involving Significant Moving to the Lane; NSSL = Number of WWD Events Involving Significant Shifting from the Lane; TLPCR = Total Lane Proportion Change Readings.

4.5 Other Factors Affecting Speed Changes and Lane Use

4.5.1 Speed Changes

As observed in the previous section on the effect of DMS activation on speed changes, the WWD message causes overall traffic speed to decrease during the WWD DMS activations. Other factors might also be in charge of the observed speed change patterns. The factors studied here were the roadway and temporal factors that might also be associated with the speed-changing behavior of the traffic during the WWD DMS activations. For each WWD event that caused the DMS activation, the day of the week, time of day, season of year, year, lane movements, DMS activation time, FDOT District, traffic conditions (vph), and number of lanes at the DMS's proximity were analyzed. The response variable was the segment speed changes on WWD DMS activations.

Least square and stepwise reduced linear regressions were used to analyze the significant factors affecting traffic speed changes during DMS activations. Least square linear regression is a statistical method used to model the relationship between a dependent variable (target) and one or more independent variables (predictors) (Raposo, 2016). Equation 4-7 represents a multiple linear regression with 'p' predictors.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_p X_p + \varepsilon \quad (4\text{-}7)$$

Where,

- Y = the response variable,
- Xi = a studied roadway or temporal factor (i.e., predictor),
- β_0 = the intercept,
- βi = the predictor's coefficient, and
- ε = the error term, accounting for the unexplained variability in the data.

The goal in multiple linear regression is to find the values of β_0, β_1, β_2, ..., β_p that minimize the sum of squared errors (residuals) between the observed data points and the values predicted by the regression model.

Stepwise regression is a method used to select the most relevant predictors in a multiple linear regression model. It can involve both forward and backward selection of predictors (Yamashita et al., 2007). Stepwise Selection combines forward selection and backward elimination to iteratively add or remove predictors based on their significance and their impact on the model's fit. The result is a final model that includes a subset of the original predictors that best explains the variation in the dependent variable, taking into account interactions and correlations among the predictors.

The Root Mean Square Error (RMSE) is a metric used to measure the accuracy of a predictive model, particularly in the context of regression analysis (Chai & Draxler, 2014). It quantifies the difference between the predicted values and the actual values in a dataset. Equations 4-8 and 4-9 elaborates on how RMSE is calculated.

$$\text{Residual } (\varepsilon) = \text{Actual Value - Predicted Value} \quad (4\text{-}8)$$
$$\text{RMSE} = \sqrt{(\Sigma(\varepsilon^2) / n)} \quad (4\text{-}9)$$

Where,

- ε^2 = the squared residuals, and
- n = the number of data points.

The RMSE provides a measure of the average magnitude of the errors made by the model, and it is often used to compare the performance of different regression models or to assess how well a model fits the data. Lower RMSE values indicate better model accuracy, while higher values indicate greater prediction errors.

The full model (least square) performed better, with a RMSE of 4.1 mph. Table 4-15 summarizes the results for the least square regression model. The model indicated that the increased number of lanes and the fall season (compared to the spring season) were significantly associated with lower traffic speed changes at 99% and 90% CL, respectively. None of the other factors were found to significantly affect the traffic speed change patterns during WWD DMS activations.

Table 4-15: Least Square Linear Regression Model Results

Variable	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	4.943241	1.689827	2.925	0.00373 **
D1	-0.64063	1.255004	-0.51	0.61014
D2	-1.09672	1.038756	-1.056	0.29199
D3	-0.05613	1.614965	-0.035	0.9723
D4	0.010881	1.169916	0.009	0.99259
D5	-1.13827	1.920694	-0.593	0.55392
D6	-0.91714	1.186705	-0.773	0.44028
D7	0.597139	1.02288	0.584	0.55985
DMS Activation Time	-0.01653	0.030369	-0.544	0.58673
Number of Segment Lanes	**-0.80413**	**0.288097**	**-2.791**	**0.00562 ****
Tuesday	-0.17092	1.207693	-0.142	0.88756
Wednesday	-0.29387	1.203782	-0.244	0.80732
Thursday	-0.17185	1.197996	-0.143	0.88604
Friday	0.588645	1.059633	0.556	0.57899
Saturday	0.546687	0.975276	0.561	0.57557
Sunday	-0.86065	1.014954	-0.848	0.3972
Summer	-1.20628	0.774374	-1.558	0.12045
Fall	**-1.21453**	**0.72287**	**-1.68**	**0.09407 .**
Winter	0.002398	0.87397	0.003	0.99781
2018	-0.25031	1.200517	-0.209	0.83499
2019	0.590729	0.956526	0.618	0.53737
2021	0.889053	0.842423	1.055	0.29219
2022	0.317204	0.914697	0.347	0.72902
Night	-0.94458	0.572744	-1.649	0.10025
Involved Traffic Shifts from Left Lanes/ Movements to the Right Lanes	0.566625	0.605609	0.936	0.35029
Traffic Volume	0.011010	0.0002715	0.406	0.68527

Note: **.** = significant at 90% CL, and ** = significant at 99% CL.

4.5.2 Lane Use

For lane use behavior, the same factors were studied to analyze their effect on traffic shifting from fast lanes and moving to slower lanes during DMS activations. Full and stepwise reduced binary logistic regression models were used to examine the significant factors affecting lane use behavior during WWD events followed by DMS activations. The response variable was whether traffic shifted from fast lanes or moved to slower lanes (1) or not (0).

The binary logistic regression model was employed to estimate the log odds of the dependent variable, indicating the likelihood of traffic moving out of fast lanes or moving in slow lanes during a WWD message DMS activation. The probability (p) of this event is modeled using Equation 4-10 (Tranmer & Elliot, 2008).

$$p = \Pr(Y = 1) = 1 / (1 + \exp(-Z)) \quad (4\text{-}10)$$

Where,

Y = the binary dependent variable (response variable),
Z = the linear combination of explanatory variables and their respective coefficients,

The logit transformation converts the probability (p) into the log-odds (logit) scale as shown in Equation 4-11 below:

$$\text{logit}(p) = \ln(p / (1 - p)) = \beta 0 + \beta 1 * X1 + \beta 2 * X2 + ... + \beta n * Xn \quad (4\text{-}11)$$

Where,

$\beta 0$ = the intercept of the model,
βi = coefficient of an explanatory variable, and
Xi = a studied roadway or temporal factor (explanatory variable)

The reduced model works the same as the stepwise linear regression works, selecting the most relevant predictors. Area Under the ROC Curve (AUC) value was used to check the prediction accuracy of the model. ROC is the ‘receiver operating characteristic,’ whose curve can be considered as the average sensitivity value for a test over all possible specificity values or vice versa (Mandrekar, 2010). The higher the AUC value from the value of 0.5, the better the model.

The full model performed better, with an AUC value of 0.78. Table 4-16 summarizes the binary logistic regression model results. The full binary logistic regression model indicates that compared to the FTE, D2 is less likely to have traffic shifting fast lanes and moving to slower lanes during the display of WWD messages on DMSs. The model also indicates that roadway segments with more lanes are more likely to have traffic shifting from fast lanes and moving to slower lanes during DMS activations. Finally, compared to 2020, traffic was less likely to move to slower lanes and shift from fast lanes during 2018 and 2019.

Table 4-16: Binary Logistic Regression Model Results

Variable	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	-0.0895	0.954765	-0.094	0.92532
D1	-0.80204	0.668851	-1.199	0.23047
D2	**-1.4151**	**0.557266**	**-2.539**	**0.01111***
D3	-0.90577	0.822207	-1.102	0.27062
D4	-0.62728	0.670418	-0.936	0.34946
D5	0.407562	1.257743	0.324	0.74591
D6	-1.02866	0.647778	-1.588	0.11229
D7	-0.37889	0.593389	-0.639	0.52313
DMS Activation Time	0.005664	0.016346	0.346	0.72899
Speed Change	0.030804	0.035025	0.879	0.37915
Number of Segment Lanes	**0.777189**	**0.178895**	**4.344**	**1.40E-05*****
Tuesday	0.019873	0.661529	0.03	0.97603
Wednesday	0.345307	0.739206	0.467	0.64041
Thursday	-0.53637	0.638714	-0.84	0.40104
Friday	-0.34238	0.58767	-0.583	0.56016
Saturday	-0.31211	0.553713	-0.564	0.57298
Sunday	-0.43571	0.566567	-0.769	0.44188
Summer	-0.12376	0.415346	-0.298	0.76572
Fall	-0.23505	0.385013	-0.611	0.54153
Winter	0.297828	0.495077	0.602	0.54745
2018	**-1.67879**	**0.63207**	**-2.656**	**0.00791****
2019	**-1.0876**	**0.537031**	**-2.025**	**0.04285***
2021	-0.53853	0.484549	-1.111	0.26639
2022	-0.45012	0.551431	-0.816	0.41434
Night	0.035558	0.308873	0.115	0.90835
Traffic Volume	0.09154	1.579e-04	0.580	0.56217

Note: * = significant at 95% CL, ** = significant at 99% CL, and *** = significant at 99.99% CL

4.6 Summary

This chapter focused on analyzing the effect of WWD DMS messages on traffic behavior. The analysis of traffic speed changes during DMS activations in the FDOT districts and agencies has provided valuable insights into the impact of DMS on traffic dynamics during WWD events. Across all the districts and agencies studied, there is a consistent pattern of traffic speed reductions during DMS activations in response to WWD events. Specifically, in 74.2% of the events, traffic speed decreased when WWD DMSs were activated, with 29.8% of these events showing significant speed drops at a 95% CL.

In the comprehensive analysis of traffic speed behavior across various districts and agencies, the impact of DMS activations during WWD events is evident. The data revealed that, overall, the mean traffic speed before and during DMS activation was 68.8 mph and 67.2 mph, respectively. The statistical analysis, represented by the z-statistic of the difference, yielded a value of 1.906, which is greater than the critical value of 1.645. This result indicates a significant overall speed reduction during DMS activations at a 95% CL. This suggests that DMS activations effectively influence the lowering of traffic speed during WWD events, decreasing the chances of a WWD crash.

The analysis of lane use during DMS activations in response to WWD events across different FDOT districts and agencies has also revealed some noteworthy findings. These findings indicate a range of lane use behaviors in 2-lane, 3-lane, 4-lane, 5-lane, and 6-lane freeway segments during WWD DMS activations. In most districts, more than 50% of the WWD events involved traffic moving to slower lanes and shifting from fast lanes during the DMS activations in the freeway segments. On the other hand, most of these movements between lanes were not significant.

Finally, examining other factors influencing speed changes and lane use behaviors has provided critical insights. These factors encompass both temporal and roadway-related elements, which may interact with DMS activations to influence driver behavior. The findings reveal that the WWD message displayed on DMSs leads to a noticeable reduction in overall traffic speeds during activations. Beyond the direct effect of DMS messages, other factors, such as the number of lanes and seasonal variations, also play a role in influencing speed change patterns. In this evaluation, the least square regression model emerged as a notably more accurate method to analyze the factors, with an MSE of 4.1 mph. According to the model, an increase in the number of lanes and the transition from spring to fall are associated with less significant traffic speed changes, a result significant at 95% CL. However, other factors under consideration did not demonstrate a significant influence on speed adjustments during WWD DMS activations.

Similarly, in lane use behavior during DMS activations following WWD events, various factors were examined to discern their impact on whether traffic shifted from faster lanes to slower lanes or remained unaltered. In this analysis, the full binary logistic regression model stood out as more robust, with an AUC value of 0.78, indicating a relatively strong predictive ability. The outcomes of this analysis underscore specific key factors affecting lane use behavior. Firstly, it appears that D2, as compared to FTE, is less likely to witness traffic shifting from faster lanes to slower lanes during DMS activations. Furthermore, it was found that road segments with a greater number of lanes are more prone to experience traffic lane changes during these activations, with drivers tending to shift from faster lanes to slower ones. Finally, the temporal dimension has its role, with the analysis suggesting that in comparison to 2020, traffic was less inclined to shift to slower lanes and move from faster lanes in the years 2018 and 2019. The insights gained from the analysis of factors affecting speed changes and lane use patterns during DMS activations provide valuable direction for optimizing safety and traffic management. Based on the real-world traffic analysis results, the research team recommends the following to the transportation agencies:

- **Variable Speed Limits:** Transportation agencies should implement variable speed limits on DMSs to slow down right-way traffic approaching a wrong-way driver. Reduced speeds can provide additional reaction time and enhance safety.

- **Lane Management Protocols:** Agencies should consider:
    - Developing and implementing SOPs for traffic management during WWD events.
    - Defining protocols for DMS activations, including the preferred lane shifts, and ensure these are communicated clearly to all relevant stakeholders.

    - Training law enforcement and first responders to coordinate with DMS activations effectively to guide traffic and manage WWD incidents.

- **Public Awareness Campaigns:** Agencies should launch campaigns to educate drivers about the risks of WWD and the actions they should take upon encountering DMS alerts. Public awareness can increase compliance with DMS instructions.

- **Comprehensive Data Gathering:** Transportation agencies should establish a robust data collection system that tracks both environmental factors and temporal factors during WWD events and DMS activations. This comprehensive data could help facilitate a more precise understanding of traffic behavior.

- **Data Analysis and Continuous Improvement:** Transportation agencies should analyze DMS activation data to assess the effectiveness of alerting right-way drivers about wrong-way incidents. This data could be used to make ongoing improvements in the effectiveness of DMS in responding to WWD.

- **Comprehensible DMS Messages:** Responsible agencies should ensure that DMS messages are succinct, clear, and utilize universally recognized symbols and colors to alert right-way drivers to the presence of a wrong-way driver. Unambiguous wording should be emphasized.

- **Integration with GPS and Navigation Apps:** Transportation agencies should collaborate with GPS and navigation app providers to incorporate DMS alerts into their systems. When a driver's navigation app detects a potential wrong-way entry, it can provide immediate guidance and alert the wrong-way driver. If the vehicle continues in the wrong direction, the upstream DMS reinforces the WWD alert to be activated with warning messages to the right-way drivers.

- **Regular Testing and Maintenance:** Agencies should conduct routine testing and maintenance of DMS systems to ensure their reliability during critical situations. Testing DMS functionality would ensure that they operate effectively.

- **Continuous Research:** Transportation agencies should continue to investigate and analyze factors influencing speed changes and lane use, incorporating additional variables and dimensions. Regular research updates will provide a continually evolving understanding of driver behavior during WWD events and DMS activations.

CHAPTER 5
HUMAN FACTORS ANALYSIS

This chapter assessed right-way drivers' comprehension of WWD-related DMS messages in a driving simulator setting. The research team conducted a driving simulator study to evaluate how quickly and effectively diverse drivers in Florida understood these messages. A set of potential messages, message formats, and scenarios were developed in accordance with human factors guidelines and best practices. These messages were then presented to participants representing younger, middle-aged, and older drivers. Participants' feedback was aimed to refine and enhance the messages to ensure optimal comprehension. Since the analysis involved human participants, it was reviewed by the Institutional Review Board (IRB). The IRB reviewed and approved all the required documents, such as the necessary Collaborative Institutional Training Initiative (CITI) training certificates, prepared consent forms, flyers, and survey questionnaires for participants. CITI trainings were taken to ensure the researchers were aware of the responsible conduct of research, especially when dealing with human participants. The documents are included at the end of this report as appendices (Appendices C-G). The following sections elaborate on the participant selection, the experiment's scenario matrix design, the simulation task, analysis, results, conclusions, and recommendations.

5.1 Participants

A total of 50 participants possessing valid US driver's licenses participated in the driving simulation experiment. The selected participants' ages ranged from 18 to over 65 years. A diverse pool of subjects with varying ages, genders, educational backgrounds, and driving experiences were recruited. Flyers (Appendix C) and personal contacts were used to reach out to the potential participants for recruitment. Flyers were distributed at FIU campuses and several shopping malls in Miami-Dade County. Each participant was also asked to provide the contacts of consented nearby relatives or friends who would be willing to participate in the driving simulation experiment.

Participants voluntarily engaged in the simulator scenarios, retaining the freedom to withdraw from the simulation or the study at any point and for any reason. An incentive of $50 Amazon gift card was given to participants at the end of their driving simulation participation. The incentive was to be given whether or not the participant was able to finish the driving simulation experiment.

Since age and gender are two variables possibly affecting WWD incidents that could be controlled during recruitment, a balanced participant pool regarding age and gender was preferred. The distribution of participant ages and genders is presented in Table 5-1. One male participant aged over 65 years got simulator sick after participating in two scenarios and could not finish the experiment. Therefore, data from 49 participants was used for analysis.

Table 5-1: Participants' Age and Gender Distribution

Age Group	Gender	
	Male	Female
Between 18 and 34	8	8
Between 35 and 64	8	8
65+	10	8
Total	26	24

5.2 Demographic Questionnaire

The driver's demographic data were collected through written questionnaires at the beginning of the driving simulation experiment. Appendix D shows the demographic questionnaire used for this study. The following demographic information was collected:

- City of residence
- Gender
- Age
- Ethnicity
- Level of education
- Years of driving in the US
- How far do they drive in a year
- Individual Income range
- Experience with WWD

Most participants did not fill out their ethnicities in the questionnaire. Also, most participants were Miami residents. Hence, these two demographic variables were not considered further in the data analysis. As can be inferred from Table 5-1, age and gender were distributed equivalently between participants. Figure 5-1 shows the participant distribution for demographic questions other than gender and age.

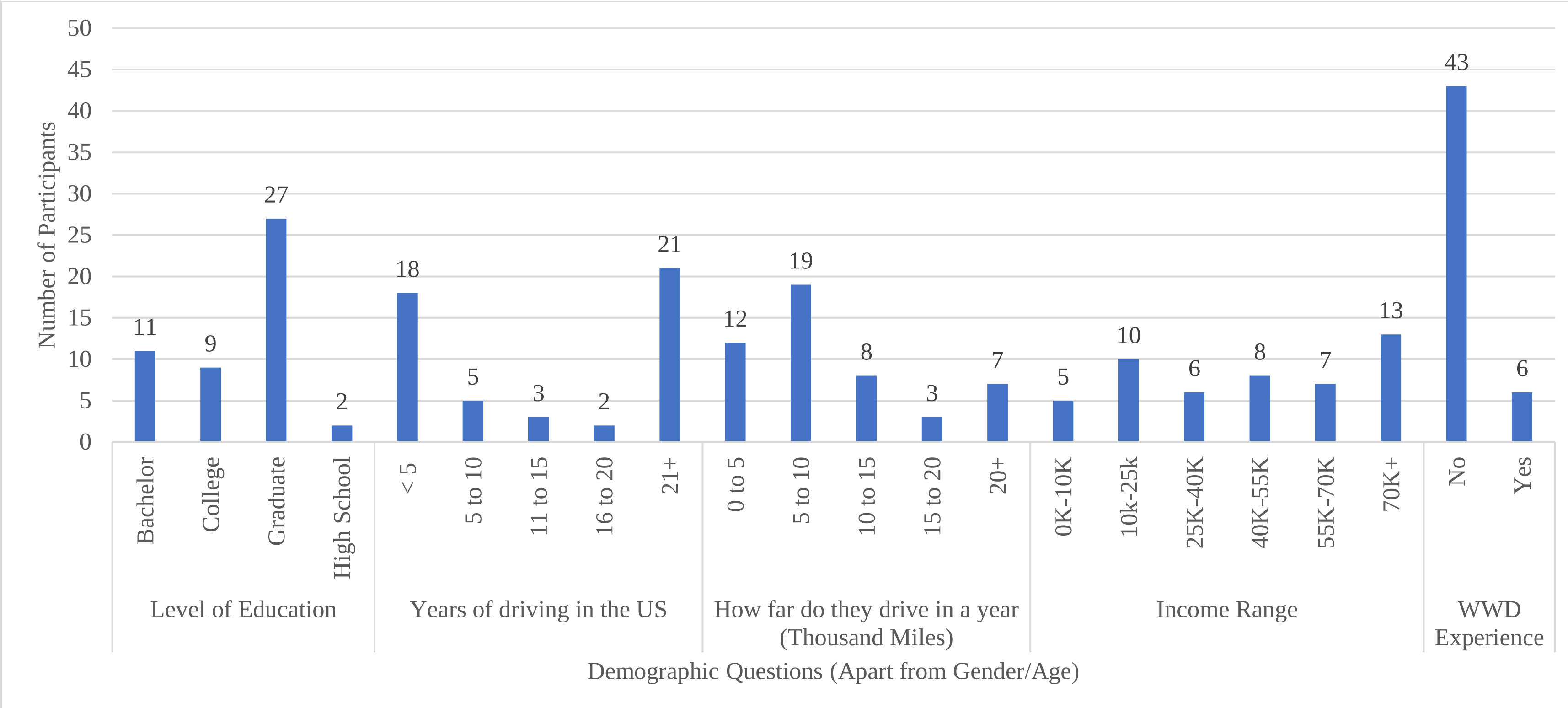

Figure 5-1: Participant Distribution for Demographic Questions Other than Gender and Age

5.3 Driving Simulation

In addition to the human attributes collected through demographics, other roadway and environmental factors influencing the response to WWD-related DMS activation were examined through driving simulation. The driving simulation experiment was used to evaluate the effectiveness of WWD-related DMS in drivers' comprehension and response. This experiment analyzed speed reduction, lane changes, WWD crash avoidance, and time to collision (TTC) linked to the WWD-related DMS as the response variables. Speed reduction, TTC, WWD crash avoidance, and lane use were the performance metrics used to measure the effectiveness of different WWD message designs in drivers' comprehension and response. The driving simulation experiment involved demographic data collected from participants through questionnaires and data derived from the designed driving simulation scenarios. The parameters that were to be derived from the driving simulation encompassed the following:

- One (1) two-level factor based on traffic levels divided into *no traffic* and *normal traffic*, which is 0.25 to 0.5 of the freeway capacity. A WWD event is expected to occur when traffic conditions are light to non-existent.
- One (1) three-level factor on visibility consisting of three categories: "day," "fog," and "night" conditions. Daytime was used as a base category in the analysis. From an initial review of SunGuide™ WWD event data, most WWD incidents were found to occur at night; hence, night visibility conditions are essential for this analysis. Since adverse weather conditions are also major causes of crashes (Wang et al., 2021), fog was used to simulate adverse weather that reduces roadway visibility.
- One (1) three-level factor contingent on the number of lanes of the simulated freeway segments (3, 4, and 5). The number of lanes defines how wide the roadway is, which could affect how drivers respond to WWD incidents.
- One (1) four-level factor describing the designed WWD-related DMS to be examined. Figures 5-2 and 5-3 depict the simulated WWD message designs currently used by the FDOT. The four WWD-related DMS messages to be studied are;

1. **WRONG WAY DRIVER REPORTED USE CAUTION**

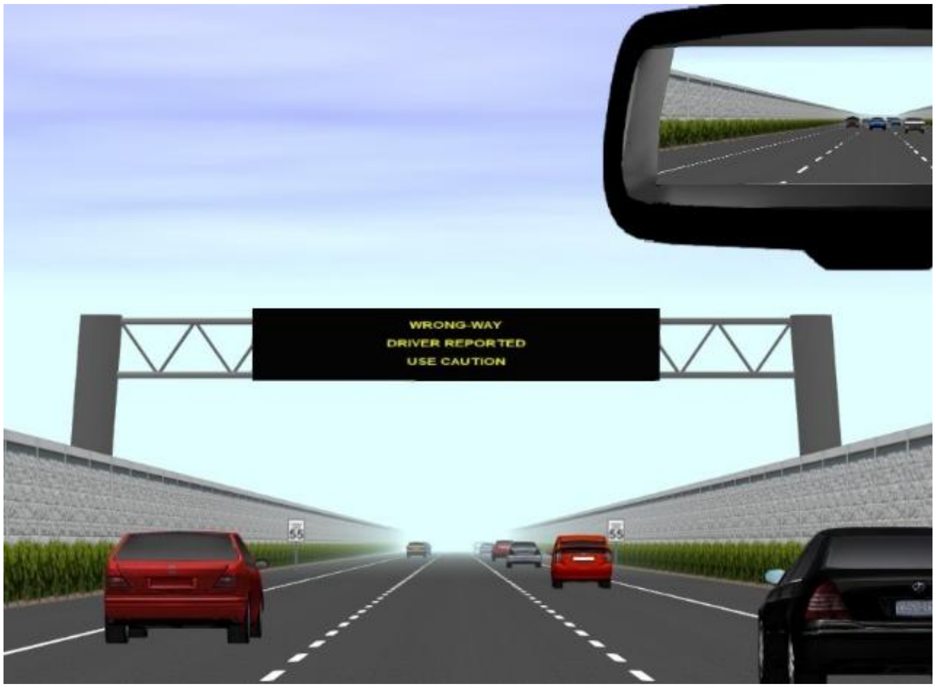

Figure 5-2: WWD Reported Use Caution DMS

2. **WRONG WAY DRIVER REPORTED USE EXTREME CAUTION**

Figure 5-3: WWD Reported Use Extreme Caution DMS

3. **Blinking WWD Message**

The blinking WWD message is the "WWD Reported-Use Caution" message (as in Figure 4-1) blinking at a rate of 0.5 seconds. The DMS displays the "WWD Reported Use Caution" message for half a second, then goes blank for another half-second, and then the cycle repeats. This blinking rate is at the standard rate of a flashing beacon flashing at a rate of 60 times per minute.

4. Two-Phase (1-WWD Reported, 2-Reduce Speed to 45 MPH) WWD Message

The two-phase message involves a cycle of the "WWD Reported" message being displayed for 2.5 seconds followed by the "Reduce Speed to 45 MPH" message being displayed for another 2.5 seconds before returning to the first message ("WWD Reported") and continuing the cycle.

5.3.1 Design of Experiment

When a study incorporates a mix of factors with varying levels to be analyzed, the driving simulation experiment may result in an extensive number of runs/scenarios. The standard number of runs for a full factorial driving simulation experimental design required to analyze all cases would be 72 scenarios. The scenarios to be studied are formed from a combination of 4 x 3 x 3 x 2 factors that have been discussed earlier in this section. Each scenario takes about 2.5 minutes, which would require each participant to undergo about three hours of the full driving simulation experiment, excluding any break time. The primary issue associated with full factorial designs lies in the extensive time required to complete the experiment. Lengthy driving simulations would potentially cause participants to endure prolonged exposure and motion sickness.

To save time while preserving the reliability of data analysis, this study employed a generalized complete block design to structure 48 participants into four blocks. Each block contained 18 distinct driving simulation scenarios. Age and gender served as the primary blocking variables. The two demographics could significantly impact WWD incident occurrences and could be directly controlled during participant recruitment. Blocking factors/variables are variables used to group experimental units (in this case, participants) into homogenous blocks. The goal is to control for variability due to these factors so their influence is isolated, allowing a more accurate assessment of the treatment effects. Instead of 72 scenarios, each participant had to undertake 18 scenarios (in one block) of driving simulation. The driving simulation experiment took about two hours and 15 minutes for each participant, including breaks. This design enhances the validity of the findings by minimizing variability related to these demographic factors while reducing the time required in simulation per participant. Participants were categorized into three age groups (Young, Middle-aged, and Old) and two gender categories (Male and Female), creating six distinct demographic groups:

- **Group 1:** Young Males (18-34 years)
- **Group 2:** Middle-aged Males (35-64 years)
- **Group 3:** Old-aged Males (65+ years)
- **Group 4:** Young Females (18-34 years)
- **Group 5:** Middle-aged Females (35-64 years)
- **Group 6:** Old-aged Females (65+ years)

Each block included two participants in each of the six demographic groups, making up to 12 participants per block and 48 balanced participants in the four blocks. With a total of 50 participants, the extra two individuals were randomly assigned to two of the blocks, introducing slight variability across blocks without compromising demographic balance.

5.3.2 Driving Simulation Scenario Development

This study used the STISIM Drive® driving simulator to collect and analyze human factors associated with the comprehension of WWD-related DMS activations on the designed freeway segments. The driving simulator uses a scenario definition language (SDL) to customize scenarios as required. Firstly, the three-mile-long freeway segment operating at 55 mph was developed. The freeway segment was then divided into three one-mile segments. This division aimed to capture driver's responses and behavioral changes with different DMS messages. The first one-mile segment was designed without any DMS or warning signs. The second one-mile segment consists of an advisory DMS at its beginning, displaying various messages such as "Buckle Up," which do not call for driver's action. At the start of the last one-mile segment, a DMS that warns drivers of the potential wrong-way driver coming their way was incorporated.

Different visibility conditions, traffic, and roadway characteristics were programmed in the SDL to simulate the WWD scenarios on the designed freeway segments. Visibility conditions included the presence of day, fog, or night conditions. Traffic levels ranging from 0 to 0.5 of the freeway capacity (about 2200 vphpl) were developed to simulate the traffic conditions open enough for a potential WWD driver to make a mistake about the traffic direction. Traffic level was analyzed into two categories: No traffic and 0.25-0.5 freeway capacity traffic (around 12-25 vpmpl). In an initial review of SunGuide™ WWD event data, it was observed that most of the WWD incidents happen at midnight when there is very little to no traffic. Nevertheless, there were a few times when the WWD events occurred during normal day non-peak hour conditions. Also, adverse conditions such as fog are expected to reduce visibility on roadways. Therefore, evaluating how different traffic levels and visibility in freeways affect driver's behavior is crucial.

Freeway segments with three, four, and five lanes in a single approach were generated to observe the effect of roadway geometry on the driver's response during WWD incidents. As described in this section (4), different sets of DMS were analyzed to see their comprehensibility and effect on the driver's response. Figure 5-4 presents a simulated 3-lane freeway segment under normal traffic conditions during fog and night conditions.

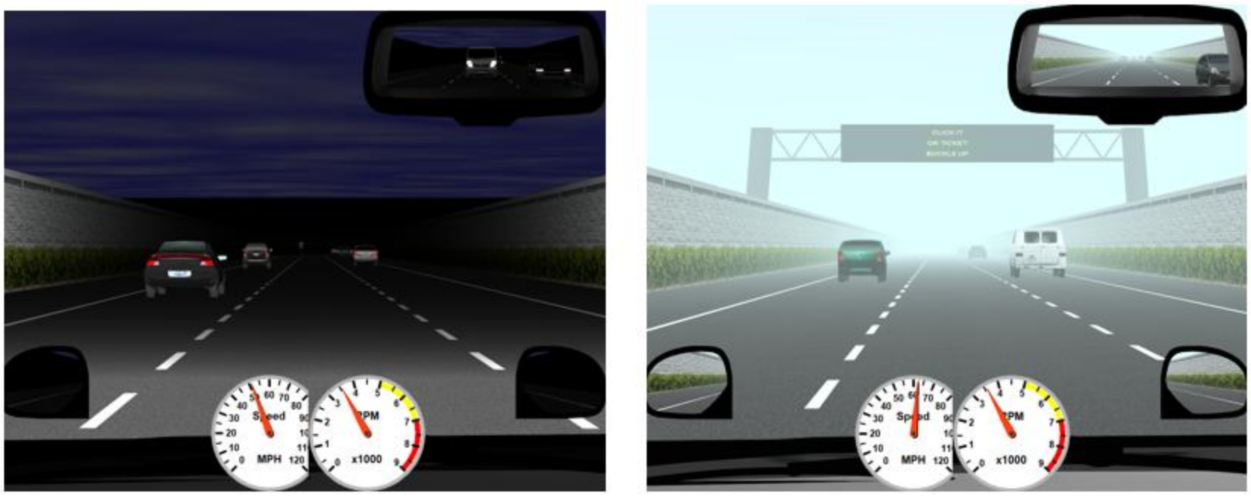

Figure 5-4: Simulated Freeway Segments with Normal Traffic at Night (Left) and under Fog (Right) Conditions

The scenarios were developed to include at least one WWD vehicle per scenario to assess the effect of the WWD-related DMS activation on crash avoidance and safety improvements. The WWD vehicle was programmed as a non-intelligent vehicle that appears at different distances ranging from 1,000 to 5,000 ft after the WWD-related DMS or the general non-warning DMS sign. The non-intelligent WWD vehicle was programmed to come in the driver's lane and not avoid crashing the driver's vehicle in the experiment. Figure 5-5 shows a WWD vehicle encounter at night. The presence effect of WWD-related DMS on the driver's safety maneuver was evaluated. The different WWD message designs were analyzed to check if they had different impacts. The impacts were measured based on how the WWD-related DMS enhanced the driver's ability to slow down, avoid a potential WWD vehicle, and maximize the TTC.

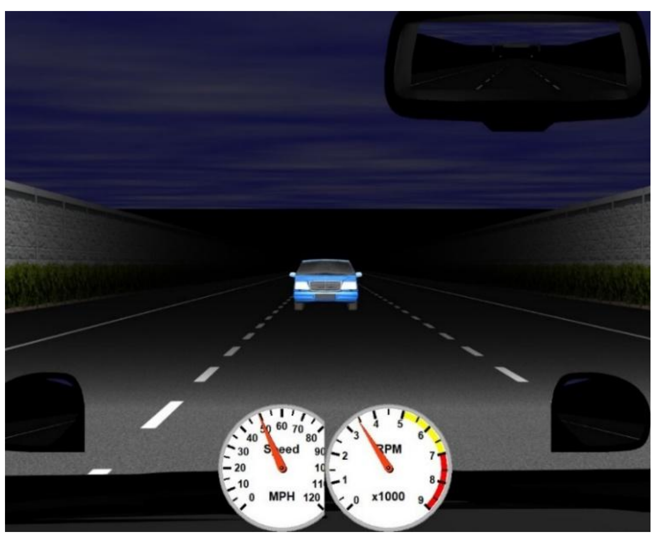

Figure 5-5: WWD Vehicle In the Driver's Lane at Night

Various random dummy scenarios, which differ from the experimental driving simulation scenarios, were randomly assigned to all participants. The dummy scenarios were deployed to minimize the carryover effect. This effect occurs when a participant's responses in one scenario are influenced by their experiences or knowledge gained in previous scenarios (Cnops et al., 2022). For example, some dummy scenarios did not include WWD vehicles at all or had different DMS arrangements or a combination of both. The data collected in these dummy scenarios were not used for analysis. The driver's speed and lane positions were collected after every 0.1 s in every scenario. TTC with the opposing vehicles (WWD) was also collected at every instance that a WWD vehicle was encountered. These data were collected to observe the effect of WWD-related DMS in safety improvement by speed reductions, safe lane changes, shorter TTC, and WWD crash avoidance.

5.4 General Statistical Analysis and Results

The comparisons of the performance metrics cater to the study's objective, which is to examine the impact of different WWD message designs on drivers' comprehension and response. As briefly discussed in Section 4, the performance measures analyzed in the driving simulation experiment were speed reduction, TTC, WWD crash avoidance, and lane use. Speed reduction in different WWD message designs and regular messages (not requiring driver's action) was evaluated to see drivers' speed change patterns in the presence of the different DMSs. TTC in different DMS designs was examined to better understand the safety implications of each DMS design. WWD crash avoidance in the presence of WWD alerts and without the alerts was analyzed to see whether the probability of avoiding a potential WWD crash increases or changes with WWD-related DMS. Finally, lane changes potentially caused by WWD-related DMS design were analyzed.

5.4.1 Speed Reduction and TTC

The mean drivers' speed reduction was compared for the four WWD message designs and the advisory non-warning DMS with messages that do not require actions from participants. The five DMS types result in ten mean speed reduction combinations to be compared. Equation 5-1 displays the combination formula used.

$$\mathrm{C}(\mathrm{n},\mathrm{k}) = \frac{n!}{k!(n-k)!} \qquad (5\text{-}1)$$

where,

$\mathrm{C}(\mathrm{n},\mathrm{k})$	=	number of ways to choose *k* elements from a set of *n* distinct elements without regard to the order,
n!	=	the product of all positive integers up to n (5),
k!	=	the factorial of k (2), and
(n−k)!	=	the factorial of n−k (4).

TTC was collected in each WWD encounter. A WWD vehicle was programmed to occur either in the designed freeway segment's second mile with a "buckle up" (or, similar) DMS or the third mile with a WWD-related DMS. Within the second mile, the WWD occurrence is random, meaning there are scenarios with and without the WWD vehicle in the second mile. Within the third mile, the WWD occurrence is definitive. As for speed reduction, the mean TTC values for the four WWD-DMS designs and the advisory DMS were compared. Using the same combination formula, a total of ten TTC combinations were compared. Table 5-2 summarizes these ten combinations for speed reduction and TTC comparisons.

Table 5-2: Speed Reduction Pairs Compared

Combination	Mean Speed Reduction 1/TTC 1	Mean Speed Reduction 2/ TTC 2
1	WWD Reported-Use Caution	WWD Reported-Use Extreme Caution
2	WWD Reported-Use Caution	Blinking
3	WWD Reported-Use Caution	Two-Phase
4	WWD Reported-Use Caution	Buckle Up/Non-Warning
5	WWD Reported-Use Extreme Caution	Blinking
6	WWD Reported-Use Extreme Caution	Two-Phase
7	WWD Reported-Use Extreme Caution	Buckle Up/Non-Warning
8	Blinking	Two-Phase
9	Blinking	Buckle Up/Non-Warning
10	Two-Phase	Buckle Up/Non-Warning

Equation 5-2 illustrates the statistical test of the mean differences in drivers' speeds and TTC.

$$Z_\alpha = \frac{\mu_2 - \mu_1}{\sqrt{\frac{S_1{}^2}{n_1} + \frac{S_2{}^2}{n_2}}} \qquad (5\text{-}2)$$

where,

Z_α = critical value of the normal distribution evaluated at 95% CL,

μ = drivers' mean speed reduction or TTC in the combinations to be compared,

S = drivers' speed reduction or TTC standard deviations in the combinations to be compared and

n_1 and n_2 = the number of drivers' speed reduction or TTC data points collected from the simulation experiment in the two compared scenarios.

The null hypothesis, alternative hypothesis, and the z-statistic used for mean speed reduction or TTC comparisons are illustrated below:

- Null hypothesis (H_o): the difference in the means of speed reduction or TTC in a combined pair is zero (i.e., H_o: $\mu_2 = \mu_1$).
- Alternative hypothesis (H_a): one of the average speed reductions or TTCs in a combined pair is greater than the other at a 95% CL(i.e., H_a: $\mu_2 > \mu_1$).
- The z-statistic value greater than 1.645 indicates a statistically significant difference in speed reductions or TTC within the compared combined pair.

5.4.1.1 Speed Reduction

On average, participants drove at about 58 mph on a 55 mph simulated freeway. Table 5-3 summarizes the mean speed reductions for the DMSs studied. Two-phased WWD-related DMS showed the highest speed reduction among all other DMSs. For the advisory non-warning DMSs, which appear within the second segment (mile), drivers seemed to increase their speed a little bit instead of reducing it. The speed increase in the second mile might be due to the comfortability drivers get as time passes in the scenarios.

Table 5-3: Speed Changes Influenced by DMS

DMS Message Format	Mean Speed Reduction (mph)	Standard Deviation (mph)	Number of Scenarios
Non-Warning DMS (NWD)	-1.3	5.13	882
WWD Reported-Use Caution (UC)	3.6	6.17	219
WWD Reported-Use Extreme Caution (UEC)	4.0	6.08	222
Blinking	4.9	6.16	220
Two-Phase	10.1	6.08	221

Table 5-4 summarizes the comparisons in speed reductions between the DMSs. UC WWD-related DMS had the lowest speed reduction among the WWD-related DMSs. Since UC DMS influences significant speed reduction compared to NWDs, all WWD-related DMSs perform better in causing speed reductions than the NWDs at 95% CL. UEC, compared to UC DMS, did not show significant differences in speed reductions at 95% CL. Blinking WWD-related DMS had a relatively higher speed reduction compared to UEC (90% CL) and UC (95% CL). The two-phased DMS had significantly higher speed reductions compared to all other DMSs at 95% CL, which showed that it was the most effective in drivers' comprehension and compliance.

Table 5-4: Speed Reduction Effect Comparisons among DMSs

Comparison Pair	Z-Values	Significance at 95% CL
UC vs. NWD	10.8847	Significant
UEC vs. UC	0.63556	Non-Significant
Blinking vs. UEC	1.62645	Non-Significant (Significant at 90% CL)
Blinking vs. UC	2.23856	Significant
Two Phase vs. Blinking	8.83804	Significant

5.4.1.2 TTC

TTC was also compared in all segments that encountered a WWD. As a surrogate safety measure, shorter TTC indicates higher crash risks (Teng et al., 2024). The differences in TTC between the DMSs were relatively minor (fractions of a second). Table 5-5 summarizes the mean TTC values for different DMS messaging formats. Following the UEC DMS, NWDs had the lowest TTC values, indicating that the lack of warning increased the WWD crash risk.

Table 5-5: TTC linked to DMS Message Formats

DMS Format	Mean TTC (secs)	Standard Deviation (secs)	Number of Scenarios
NWD	1.03	0.63	567
UC	1.35	0.67	219
UEC	1.30	0.71	222
Blinking	1.32	0.62	220
Two-Phase	1.34	0.59	221

Table 5-6 summarizes the statistical comparison among TTC values from different DMS message formats. The z-test compared mean TTC values with the smallest and largest differences so that if one checks as significant/non-significant, all are significant/non-significant. Since UEC DMS showed statistically significantly longer TTC than NWDs, all WWD-related DMSs significantly improved TTC. Also, all the WWD-related DMSs had relatively similar TTC values, indicating indifferent TTC improvements among different WWD messages in DMSs.

Table 5-6: TTC comparisons among DMS Message Formats

Comparison Pair	Z-Values	Significance at 95% CL
UEC vs. NWD	4.92393	Significant
UC vs. UEC	0.74256	Non-Significant

5.4.2 WWD Crashes and Lane Use

The 49 participants experienced a total of 92 WWD crashes. Although freeway segments with NWDs had fewer simulated WWD movements, more WWD crashes occurred within those segments. Table 5-7 summarizes the frequency of WWD crashes in segments with and without WWD alerts. Participants rarely changed lanes after seeing the WWD alerts on the DMSs. Most lane changes involved avoiding an oncoming WWD vehicle and were not influenced by the WWD alerts on the DMSs.

Table 5-7: WWD Crashes

WWD	WWD-Related DMSs Segments	Non-Warning DMSs Segments
Total number of simulated WWD movements	882	567
WWD Crashes	33	59
% WWD Crashes (WWD Crash Proportion)	3.7%	10.4%

5.4.2.1 WWD Crash Proportion Comparison

Z-statistics was used to examine the significance of WWD crash avoidance in WWD-related DMS. The proportions were obtained from the ratio of the data points involving WWD crashes to the total data points with simulated WWD movements in the scenarios. Equations 5-3 and 5-4 illustrate the significance test of WWD crash proportions.

$$Z_\alpha = \frac{P_2 - P_1}{\sqrt{P(1-P)\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}} \tag{5-3}$$

$$P = \frac{X_1 + X_2}{n_1 + n_2} \tag{5-4}$$

where,

Z_α = critical value of the normal distribution evaluated at 95% CL,

P_2 = WWD crash proportion in segments with NWD,

P_1 = WWD crash proportion in segments with WWD-related DMS,

n_2 = the total number of simulated WWD movements in segments with NWD,

n_1 = the total number of simulated WWD movements in segments with WWD-related DMS,

X_2 = number of WWD crashes in segments with NWD, and

X_1 = number of WWD crashes in segments with WWD-related DMS.

The null hypothesis, alternative hypothesis, and the z-statistic used for WWD crash proportion comparisons are illustrated below:

- Null hypothesis (H_o): the difference in WWD crash proportions between segments with NWD and WWD-related DMS is zero (i.e., H_o: $P_2 = P_1$).
- Alternative hypothesis (H_a): WWD crash proportion in segments with NWD is higher than in those with WWD-related DMS at a 95% CL (i.e., H_a: $P_2 > P_1$).
- The z-statistics value greater than 1.645 indicates a significant reduction in WWD crashes by the WWD-related DMSs.

As shown in Table 5-6, the proportion of WWD crashes in roadway segments with WWD alerts was 3.7%, which was lower than 10.4% in segments without WWD warnings. The statistical analysis yields a z value of 388.845 (> 1.645), indicating a significant reduction in WWD crashes when WWD-related DMSs are displayed. This shows that WWD alerts on DMS improve safety.

5.5 Modeling

Drivers' comprehension and response during WWD incidents could additionally be influenced by other factors apart from the WWD-related DMS. Hence, it is crucial to analyze whether other roadway and environmental factors had an impact on how drivers responded to the DMSs. Models that predict other factors (apart from the DMSs) affecting speed reductions and TTC (response variables) were generated. Originally, lane use behavior and WWD crash avoidance were also to be analyzed as response variables in the models. Since only a few lane changes occurred in the simulation, there was no need to further examine the lane use behavior on WWD-related DMS through models. Also, from the initial statistical analysis, WWD-related DMS has been proven to reduce the proportion of WWD crashes significantly, leaving the data with only 33 WWD crashes. Modeling in such a high imbalance (crash versus non-crash) was not deemed suitable. That leaves speed reductions and TTC as the response variables to obtain a deeper understanding through modeling.

Mixed effect linear regression (MELR) and decision tree ensemble (DTE) models were used to analyze the factors that significantly influence speed reductions and TTC. MELR was selected due to the nature of the driving simulation data involved in this study. For the 49 participants, modeling involved 882 data points, with each participant involved in multiple (18) scenarios (data points). Since each participant consisted of multiple data points, a variation between one participant and another is a concern since it could have an impact on the response variable analyzed. To account for a variation between one participant and another, a random effect was introduced through mixed-effect modeling. On the other hand, the DTE model is used in comparison with the MELR since it is one of the machine-learning models suitable for dealing with small sample-size datasets (Treboux et al., 2018).

5.5.1 Mixed Effect Linear Regression (MELR)

The mixed-effects linear regression model was selected for its ability to model both fixed effects (predictors that apply across all participants) and random effects (accounting for the participant-specific variability). Specifically, the model accounts for repeated measures within each participant by including a random intercept for each participant. The mixed-effects model is expressed using Equation 5-5:

$$Y_{ij} = \beta_0 + \beta_1 X_{1ij} + \beta_1 X_{1ij} + \cdots + \beta_k X_{kij} + u_j + \epsilon_{ij} \qquad (5\text{-}5)$$

where,

- Y_{ij} = the response variable (speed reduction/TTC) for the i-th observation of the j-th participant,
- β_0 = the overall intercept, representing the baseline speed reduction/TTC,
- β_k = the fixed effect coefficient for the k-th predictor variable, indicating the average effect of each predictor on speed reduction/TTC,
- X_{kij} = the k-th predictor variable for the i-th observation of the j-th participant,
- u_j = the random effect for the j-th participant, which captures the deviation from the overall intercept due to individual differences; it is assumed to be normally distributed with mean 0 and variance σ_u^2, and
- ϵ_{ij} = the residual error term for the i-th observation of the j-th participant, assumed to follow a normal distribution with mean 0 and variance σ_ϵ^2.

The mixed-effects model was fitted using the **lme4** package in **R**, which allows for the specification of complex random effects structures. The **lmer** function was used to fit the model with speed reduction/TTC as the response variable, 12 fixed-effect predictors, and a random intercept for each participant to account for within-participant correlation. The fixed effects coefficients (β_k) represent the average effect of each predictor on speed reduction or TTC. For example, the coefficient for male gender represents the speed reduction or TTC relative to the reference category of the gender variable (female), holding other factors constant. For example, if the coefficient is negative, it means that compared to females, males are less likely to have higher speed reductions/TTC on WWD-related DMS. The random intercepts (u_j) capture individual differences in speed reduction/TTC not explained by the fixed predictors. By including a random effect for participant number, the model allows each participant to have a unique baseline speed reduction, accounting for unobserved heterogeneity among participants. The MELR model was checked to avoid correlation in the explanatory variables.

5.5.2 Decision Tree Ensemble (DTE)

DTE combines multiple decision trees to improve predictive accuracy and reduce overfitting (Lee et al., 2020). Each tree in the forest is trained on a random sample of the data (bootstrapping) and a random subset of the features (feature subsampling). The equations for DTE involve combining the predictions from individual trees. For regression tasks (continuous responses), the ensemble prediction for multiple explanatory variables (vector X) is presented by Equation 5-6. The predicted value is an average of the values predicted in all trees used in the ensemble.

$$y\hat{}DTE\ (X) = \frac{1}{B}\sum_{b=1}^{B} y\hat{}b\ (X) \qquad (5\text{-}6)$$

where,

y^DTE (X)	=	predicted value of the response variable,
B	=	the number of trees in the ensemble, and
y^b (X)	=	the prediction of the b-th tree for the input vector X.

The same predictors and response variables analyzed in MELR were modeled in DTE. DTE uses variable importance to rank the predictors from the most to the least important in predicting the response. The partial dependence plots checked the patterns of how each predictor affected the response.

5.5.3 Root Mean Square Error (RMSE)

The Root Mean Square Error (RMSE) provides a measure of the average magnitude of the errors made by the model, and it is used in this study to compare the performance of MELR and DTE models by assessing how well their predictions meet the true values. Lower RMSE values indicate better model accuracy, while higher values indicate greater prediction errors. RMSE quantifies the difference between the predicted values and the actual values in a dataset. Equations 5-7 and 5-8 elaborate on how RMSE is calculated. To ensure reliability, RMSE was calculated in data sets that were not used for training the model.

Residual (ε) = Actual Value - Predicted Value (5-7)

$$RMSE = \sqrt{\sum(\varepsilon)^{2}/n} \qquad (5\text{-}8)$$

where,

ε^2	=	the squared residuals for each analyzed data point,
n	=	the number of analyzed data points, and
RMSE	=	Root Mean Square Error.

5.5.4 Cross Validation (CV)

To ensure more reliability in the models, a 4-fold cross validation (CV) was used to separate the data in four sets, three sets were used for training and one was used for testing. The 4-fold cross-validation approach selects the portion of the dataset used for training and testing four times. The test set was different each time in this selection. All the model's validation parameters were analyzed four times, and the consistency in the reliability of the model was checked. In each model run, one data set was the test set, while the other three equal-sized data sets were the training sets. For the purpose of this study, four different sets of 12 participants were used for testing, while the remaining were used for training in each of the four folds. The 12 participants in each fold were carefully selected to balance gender and age distribution. The four-fold cross-validation is preferred to allow enough data to be used for training and testing purposes (Pal & Patel, 2020). The validation fold represents the test set, while the training represents the training set.

5.6 Modeling Results

MELR performed better than DTE for both speed reduction and TTC modeling with an average RMSE of 2.462 for speed reduction and 0.447 for TTC, compared to 3.118 and 0.701 for DTE in speed reduction and TTC, respectively. Table 5-8 summarizes the speed reduction results for MELR. As indicated in the modeling section (Section 6), the model included a random intercept for each participant to account for individual differences in baseline responses.

Table 5-8: MELR Model Results for Speed Reduction

Effect	Variable	Category	β	Std.Error	t-value	p-value
Fixed Effects	Intercept		-18.0664	3.228418	-5.59605	0
	Age	18-34[b]				
		35-64	1.181334	1.827372	0.646466	0.5239
		65+	1.497165	2.17924	0.687012	0.4984
	Gender	Female[b]				
		Male	-2.66335	1.373257	-1.93944	0.0638
	Income	0k-10k[b]				
		10k-25k	-3.24302	2.079118	-1.55981	0.1314
		25K to 40K	-1.55039	2.704153	-0.57334	0.5715
		40K-55K	-1.92183	2.544874	-0.75518	0.4572
		55K to 70K	-0.07309	2.749782	-0.02658	0.979
		70K+	-1.33932	2.287279	-0.58555	0.5634
	WWD Experience	No[b]				
		Yes	2.857222	1.645766	1.736105	0.0829
	WWD-Related DMS	UC[b]				
		Two-Phase	6.825633	0.47031	14.51305	0
		Blinking	1.194288	0.472766	2.52617	0.0117
		UEC	0.69103	0.474244	1.45712	0.1455
	Visibility	Day[b]				
		Fog	0.092303	0.475792	0.193999	0.8462
		Night	0.117765	0.408889	0.288011	0.7734
	Number of Lanes	3[b]				
		4	-0.09253	0.40227	-0.23002	0.8181
		5	0.512676	0.423296	1.211152	0.2262
	Traffic Level	No Traffic[b]				
		Normal Traffic	-1.17772	0.334543	-3.52039	0.0005

Table 5-9, Continued: MELR Model Results for Speed Reduction

Effect	Variable	Category	β	Std.Error	t-value	p-value
	Initial Speed	continuous	0.434362	0.035836	12.12083	0
	Lane Change Maneuver	None				
		Left	-1.03679	1.540081	-0.67321	0.501
		Right	0.970651	0.590057	1.645012	0.1004
	Driving Experience (Years)	< 5				
		5-10	-0.77829	2.099337	-0.37073	0.714
		11-15	3.311086	2.913896	1.136309	0.2666
		16-20	-0.42703	3.622451	-0.11789	0.9071
		>21	0.720171	1.996085	0.360792	0.7213
	Annual Mileage	< 5,000				
		5,000 – 10,000	-3.15722	1.679274	-1.88011	0.0718
		10,000 – 15,000	-1.78451	2.193708	-0.81347	0.0636
		15,000 – 20,000	-6.00189	3.00163	-1.99954	0.0565
		> 20,000	-5.7542	2.882797	-1.99605	0.0569
	Variable	**Category**	**Std Deviation**	**Residual**		
Random Effect	Participant #	(1-49)	3.101878	2.578196		

Note: b is the base category.

The random effect for "Participant" had a standard deviation of 3.10, indicating moderate variability in baseline speed reduction across individuals. This variability captures unobserved heterogeneity among participants, such as differences in driving habits or sensitivity to DMS warnings, which may not be directly measured by the fixed effects. The residual standard deviation of 2.58 suggests additional variability in speed reduction that is not explained by the model, likely due to other unaccounted factors or random fluctuations in driver response. Three factors (fixed): WWD-Related DMS type, traffic conditions, and the average speed of drivers had p-values less than or equal to 0.05, indicating a statistically significant effect with 95% confidence (95% CL). **The Two-phase DMS**, displaying "Wrong-Way Driver Reported, Reduce Speed to 45 MPH," showed a substantial positive effect on speed reduction (coefficient estimate, $\beta = 6.83$, $p < 0.001$) relative to the base "Use Caution" message. This suggests that specifying a speed limit may enhance compliance, potentially because it provides a clear and actionable directive for drivers. Specific speed reduction messages can be more effective at influencing driver behavior in high-risk situations, as drivers might respond better to precise instructions over vague warnings.

The blinking "Use Caution" message, set to flash at 60 times per minute, also had a significant positive effect on speed reduction ($\beta = 1.19$, $p = 0.0117$). Blinking messages likely attract more attention, as previous research has shown that flashing signs are effective in alerting drivers and encouraging a quicker response (Gregory et al., 2016). Also, in **normal traffic conditions,** drivers reduced their speed less significantly compared to when there was no traffic on the simulated freeway segments ($\beta = -1.18$, $p = 0.0005$). This pattern might be caused by drivers' concerns about being rear-ended by vehicles behind them if they reduce their speed significantly. **The average speed** before encountering the WWD DMS warning had a highly significant positive association with speed reduction (estimate = 0.43, $p < 0.001$). This implies that drivers traveling at higher initial speeds tend to reduce their speed more when alerted to a potential wrong-way vehicle. The faster the drivers were in the scenarios, the more speed they needed to reduce to feel as safe as drivers going at lower speeds.

At 90% CL, other factors such as gender, driving distance per year, and whether drivers had ever been in or experienced a WWD incident before (WWD experience) had relatively significant impacts on speed reduction. Compared to **females, males** showed less speed reductions when warned about potential oncoming WWD. Gender differences in driving behavior have been well-documented in transportation research. Studies have consistently shown that female drivers are generally more risk-averse compared to male drivers, which often translates into greater adherence to traffic warnings and a higher likelihood of speed reduction in response to hazardous situations. For example, a study by Nazir et al. (2023) found that males are more likely to take risks in driving scenarios, often influenced by overconfidence in their driving abilities.

As **annual driving distance** increased, drivers showed less speed reduction in response to WWD warnings. Drivers who cover longer distances annually tend to develop greater familiarity with roadways, which can lead to overconfidence in their ability to navigate hazardous situations safely. The behavioral adaptation phenomenon suggests that drivers who drive long distances may feel more in control and, thus, less likely to respond to warnings by reducing speed (Amoadu et al., 2023). Drivers with prior **WWD experience** exhibited greater speed reductions when warned about a potential oncoming WWD vehicle. Personal experience with hazardous traffic situations, such as a prior WWD incident, often heightens risk perception and increases caution. According to the Theory of Risk Homeostasis (Wilde, 1998), individuals adjust their behavior based on their perceived level of risk. Drivers who have previously encountered or been involved in WWD incidents are more likely to perceive the danger as real and immediate, prompting a more pronounced response to warnings.

For TTC, the random effect for "Participant" had a standard deviation of 0.1993, indicating modest variability in baseline TTC across individuals. This variability also reflects unobserved heterogeneity among participants, such as differences in driving habits or responsiveness to external driving conditions. The residual standard deviation of 0.4610 suggests additional unexplained variability in TTC, likely due to other unmeasured factors or random fluctuations in driving behavior. Table 5-9 summarizes the results of the TTC.

Table 5-10: MELR Model Results for TTC

Effect	Variable	Category	β	Std.Error	t-value	p-value
Fixed Effects	Intercept		1.8096906	0.2388453	7.576832	0
	Age	18-34[b]				
		35-64	0.118869	0.119755	0.992595	0.3284
		65+	0.049907	0.142571	0.350048	0.7286
	Gender	Female[b]				
		Male	0.0037557	0.08617673	0.043581	0.9655
	Income	0k-10k[b]				
		10k-25k	0.1330577	0.12861223	1.034565	0.3086
		25K to 40K	-0.0011635	0.16112068	-0.007221	0.9943
		40K-55K	0.183296	0.15808871	1.15945	0.2549
		55K to 70K	0.1867307	0.15859993	1.177369	0.2477
		70K+	0.0505266	0.14341543	0.352309	0.7269
	WWD Experience	No[b]				
		Yes	0.1312799	0.10934613	1.200591	0.2303
	WWD-Related DMS	UC[b]				
		2-Phase	0.0114035	0.04954806	0.23015	0.818
		Blinking	0.0150977	0.04497172	0.335716	0.7372
		UEC	-0.0394558	0.04495091	-0.877752	0.3803

Table 5-11, Continued: MELR Model Results for TTC

Effect	Variable	Category	β	Std.Error	t-value	p-value
	Visibility	Day[b]				
		Fog	-0.8606405	0.04442743	-19.371829	0
		Night	-0.0236517	0.03878239	-0.609858	0.5421
	Number of Lanes	3[b]				
		4	-0.0032142	0.03817749	-0.084191	0.9329
		5	0.0364238	0.03997013	0.911275	0.3624
	Traffic Level	No Traffic[b]				
		Normal Traffic	-0.2991055	0.03188919	-9.379525	0
	Initial Speed	continuous	-0.0054938	0.00347815	-1.579508	0.1146
	Lane Change Maneuver	None				
		Left	-0.1889789	0.14464328	-1.306517	0.1917
		Right	-0.1077312	0.05583249	-1.929543	0.2544
	Driving Experience (Years)	< 5				
		5-10	0.0703085	0.12594615	0.558242	0.5806
		11-15	0.3165978	0.17982696	1.760569	0.3879
		16-20	0.215417	0.21410635	1.006121	0.3219
		>21	-0.0216946	0.12508125	-0.173444	0.8634
	Annual Mileage	<5000				
		5000 to 10000	0.1211062	0.09808823	1.234666	0.2259
		10000-15000	0.1972717	0.12412011	1.589361	0.1218
		15000-20000	0.0235705	0.18181656	0.129639	0.8977
		>20000	0.0345352	0.16673477	0.207127	0.8372
	Variable	**Category**	**Std Deviation**	**Residual**		
Random Effect	Participant #	(1-49)	0.1993483	0.4610152		

Note: b is the base category.

Only visibility and traffic conditions impacted TTC at 95% CL. Driving in **foggy** conditions significantly shortened TTC by 0.86 seconds (β = -0.8606, p < 0.001) compared to clear daytime conditions. This finding highlights the increased likelihood of collisions under low-visibility conditions. Fog limits drivers' ability to perceive hazards ahead, which reduces their reaction time and safety margins. Similar to fog, heavy rainfall could also limit visibility and have a similar effect (Wang et al., 2021). Similarly, in **normal traffic conditions**, TTC was significantly shorter by 0.30 seconds (estimate = -0.2991, p < 0.001) compared to no-traffic scenarios. This suggests that the presence of other vehicles increases the perceived or actual likelihood of collisions, as drivers must simultaneously manage their own vehicles and respond to unpredictable movements from others. Previous research supports the idea that traffic density amplifies risk, particularly when paired with challenging driving scenarios such as WWD (Tian et al., 2013). None of the other factors significantly affected TTC, even at 90% CL.

5.7 Exit Survey

After completing the driving simulation experiment, participants were asked to fill out an exit survey (Appendix E). The survey mostly aimed to get the stated responses and preferences of the participants right after experiencing the scenarios in the driving simulation. The two main questions on the exit survey were:

1. How did you respond to the wrong-way driving (WWD) incident messages on the dynamic message signs (DMS)?

    a. Slowing down

b. Moving to slower lanes
c. Both a & b
d. Other ways

If other ways, how exactly did you respond to the WWD messages on DMS?

2. Which WWD message format got your attention quickly and easily?
a. Regular WWD message
b. WWD message with a "USE EXTREME CAUTION" phrase
c. Blinking/Flashing WWD message
d. Two-Phase WWD message

With minor discrepancies, most stated responses from the participants correlated with the revealed patterns observed during the driving simulation experiment. Most participants (24) stated that they slowed down when alerted of WWD. Eighteen (18) participants stated that they both slowed down and moved to the right (slower) lanes after seeing the WWD alerts on DMS. As discussed earlier, only a few lane changes were linked with WWD alerts. Participants mostly changed lanes to avoid being hit by the WWD vehicle. Participants probably thought this question involved that kind of lane change, too. Two (2) participants stated that they solely moved to the right lanes after being warned of WWD by the DMSs. The remaining five (5) participants stated that they did other maneuvers when they saw the WWD-related DMSs. The maneuvers involved being more vigilant and scanning their environment more carefully. Figure 5-6 shows the distribution of participants' stated responses to WWD-related DMS.

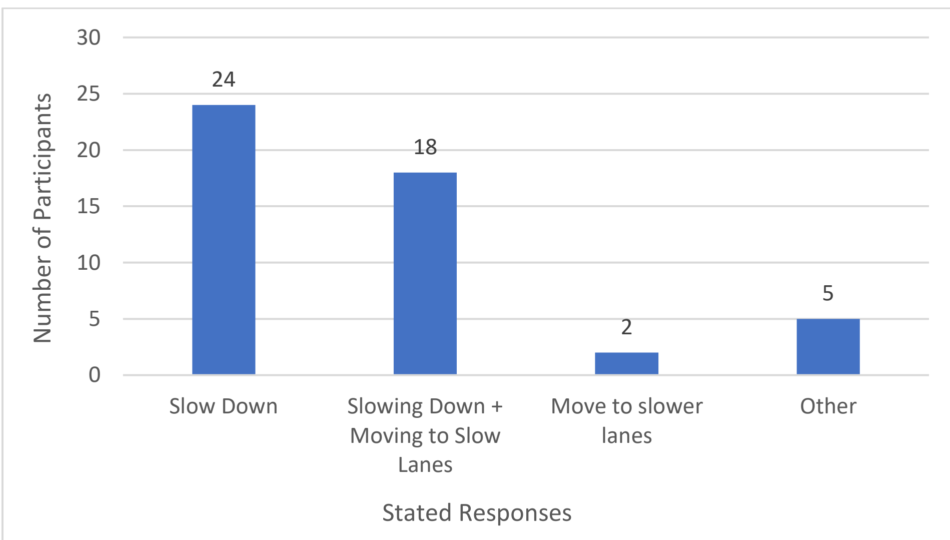

Figure 5-6: Participants' Stated Responses to WWD-Related DMS

When asked about the WWD-related DMS, which they easily comprehended, most participants (19) preferred blinking DMS, followed by the two-phase DMS (13). Ten (10) participants stated that the "extreme" phrase (UEC) addition in the regular "use caution" WWD alert caught their attention even faster. Seven participants stated that the regular "use caution" (UC) message on the

WWD alerts was enough to understand and take the required response. Figure 5-7 summarizes the distribution of participants' stated preferences on WWD-related DMS.

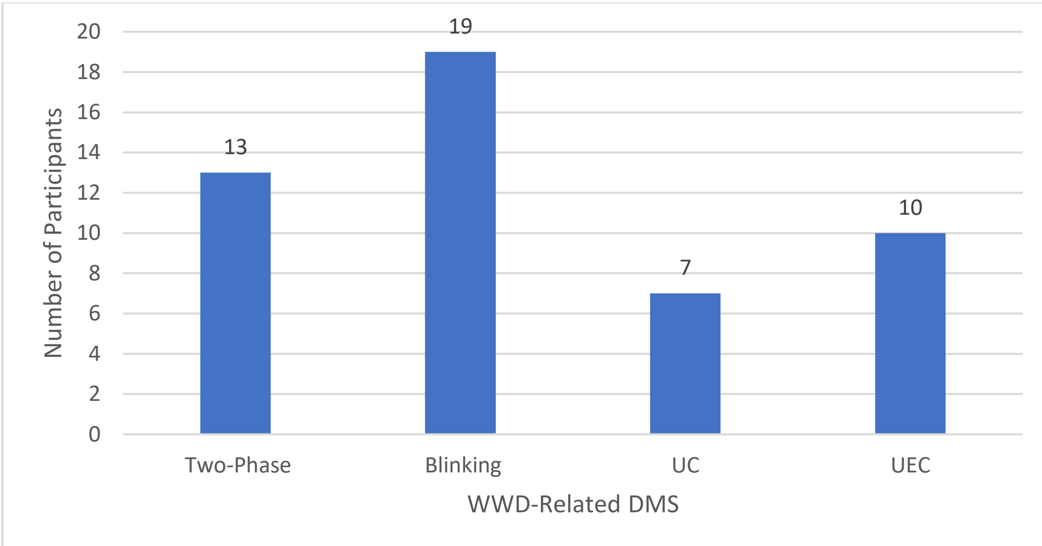

Figure 5-7: Participants' Stated Preferences on WWD-Related DMS

The exit survey also asked participants what could be done to improve their response to the WWD messages on the DMS and their general driving simulation experience. Several respondents responded with "N/A," implying that they understood the signs as they were in the driving simulation experiment and that their simulation experience was sufficient. Some respondents suggested that red fonts in the messages and using flashing warnings with suggested speed would improve their comprehension of the WWD-related DMS.

5.8 Summary

This chapter utilized a driving simulator to analyze the comprehension of WWD-related DMS to the right-way drivers. In addition to WWD message designs, human attributes, roadway geometric features, and environmental or visibility conditions were studied to understand their influence on compliance with WWD alerts. Comprehension and compliance with the WWD alerts were mainly measured by speed reductions and lane use changes by the drivers when alerted. In addition to speed reduction and lane use, TTC and WWD crash reduction were the performance measures for the effectiveness of WWD-related DMS in safety improvement. The 50 driving simulation experiment participants were distributed almost equivalently based on their age and gender. A combination of driving simulation scenarios was generated using WWD-related DMS types, visibility conditions, number of lanes, and traffic levels.

Statistical methods such as mean and proportion comparisons were used to examine the effectiveness of WWD-related DMS based on the following performance metrics: speed reduction, TTC, lane change, and WWD crash mitigation. Participants rarely changed lanes in response to the alerts; hence, lane use was not analyzed further. Statistical (MELR) and machine learning (DTE) models were used to study other roadway and environmental factors apart from the WWD-related DMS affecting speed reduction and TTC. WWD crashes were significantly reduced in simulated freeway segments with WWD-related DMS. Statistical and machine learning models were hence not feasible for further analysis of WWD crash avoidance since there would be a potential imbalance and bias.

The findings of this driving simulation experiment reinforce the importance of existing and simulation-designed WWD alerts in drivers' comprehension in response to WWD events. All WWD-related DMSs were associated with significantly higher speed reductions than other DMSs. WWD alerts on DMSs also significantly reduced the occurrence of WWD crashes, reinforcing the critical role of WWD-related DMS in mitigating WWD crashes. Although only slightly, WWD alerts elongated TTC, which also indicates their safety improvement potential in the real-world scenario.

Results from this chapter further demonstrate the critical importance of message specificity in enhancing driver compliance with safety interventions. The "Two-Phase" DMS message specifying a speed limit ("Reduce Speed to 45 MPH") was the most effective, significantly improving speed reduction compared to the general "Use Caution" message. Flashing "Use Caution" messages also yielded significant speed reduction, underlining the importance of calling for attention in alerting drivers. The "Use Extreme Caution" message had an almost equal complying effect as the general "Use Caution" message.

Individual characteristics influenced driver response. For instance, male drivers and drivers who drive long distances in a year exhibited a lower reduction in speed, aligning with existing literature on gender-related risk behavior and driver habituation. Conversely, drivers with prior WWD experience demonstrated greater reductions, highlighting the role of heightened risk awareness. Traffic levels negatively influenced both speed reduction and TTC. Although it is highly unlikely for WWD incidents on freeways to occur in the presence of traffic, in those low chances, it significantly hinders speed reduction and shortens the TTC. The presence of other vehicles likely increases collision risk by requiring drivers to manage their own movements while responding to the unpredictable behaviors of others. Fog conditions significantly shortened the TTC, underscoring the heightened likelihood of WWD crashes in low-visibility conditions. Fog limits drivers' ability to perceive hazards, reducing reaction time and safety margins. Similar challenges could arise from heavy rainfall, as prior research has suggested.

Based on the driving simulation experiment findings, the following recommendations are proposed to transportation agencies and the FDOT to improve traffic safety and reduce the risks associated with WWD:

- **Continue Using Existing WWD-Related DMS.** Activate the WWD-related DMS as directed in the SOPs on every WWD incident detected or reported since they have been shown to improve safety during WWD events.

- **Enhance Message Specificity:** Provide explicit and actionable DMS messages, such as speed limit advisories (e.g., "Reduce Speed to 45 MPH"). These messages showed the greatest positive impact on speed reduction, influencing clear behavioral responses from drivers.

- **Leverage Dynamic Visual Cues:** Incorporate attention-seeking MUTCD enforceable alerts similar to the blinking messages into DMS designs, as flashing signs (60 blinks/min) were shown to attract driver attention more effectively than the existing static WWD-related DMSs.

- **Integrate DMS WWD Alerts with Navigation Apps or Vehicle Systems:** Introduce integrated DMS alerts primarily for WWD incidents during night times, fog, or heavy rainfall. These alerts can integrate with navigation apps or vehicle systems to warn of upcoming WWD during low-visibility conditions and suggest speed adjustments or alternate routes. The integration would serve best during night times or adverse weather conditions. Drivers can see the WWD alerts through their mobile devices or vehicles without being affected by the low visibility caused by darkness, fog, or heavy rainfall. Besides a possible additional distraction, the integration could also be efficient in normal visibility conditions.

- **Targeted Resources for High-Risk Groups:** Public education campaigns addressing risk-taking behavior and overconfidence should be prioritized for male drivers and drivers who drive long distances (e.g., > 5000 miles) in a year. Collaborate with the National Highway Traffic Safety Administration (NHTSA) to foster a proactive safety culture. Outreach programs should focus on high-risk populations and continuously educate drivers about compliance with safety messages.

- **Enhance Public Awareness:** Develop driver education programs that leverage real-life testimonials or simulations to raise awareness of WWD dangers. Sharing personal experiences could help bridge the gap for those without direct WWD encounters. All road users should also be educated about WWD incidents and the current measures used by FDOT to mitigate those incidents, including the DMS alerts.

- **The "Extreme" Phrase Could be Dropped.** Consider reducing the redundancy in WWD alerts by using the shorter ("Use Caution") message. The "Extreme" did not improve drivers' comprehension of the WWD alerts. Therefore, it is deemed redundant and adds unnecessary mental load to drivers.

By implementing these strategies, FDOT and other transportation agencies could improve driver responsiveness to WWD scenarios, ultimately reducing crash risks and enhancing road safety for all users. Further studies could design and analyze other WWD-related DMS to establish if there are wording patterns in the DMS that could work better than the ones used in this study. Also, different software with different enhanced capabilities, such as simulating rainfall, could be considered in future studies.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

This chapter consolidates the insights gained from identifying the national best practices in responding to WWD events and evaluating FDOT's strategic response plan for WWD events on freeways. It provides a summary of key findings, synthesizes conclusions from the analyses conducted, and offers recommendations to enhance current strategies. As WWD on freeways remains a critical safety concern, with an average of 355 fatalities across the U.S., FDOT has developed strategic response plans aimed at mitigating WWD incidents. WWD risk mitigation is targeted to be achieved through a combination of engineering solutions, policy adjustments, advanced technologies, and multi-agency coordination.

This research project aimed to thoroughly evaluate FDOT's strategic response plan for addressing WWD events on freeways. It sought to assess the plan's effectiveness in enabling a consistent, well-coordinated, and efficient response. By leveraging existing ITS and TSM&O technologies, such as DMSs and video detection, this study intended to analyze and optimize real-time responses to WWD incidents on freeways. The specific objectives include:

- Identify best practices nationwide for responding to WWD incidents on freeways.
- Assess the effectiveness of the existing WWD response plan outlined in the RTMC SOPs.
- Evaluate the impact and efficiency of WWD DMS messaging in mitigating WWD events.

The research employed multiple methodological approaches, including a nationwide survey of state DOTs, an analysis of sampled SunGuide™ WWD event logs spanning five years, performance assessments of DMS using data from the FDOT districts, RITIS, and a driving simulator study. Statistical methods were used to examine roadway and environmental factors affecting the driver's response to WWD-related DMSs during WWD events. These methods allowed for a comprehensive evaluation of WWD incident responses, traffic behavior changes linked to WWD-related DMS alerts, and human factors influencing driver comprehension and responses to WWD warning messages.

6.1 Summary

6.1.1 State-of-the-practice Review

A nationwide survey of state DOTs revealed best practices and innovative WWD detection and prevention strategies, which provided insights into FDOT's approach. In Florida, each FDOT District and the FTE elaborated on their strategies for responding to WWD incidents. After conducting the state-of-the-practice survey, five years of SunGuide™ event logs were sampled and reviewed to understand the existing responses to WWD incidents in Florida. SunGuide™ event logs showed the timeline of how a certain WWD incident was responded to until it was closed. The review aimed to analyze how the responses to WWD events follow the SOPs set for each FDOT District and the FTE. The findings highlighted the efficiency and effectiveness of the FDOT's real-time response to WWD events. DMSs were found to be the most common ITS technology to warn right-way drivers when responding to WWD incidents.

6.1.2 Performance Analysis of DMS Messaging

Real-world data from RITIS demonstrated the impact of WWD-related DMS messages on traffic behavior. Speed and lane use data were used to examine the traffic behavioral changes linked to WWD-related DMS alerts. Speed reductions and lane shifts to slower designated lanes were interpreted as compliance and comprehension by the right-way drivers of the WWD-related DMS alerts during WWD incidents. The analysis confirmed that timely and well-designed messages reduce WWD crash risks by alerting right-way drivers regarding potential WWD incidents. The study also documented traffic compliance and situational awareness influenced by the existing FDOT messaging strategies.

6.1.3 Analysis of Human Factors

A driving simulator study was conducted to evaluate how individual drivers interpret and respond to DMS messages related to different WWD scenarios. The simulation scenarios were developed and programmed to assess how different WWD-related DMSs influence drivers' responses to the alerts and whether it improves their chances of avoiding WWD crashes. The experiment involved both existing WWD-related DMS and the proposed ones and examined each for their effectiveness in improving drivers' safety in response to WWD incidents. Results showed that clear, concise messaging with actionable instructions significantly improves driver comprehension, response times, and hence safety. These findings were critical in refining message formats for maximum effectiveness across diverse driver demographics and environmental conditions.

6.2 Conclusions

This report presented the efforts that transportation agencies use to actively respond to WWD incidents and how effective their responses were. New warning techniques were proposed and recommendations on WWD response were made. The following points summarize the conclusions from this research.

- Transportation agencies are actively making efforts to mitigate WWD occurrences: FDOT's active implementation of WWD-specific policies and response plans is a benchmark for addressing freeway WWD incidents.

- Real-time coordination and adherence to guidelines are critical to effectively managing WWD incidents: SOPs should be efficiently adhered to across different jurisdictions when responding to WWD incidents.

- DMS activations are effective in mitigating WWD risks by reducing speeds and influencing driver behavior: Alerting right-way drivers is as important as alerting wrong-way drivers in preventing and reducing the impacts of WWD incidents. Also, enhancements in WWWD-related DMS message design are still recommended.

- Variations in compliance across districts, driver demographics, and roadway conditions underscore the need for tailored interventions: Different conditions call for different specific actions in effectively enhancing the comprehension of WWD-related DMS during WWD events.

- The driving simulation experiment reinforces the importance of WWD-related DMS message specificity, visibility, and environmental considerations in enhancing safety interventions. When it gets challenging to use real-world data to study human behavior and comprehension, driving simulation experiments could be considered as an alternative.

6.3 Recommendations for Future Efforts

To further enhance the effectiveness of WWD countermeasures, future efforts should focus on policy improvements, technological advancements, and data-driven strategies. The following recommendations outline key areas for improvement and implementation:

- **Enhance WWD Policy Adoption Nationwide:**
  - State DOTs should adopt comprehensive WWD-specific policies and response plans, using FDOT as a model.

- **Expand the Use of Advanced WWD Detection Technologies:**
  - Continuously emphasize using advanced detection technologies to mitigate WWD incidents.

- **Optimize DMS Usage:**
  - Implement advisory speed limits on DMSs during WWD incidents.
  - Use clear, specific messages (e.g., "WWD Reported, Reduce Speed") to improve compliance.
  - Assess the feasibility of displaying blinking WWD alerts on DMS.
  - Conduct pilot tests to assess the drivers' reactions to these blinking WWD alerts in real-world scenarios.

- **Improve Real-Time Coordination:**
  - Update standard protocols to enhance interagency communication and response during WWD events.

- **Increase Public Awareness:**
  - Conduct campaigns to educate the public about WWD risks and DMS compliance.

- **Leverage Technology:**
  - Integrate DMS alerts with GPS and navigation systems to warn and protect both wrong-way and right-way drivers.
  - Promote the use of smartphone applications for real-time notifications.

- **Data-Driven Improvements:**
  - Establish robust data collection systems to track environmental and temporal factors during WWD events.
  - Continuously analyze and refine DMS activation strategies based on collected data.

- **Driver-Centric Approaches:**
  - Design interventions considering demographic-specific behaviors, especially for higher-risk groups such as male and long-distance drivers.

- **System Reliability:**
  - Regularly test and maintain DMS to ensure operational effectiveness during critical WWD situations.

- **Expand Simulation Studies:**
  - Explore additional combinations of WWD scenarios to further refine safety interventions and evaluate new message designs under varying conditions.

Implementing these recommendations can significantly enhance the management of WWD incidents and improve freeway safety by minimizing their risks. By adopting a comprehensive approach that includes policy development, technological advancements, public education, and data-driven refinements, transportation agencies can address the challenges posed by WWD events. Furthermore, tailoring interventions to demographic and environmental factors ensures that strategies remain effective across diverse conditions. FDOT's proactive efforts serve as a model, demonstrating the value of systematic coordination and innovative solutions. Continued research will play a vital role in refining these strategies, ultimately contributing to safer roadways nationwide.

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APPENDIX A: SURVEY QUESTIONS

State-of-the-Practice Survey on Countermeasures and Response Plans for Responding to Wrong-Way Driving (WWD) Events on Freeways

Dear Participant:

Thank you for taking the time to respond to this survey.

Florida International University (FIU) is working on a research project for the Florida Department of Transportation (FDOT) Traffic Engineering and Operations Office to determine the current policies, countermeasures, and response plans for responding in real time to wrong-way driving (WWD) incidents on *freeways*. The research team has created the following questionnaire survey to be completed by at least one employee of your agency (ideally a TSM&O/ITS manager or their designee).

There are a total of 16 questions in this survey. We anticipate that this survey will take less than 15 minutes to complete.

If you have any questions, please feel free to contact the project managers or the principal investigator:

Project Manager: Edith Wong, P.E., FDOT Traffic Engineering and Operations Office
edith.wong@dot.state.fl.us

Co-Project Manager: Eric Gordin, P.E., Florida's Turnpike Enterprise
eric.gordin@dot.state.fl.us

Co-Project Manager: Jeff Frost, Traffic Engineering and Operations Office
jeff.frost@dot.state.fl.us

Principal Investigator: Priyanka Alluri, PhD., P.E., RSP_{2BI}, Florida International University
palluri@fiu.edu; 305-348-3485

Please provide the following general information:
First Name:
Last Name:
Title:
District / Agency:
Phone:
Email:

1. Does your agency have a **specific policy** for addressing wrong-way driving incidents on freeways?
 Yes (please specify): _____________ *(*conditional on Qualtrics)*
 No
 I am not sure

2. Does your agency have a **specific response plan or procedures** for intercepting wrong-way drivers on freeways in real time?
 Yes (please specify): _____________ *(*conditional on Qualtrics)*
 No
 I am not sure

3. What **type of signs and pavement markings** does your agency use to **prevent** wrong-way drivers from entering the freeway? *(Please select all that apply)*
 Oversized signs
 Supplemental signs (e.g., No Right/Left Turn signs)
 Lower mounting height of "DO NOT ENTER" and "WRONG WAY" signs
 Red retroreflective strips on sign supports
 Flashing LEDs around signs (not detection based)
 Flashing beacons (not detection based)
 Raised pavement markers
 Wrong-Way pavement marking
 Directional rumble strips
 Retro-reflective delineators along off-ramps
 Detection triggered devices (e.g., red rectangular rapid flashing beacons (Red-RRFBs), LED lights around the wrong-way signs, wigwag flashing beacons, audible systems)
 Passive warning systems (e.g., internally illuminated raised pavement markers (iiRPMs))
 Other (please specify): _____________

4. What specific **type of ITS technologies** does your agency uses to **detect** wrong-way drivers on freeways in real time? *(Please select all that apply)*
 CCTV
 Video detection
 Inductive Loop Detectors (ILDs) (e.g., negative speed detection)
 Magnetic sensors
 Thermal imaging/sensors
 Radar
 Other (please specify): _____________

5. How does your agency **track the trajectory** of wrong-way drivers on freeways in **real time**? *(Please select all that apply)*
☐ ITS technologies (e.g., cameras, sensors)
☐ Data from 911 calls or other emergency services
☐ TMC operators
☐ Other (please specify): ____________

6. What **steps** does your agency take when a **wrong-way driver is detected** on the freeway? *(Please select all that apply)*
☐ Alert right-way drivers on the freeway through dynamic message signs
☐ Alert right-way drivers through smartphone apps (e.g., Google Maps, Waze, Apple Maps)
☐ Dispatch law enforcement to the scene
☐ Other (please specify): ____________

7. How does your agency **notify the public and media in real time** about a wrong-way driving incident on freeways? *(Please select all that apply)*
☐ Use of dynamic (changeable) message signs
☐ Use of social media (e.g., Twitter)
☐ Highway Advisory Radio (HAR) releases
☐ Smartphones applications (e.g., Google Maps, Waze, Apple Maps)
☐ Other (please specify): ____________

8. How does your agency **coordinate in real time with other agencies and organizations** (e.g., law enforcement, emergency responders, transportation agencies) **during** a wrong-way driving incident on freeways?

9. How does your agency **analyze and evaluate** the effectiveness of its wrong-way driving **countermeasures** on freeways? *(Please select all that apply)*
☐ Crash data analysis
☐ Public feedback
☐ Evaluation of warning and detection systems
☐ Analysis of wrong-way driving incidents
☐ Surveys of motorists
☐ Analysis of traffic flow data
☐ Other (please specify): ____________

10. What **content** does your agency display on **dynamic message signs** during an active wrong-way driving incident to alert right-way drivers on freeways? (Please specify)

11. How does your agency determine **which dynamic message signs** shall **display** the warning message during an active wrong-way driving incident? (Please specify)

12. For **how long** do you usually post messages on **dynamic message signs** during active wrong-way driving incidents on freeways? (Please specify)

13. Which of the following **information is documented** in a wrong-way driving incident on the freeway? *(Please select all that apply)*
☐ Final location of the wrong-way driver
☐ Location where the wrong-way driver entered the freeway
☐ Direction of travel of the wrong-way driver
☐ Vehicle description
☐ Detection method/information
☐ Event result (e.g., crash, intercept, WWD left the freeway)
☐ Other (please specify): _____________

14. What **type of data** does your agency **collect and analyze** in wrong-way driving incidents on freeways? *(Please select all that apply)*
☐ Incident reports
☐ Data from detection and warning systems
☐ Video recordings
☐ Reports from first responding agencies
☐ Surveys of motorists
☐ Wrong-way driving crash data
☐ Other (please specify): _____________

15. Has your agency conducted any **studies or evaluations of the effectiveness** of its policies, countermeasures, and response plans for addressing wrong-way driving incidents on freeways?
☐ Yes (please specify): _____________ *(*conditional on Qualtrics)*
☐ No
☐ I am not sure

16. Is your agency planning to test **new technologies** to **detect, prevent, or track** wrong-way driving entries on freeways in the near future?
☐ Yes (please specify): _____________ *(*conditional on Qualtrics)*
☐ No
☐ I am not sure

APPENDIX B: SURVEY RESPONSES

Table B1: Responses for the Existence of Specific WWD Policy and Response Plan

State	District / Agency:	**Q1**. Does your agency have a **specific policy** for addressing wrong-way driving incidents on freeways?	If yes. Please describe the **specific policy** for addressing wrong-way driving incidents on freeways that your agency has in place.	**Q2.** Does your agency have a **specific response plan or procedures** for intercepting wrong-way drivers on freeways in real time?	If yes. Please describe the **specific response plan or procedures** for intercepting wrong-way drivers on freeways in real time that your agency has in place.
Arizona	Arizona Department of Transportation (ADOT)	No		Yes	H
Arkansas	Arkansas Department of Transportation	No		No	
Delaware	Delaware Department of Transportation (DelDOT)	No		No	
Florida	Florida Department of Transportation	Yes	U	Yes	V
Florida	Florida Department of Transportation (FDOT) / District 1	Yes	A	Yes	I
Florida	Florida Department of Transportation (FDOT) / District 2	Yes	B	Yes	J
Florida	Florida Department of Transportation (FDOT) / District 3	Yes	C	Yes	K
Florida	Florida Department of Transportation (FDOT) / District 4	I am not sure		Yes	L
Florida	Florida Department of Transportation (FDOT) / District 5	No		Yes	M
Florida	Florida Department of Transportation (FDOT) / District 6	Yes	D	No	
Florida	Florida Department of Transportation (FDOT) / District 7	Yes	E	Yes	N

Table B1, Continued: Responses for the Existence of Specific WWD Policy and Response Plan

State	District / Agency:	**Q1**. Does your agency have a **specific policy** for addressing wrong-way driving incidents on freeways?	If yes. Please describe the **specific policy** for addressing wrong-way driving incidents on freeways that your agency has in place.	**Q2.** Does your agency have a **specific response plan or procedures** for intercepting wrong-way drivers on freeways in real time?	If yes. Please describe the **specific response plan or procedures** for intercepting wrong-way drivers on freeways in real time that your agency has in place.
Florida	Florida Turnpike Enterprise (FTE)	Yes	W	Yes	X
Georgia	Georgia Department of Transportation (GDOT)	No		Yes	O
Hawaii	Hawaii Department of Transportation (HDOT)	I am not sure		No	
Iowa	Iowa Department of Transportation (IDOT)	No		No	
Kansas	Kansas Department of Transportation (KDOT)	No		No	
Maine	Maine Department of Transportation (MaineDOT)	No		No	
Michigan	Michigan Department of Transportation	No		I am not sure	
Minnesota	Minnesota Department of Transportation (MnDOT)	No		No	
Montana	Montana Department of Transportation (MDT)	No		No	
Nebraska	Nebraska Department of Transportation (NDOT)	No		No	
North Carolina	North Carolina Department of Transportation (NCDOT)	No		No	
Ohio	Ohio Department of Transportation (ODOT)	I am not sure		Yes	P

Table B1, Continued: Responses for the Existence of Specific WWD Policy and Response Plan

State	District / Agency:	**Q1**. Does your agency have a **specific policy** for addressing wrong-way driving incidents on freeways?	If yes. Please describe the **specific policy** for addressing wrong-way driving incidents on freeways that your agency has in place.	**Q2.** Does your agency have a **specific response plan or procedures** for intercepting wrong-way drivers on freeways in real time?	If yes. Please describe the **specific response plan or procedures** for intercepting wrong-way drivers on freeways in real time that your agency has in place.
Pennsylvania	Pennsylvania Department of Transportation (PennDOT)	No		No	
Rhode Island	Rhode Island Department of Transportation (RIDOT)	Yes	F	Yes	Q
South Carolina	South Carolina Department of Transportation (SCDOT)	No		No	
Texas	Texas Department of Transportation (TxDOT)	Yes	G	Yes	R
Utah	Utah Department of Transportation (UDOT)	No		No	
Vermont	Vermont Agency of Transportation (VTrans)				
Virginia	Virginia Department of Transportation (VDOT)	No		No	
Washington	Washington State Department of Transportation (WSDOT)	No		Yes	S
Wyoming	Wyoming Department of Transportation (WYDOT)	No		Yes	T

A: 7.12 Wrong Way Driving Events (WWD)

Wrong-way driving (WWD) events pose an extreme danger to the motoring public. A WWD event occurs when a motorist enters the roadway using an exit ramp rather than an entrance ramp, turns into a wrong lane at an intersection, turns into a wrong lane using a median opening, or turns around within the travel lanes. Traveling in the wrong direction against traffic creates extreme peril to all roadway users. TMC staff utilize ITS countermeasures (where deployed) along with CCTV cameras and DMS to quickly detect a WWD, warn motorists, and manage a WWD incident.

WWD Initial Response

Automatic Response for Limited Access Facility WWD Events: In District 1, any WWD event created will automatically generate a response plan by activating signs within a radius of the incident as defined by the operator. The minimum DMS radius shall be 15 miles, and the minimum time spent attempting to locate the WWD is 15 minutes from the last received information. The operator shall use discretion in augmenting that radius based on information such as time delay and subsequent reports. The TAPCO deployment features fixed cameras, radar, thermal detection aids, and edge-lit LED signage. The cameras and sensors identify vehicles moving against the established traffic flow direction and automatically trigger the LED signage to begin blinking intensely. This notifies the driver that they are driving the wrong way on the ramp. A notification is immediately sent to the operator to generate an event and response plan.

WWD Detection Deployments: Currently, District 1 has one WWD detection deployment located at the Interchange of I-75 and US-17/Duncan Road in Charlotte County (Exit 164). The TAPCO deployment confirms the primary and secondary link was made in the WWD event and shall include comments on the result of the WWD event.

Responding to WWD Reports and Alerts: Upon the receipt of any report regarding a Wrong Way Driver, TMC staff shall immediately prioritize the event as urgent and begin working on the following steps:

Confirm directions, often, WWD events can be confusing because of the multi-direction reporting (ex. NB in SB lanes).

Create the event and activate the automatic response plan to provide the fastest possible alert to the motoring public.

If the report is generated through a WWD ITS device or discovered by an operator, alert FHP immediately.

Broadcast the message to all Road Rangers with the reported location, the direction of travel of the WWD and which directional lanes the vehicle is traveling in (ex. NB in SB lanes), and any known or reasonable time delay.

Utilize CCTV cameras to search for and confirm the WWD. This should be performed by multiple operators when possible.

A supervisor or manager will direct the steps above so that multiple operators are working to complete the tasks at the same time, minimizing any unnecessary delay in beginning a step.

Confirmation: When a WWD event is confirmed, TMC staff must work to continue the following life-saving measures:

Continue to refine and augment the DMS Response plan based on the position and speed of the WWD.

Maintain CCTV visual contact on the WWD vehicle.

Continue to update FHP and Road Rangers on the position and movement of the WWD vehicle.

TMC Management: Notify TMC management of any WWD incident as soon as it is confirmed, but

without detracting from the response procedures above.
Crash Resulting from WWD: When a reported or confirmed WWD results in a crash, TMC staff will clone the event and change the new event to Crash and check type. TMC staff shall continue to work on the incident as a crash providing highly detailed comments when information becomes available. Prior to closing out the original WWD event, TMC staff shall confirm the primary and secondary link was made in the WWD event and shall include comments on the result of the WWD event.

Terminating a WWD Event
Unconfirmed WWD: When a reported WWD cannot be found or confirmed after 15 minutes, TMC staff shall terminate the response plan and set the event status to "False Alarm". It is important to "Close" the event as this will impact reporting and create the need for tedious sorting of incidents.
Confirmed WWD: When a confirmed WWD self-corrects or is intercepted, the response plan shall be terminated once there is no longer any danger to the motoring public. The event shall be closed once the WWD and any associated response have cleared. When a confirmed WWD results in a crash, follow the procedures in the subsection above.
B: Within the Standard Operating Guidelines, it defines what needs to be done when a WWD is involved.
C: WRONG WAY DRIVER EVENTS

a. Periodically, a motorist will enter the interstate using an exit ramp rather than an entrance ramp. There are other instances where the motorist will be traveling in the correct direction and turn around. The motorist will then be traveling in the wrong direction against the flow of traffic. For example, a vehicle will be traveling southbound in the northbound travel lanes. This poses an extreme danger for all motorists, and immediate action is required to inform motorists traveling in the correct direction that they may encounter a vehicle potentially resulting in a high-speed head-on collision.
b. Upon a report of a wrong-way driver, visually or by FHP Radio, FHP Dispatch Code: Signal 12-W (Whiskey), all staff will make a response to the report their highest priority. The Supervisor will take control of the situation and take immediate action. The operator assigned to the area will activate a WWD Event while all other staff tour the area to locate the WWD via CCTV.

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c. Wrong Way Driving (WWD) DMS messages will be posted immediately via the Add New WWD Event feature in SunGuide™ using the information located in the Desktop Reference Guide.
d. After the DMS have been activated, Operators will document all activities, communications, and steps taken throughout the incident in the SunGuide™ event.
    1. Notify Road Ranger.
    2. If the vehicle is located, notify FHP.
    3. If unconfirmed, update the event every 20 minutes until disposition can be established.
    4. If unfounded, terminate the event, and ensure DMS messages are cleared.
    5. Notify FDOT personnel via email, phone call, or any additional means approved by management.
e. WWD involving a Crash:
    1. Create a secondary event, linking events.
    2. Update the secondary "Event type" to Crash.
    3. Remove the response plan and close the WWD event.
    4. Manage the crash event to include proper notifications

a. Crashes because of a WWD on limited access facilities, including ramps, meet the criteria for Executive notifications. All other crashes involving WWD are significant events.

5. Send Event Chronological Report to FDOT management and to the D3-NWFSsuper email group.

D: The FDOT District Six has a procedure that is used by Transportation Management Center personnel whenever a Wrong Way Driving incident is detected/confirmed, which includes coordination with Florida Highway Patrol, notification to Road Ranger personnel, dissemination of information via dynamic message signs, notifications to FDOT executive leadership and other FDOT District personnel.

E: Please refer to the attached file: QRG Wrong Way Drivers 08-04-22.

F: Whenever an incident accord that is the Wrong - way Driving System alarm go off, we verified the location and notified the police. Depends on the location we notified the on the vehicles using our Changeable Message Signs (CMS) to warn of the danger (this we haven't done, because in most cases the wrong way driver self-correct).

G: TxDOT has been exploring solutions to address wrong-way driving incidents for more than a decade. Many districts have deployed various mitigation measures to address wrong-way driving issues. The Traffic Management Systems (TMS) Working Group, a technical advisory board for TxDOT leadership, districts, and divisions, is working on wrong-way driving guidelines and countermeasures, which should be available later this year.

H: Please refer to ADOT's document at: https://azdot.gov/content/i-17-wrong-way-vehicle-detection-pilot-program-june-2020.

I: If the report is generated through a WWD ITS device or discovered by an operator, alert FHP immediately. Broadcast the message to all Road Rangers with the reported location, the direction of travel of the WWD and which directional lanes the vehicle is traveling in (ex. NB in SB lanes), and any known or reasonable time delay. Utilize CCTV cameras to search for and confirm the WWD. This should be performed by multiple operators when possible.

J: Within the Standard Operating Guidelines.

K: Once alerted, active search on CCTV for validation and notify Law Enforcement.

L: WWD is detected, then confirmed, then we post DMS messaging as applicable and disseminate information, notify responders. If FHP is not the one that notified the TMC of WWD, then we notify FHP first.

M: 4.1.6.6 Wrong Way Driver Alerts.

Wrong Way Driving (WWD) equipment is deployed at various ramps along the District Five roadway network. This WWD equipment is designed with 2 sets of detection devices located at the bottom of an exit ramp (near the surface street) and at the top (near the expressway). When the first set of devices are triggered, an alert is sent to the monitoring software, and a set of red flashing WRONG WAY signs are activated on the affected ramp. These alerts are often caused by maintenance personnel, traffic on the ramp, vehicles being detected on the surface street, and vehicles that self-correct. When the second set of devices are triggered, another alert is sent to the monitoring software, causing an audible alarm to sound alerting the ICM Operator that immediate attention is required. These alerts are typically caused by vehicles that have indeed driven the incorrect direction on the ramp in question and have failed to self-correct their direction of travel after the first set of devices. The triggering of this second threshold of detection devices is what produces the WWD Alert in SunGuide™ for which the ICM Operator must then manage.

N: RTMC reporting to FHP regarding the location of the WW drive.

O: We have Automatic Incident Detection (AID) cameras on a stretch of our interstate (I-475). When a WWD is detected, we alert enforcement. Otherwise, if we receive a call we alert enforcement.

P: For some of our WWD installations, we have set up alarms in our camera software, and our TMC operators will then contact the appropriate authorities to alert them.
Q: We notified the Police.
R: TxDOT San Antonio District has been partnering San Antonio Police Department (SAPD) on responding to wrong-way driving incidents. If a wrong-way driving incident is detected/reported, an automated alert would be generated and sent to SAPD. At the same time, TransGuide (TxDOT San Antonio District TMC) operators would use cameras and other tools to locate where the wrong-way driver is, then post messages on dynamic messages signs to alert traveling public and at the same time to share the info with SAPD for intercepting.
S: Wrong Way Vehicle .
Upon receiving notification, check the cameras to confirm the wrong-way vehicle.

Actions:

- Review Sense cameras and provide WSP updated vehicle description and location if applicable.
- Record the incident in the TMC Log using Incident as the Event Type.
- When TMC receives a report of and confirms a vehicle traveled the wrong way on any interstate or state route, send a major page to the appropriate area.

ReadyOp examples for your reference; however, you can modify them to reflect the events of each occurrence.

- Wrong way vehicle traveled NB in the SB lanes of I-5 from MP 3-5. No collisions, vehicle self-corrected or exited the freeway.
- Wrong way vehicle traveled NB in the SB lanes of I-5 from MP 3-5. Vehicle involved in a 2 car collision (add blocking info) with injuries, WSP investigating.
- Also, if you have additional information (wrong way vehicle traveled through a construction zone or the driver was arrested for DUI), add that to the page.

T: Our WY Highway Patrol respond to reports of a wrong way driver. / This is handled by the Wyoming Highway Patrol.
U: FDOT RTMC Standard Operating Guidelines
V: FDOT RTMC Standard Operating Guidelines
W: FTE Standard Operating Guidelines include a procedure for notification of a wrong way driver by FHP Dispatch, and TMC Operators. #1 Create a SunGuide™ event. #2 Broadcast on SLERS 800 MHz a BOLO for all Road Ranger Service Patrols and provide wrong way driver location information. #3 Attempt to find Wrong Way Driver on Camera. #4 Activate appropriate Highway Advisory Radio stations.
X: FTE Standard Operating Guidelines include a procedure for notification of a wrong way driver by FHP Dispatch, and TMC Operators. #1 Create a SunGuide™ event. #2 Broadcast on SLERS 800 MHz a BOLO for all Road Ranger Service Patrols and provide wrong way driver location information. #3 Attempt to find Wrong Way Driver on Camera. #4 Activate appropriate Highway Advisory Radio stations. In addition, for exit ramps that are equipped with Wrong Way Vehicle Detection Systems (WWVDS), a quick assessment will be made based on the snapshots and/or videos captured from the devices.

Table B2: Responses for the Types of Signs and Pavement Markings to Prevent WWD

State	District / Agency:	**Q3.** What **type of signs and pavement markings** does your agency use to prevent wrong-way drivers from entering the freeway? (Please select all that apply)												
		Oversized signs	Supplemental signs (e.g., No Right/Left Turn signs)	Lower mounting height of " DO NOT ENTER" and " WRONG WAY" signs	Red retroreflective strips on sign supports	Flashing LEDs around signs (not detection-based)	Flashing beacons (not detection based)	Raised pavement markers	Wrong-Way pavement marking	Directional rumble strips	Retro-reflective delineators along off-ramps	Detection triggered devices (e.g., red rectangular rapid flashing beacons (Red-RRFBs), LED lights around the wrong-way signs, wigwag flashing beacons, audible systems)	Passive warning systems (e.g., internally illuminated raised pavement markers (iiRPMs))	Other (please specify)
Arizona	Arizona Department of Transportation (ADOT)	X	X	X	X			X	X		X	X		A
Arkansas	Arkansas Department of Transportation	X	X	X	X				X					
Delaware	Delaware Department of Transportation (DelDOT)		X	X	X			X	X		X	X		
Florida	Florida Department of Transportation (FDOT)	X	X	X	X		X	X	X		X	X	X	
Florida	Florida Department of Transportation (FDOT) / District 1		X	X		X		X	X					
Florida	Florida Department of Transportation (FDOT) / District 2		X									X		

Table B2, Continued: Responses for the Types of Signs and Pavement Markings to Prevent WWD

State	District / Agency:	**Q3.** What **type of signs and pavement markings** does your agency use to prevent wrong-way drivers from entering the freeway? (Please select all that apply)												
		Oversized signs	Supplemental signs (e.g., No Right/Left Turn signs)	Lower mounting height of " DO NOT ENTER" and " WRONG WAY" signs	Red retroreflective strips on sign supports	Flashing LEDs around signs (not detection-based)	Flashing beacons (not detection based)	Raised pavement markers	Wrong-Way pavement marking	Directional rumble strips	Retro-reflective delineators along off-ramps	Detection triggered devices (e.g., red rectangular rapid flashing beacons (Red-RRFBs), LED lights around the wrong-way signs, wigwag flashing beacons, audible systems)	Passive warning systems (e.g., internally illuminated raised pavement markers (iiRPMs))	Other (please specify)
Florida	Florida Department of Transportation (FDOT) / District 3		X				X					X		
Florida	Florida Department of Transportation (FDOT) / District 4	X	X	X					X			X		
Florida	Florida Department of Transportation (FDOT) / District 5	X	X	X	X	X		X	X			X		
Florida	Florida Department of Transportation (FDOT) / District 6	X	X		X			X	X			X		
Florida	Florida Department of Transportation (FDOT) / District 7		X		X	X	X	X	X			X	X	
Florida	Florida Turnpike Enterprise (FTE)		X	X	X				X		X	X		

Table B2, Continued: Responses for the Types of Signs and Pavement Markings to Prevent WWD

State	District / Agency:	**Q3.** What **type of signs and pavement markings** does your agency use to prevent wrong-way drivers from entering the freeway? (Please select all that apply)												
		Oversized signs	Supplemental signs (e.g., No Right/Left Turn signs)	Lower mounting height of " DO NOT ENTER" and " WRONG WAY" signs	Red retroreflective strips on sign supports	Flashing LEDs around signs (not detection-based)	Flashing beacons (not detection based)	Raised pavement markers	Wrong-Way pavement marking	Directional rumble strips	Retro-reflective delineators along off-ramps	Detection triggered devices (e.g., red rectangular rapid flashing beacons (Red-RRFBs), LED lights around the wrong-way signs, wigwag flashing beacons, audible systems)	Passive warning systems (e.g., internally illuminated raised pavement markers (iiRPMs))	Other (please specify)
Georgia	Georgia Department of Transportation (GDOT)	X	X	X	X			X	X	X	X		X	B
Hawaii	Hawaii Department of Transportation (HDOT)		X	X					X		X			
Iowa	Iowa Department of Transportation (IDOT)	X	X						X					
Kansas	Kansas Department of Transportation (KDOT)		X	X			X							
Maine	Maine Department of Transportation (MaineDOT)	X		X		X			X			X		
Michigan	Michigan Department of Transportation			X								X		
Minnesota	Minnesota Department of Transportation (MnDOT)	X	X				X							
Montana	Montana Department of Transportation (MDT)	X	X	X	X				X		X	X		

Table B2, Continued: Responses for the Types of Signs and Pavement Markings to Prevent WWD

State	District / Agency:	**Q3.** What **type of signs and pavement markings** does your agency use to prevent wrong-way drivers from entering the freeway? (Please select all that apply)												
		Oversized signs	Supplemental signs (e.g., No Right/Left Turn signs)	Lower mounting height of " DO NOT ENTER" and " WRONG WAY" signs	Red retroreflective strips on sign supports	Flashing LEDs around signs (not detection-based)	Flashing beacons (not detection based)	Raised pavement markers	Wrong-Way pavement marking	Directional rumble strips	Retro-reflective delineators along off-ramps	Detection triggered devices (e.g., red rectangular rapid flashing beacons (Red-RRFBs), LED lights around the wrong-way signs, wigwag flashing beacons, audible systems)	Passive warning systems (e.g., internally illuminated raised pavement markers (iiRPMs))	Other (please specify)
Nebraska	Nebraska Department of Transportation (NDOT)		X		X									
North Carolina	North Carolina Department of Transportation (NCDOT)		X	X	X	X		X	X			X		
Ohio	Ohio Department of Transportation (ODOT)			X				X	X			X		
Pennsylvania	Pennsylvania Department of Transportation (PennDOT)	X	X	X	X									
Rhode Island	Rhode Island Department of Transportation (RIDOT)					X	X					X		
South Carolina	South Carolina Department of Transportation (SCDOT)	X	X					X						

Table B2, Continued: Responses for the Types of Signs and Pavement Markings to Prevent WWD

State	District / Agency:	**Q3.** What **type of signs and pavement markings** does your agency use to prevent wrong-way drivers from entering the freeway? (Please select all that apply)												
		Oversized signs	Supplemental signs (e.g., No Right/Left Turn signs)	Lower mounting height of " DO NOT ENTER" and " WRONG WAY" signs	Red retroreflective strips on sign supports	Flashing LEDs around signs (not detection-based)	Flashing beacons (not detection based)	Raised pavement markers	Wrong-Way pavement marking	Directional rumble strips	Retro-reflective delineators along off-ramps	Detection triggered devices (e.g., red rectangular rapid flashing beacons (Red-RRFBs), LED lights around the wrong-way signs, wigwag flashing beacons, audible systems)	Passive warning systems (e.g., internally illuminated raised pavement markers (iiRPMs))	Other (please specify)
Texas	Texas Department of Transportation (TxDOT)	X	X	X	X	X			X			X		
Utah	Utah Department of Transportation (UDOT)	X	X		X	X	X		X			X		C
Vermont	Vermont Agency of Transportation (VTrans)		X		X				X					D
Virginia	Virginia Department of Transportation (VDOT)													E
Washington	Washington State Department of Transportation (WSDOT)	X	X		X	X		X	X			X		
Wyoming	Wyoming Department of Transportation (WYDOT)		X	X										F

A: Internally Illuminated Wrong-Way Sign with LED lights.

B: Automatic Incident Detection
C: Use straight up green arrows at interchange traffic signal heads to emphasize correct direction of travel.
D: Gateposted DO NOT ENTER signs; additional WRONG WAY signs on mainline of interstate just upstream of off-ramps.
E: DO NOT ENTER/WRONG WAY Static Signage.
F: We follow the MUTCD and you have to realize we have +500,000 population.

Table B3: Responses for the Types of ITS Technologies to Detect WWD and WWD Trajectory Tracking Methods

State	District / Agency:	**Q4.** What specific **type of ITS technologies** does your agency uses to **detect** wrong-way drivers on freeways in real time? (Please select all that apply)							**Q5.** How does your agency **track the trajectory** of wrong-way drivers on freeways in **real time**? (Please select all that apply)			
		CCTV	Video detection	Inductive Loop Detectors (ILDs) (e.g., negative speed detection)	Magnetic sensors	Thermal imaging/sensors	Radar	Other (please specify)	ITS technologies (e.g., cameras, sensors)	Data from 911 calls or other emergency services	TMC operators	Other (please specify)
Arizona	Arizona Department of Transportation (ADOT)	X	X			X		A	X	X	X	F
Arkansas	Arkansas Department of Transportation	X									X	
Delaware	Delaware Department of Transportation (DelDOT)	X	X				X		X	X	X	
Florida	Florida Department of Transportation (FDOT)	X	X			X	X		X	X	X	
Florida	Florida Department of Transportation (FDOT) / District 1	X	X			X			X	X	X	
Florida	Florida Department of Transportation (FDOT) / District 2	X				X	X		X	X	X	
Florida	Florida Department of Transportation (FDOT) / District 3	X									X	
Florida	Florida Department of Transportation (FDOT) / District 4	X	X			X	X		X	X	X	
Florida	Florida Department of Transportation (FDOT) / District 5	X	X			X			X	X	X	
Florida	Florida Department of Transportation (FDOT) / District 6					X	X	B	X	X		
Florida	Florida Department of Transportation (FDOT) / District 7	X	X	X		X	X		X	X	X	
Florida	Florida Turnpike Enterprise (FTE)	X	X			X	X		X	X	X	

Table B3, Continued: Responses for the Types of ITS Technologies to Detect WWD and WWD Trajectory Tracking Methods

State	District / Agency:	**Q4.**What specific **type of ITS technologies** does your agency uses to **detect** wrong-way drivers on freeways in real time? (Please select all that apply)							**Q5.** How does your agency **track the trajectory** of wrong-way drivers on freeways in **real time**? (Please select all that apply)			
		CCTV	Video detection	Inductive Loop Detectors (ILDs) (e.g., negative speed detection)	Magnetic sensors	Thermal imaging/sensors	Radar	Other (please specify)	ITS technologies (e.g., cameras, sensors)	Data from 911 calls or other emergency services	TMC operators	Other (please specify)
Georgia	Georgia Department of Transportation (GDOT)		X						X	X	X	
Hawaii	Hawaii Department of Transportation (HDOT)	X										
Iowa	Hawaii Department of Transportation (IDOT)	X	X				X		X	X	X	
Kansas	Kansas Department of Transportation (KDOT)	X								X	X	
Maine	Maine Department of Transportation (MaineDOT)					X				X		
Michigan	Michigan Department of Transportation						X			X	X	
Minnesota	Minnesota Department of Transportation (MnDOT)			X					X	X	X	
Montana	Montana Department of Transportation (MDT)		X				X					G
Nebraska	Nebraska Department of Transportation (NDOT)							C		X	X	
North Carolina	North Carolina Department of Transportation (NCDOT)	X	X	X					X	X	X	
Ohio	Ohio Department of Transportation (ODOT)	X	X				X		X		X	H
Pennsylvania	Pennsylvania Department of Transportation (PennDOT)	X							X	X	X	
Rhode Island	Rhode Island Department of Transportation (RIDOT)	X	X			X	X		X		X	
South Carolina	South Carolina Department of Transportation (SCDOT)	X	X						X	X	X	
Texas	Texas Department of Transportation (TxDOT)	X	X			X	X		X	X	X	
Utah	Utah Department of Transportation (UDOT)	X				X	X		X	X	X	I

Table B3, Continued: Responses for the Types of ITS Technologies to Detect WWD and WWD Trajectory Tracking Methods

State	District / Agency:	**Q4.** What specific **type of ITS technologies** does your agency uses to **detect** wrong-way drivers on freeways in real time? (Please select all that apply)							**Q5.** How does your agency **track the trajectory** of wrong-way drivers on freeways in **real time**? (Please select all that apply)			
		CCTV	Video detection	Inductive Loop Detectors (ILDs) (e.g., negative speed detection)	Magnetic sensors	Thermal imaging/sensors	Radar	Other (please specify)	ITS technologies (e.g., cameras, sensors)	Data from 911 calls or other emergency services	TMC operators	Other (please specify)
Vermont	Vermont Agency of Transportation (VTrans)							D				J
Virginia	Virginia Department of Transportation (VDOT)	X								X	X	
Washington	Washington State Department of Transportation (WSDOT)	X	X						X	X	X	
Wyoming	Wyoming Department of Transportation (WYDOT)							E		X	X	K

A: Decision Support Software (DSS).
B: Detection devices on the off-ramps, not on freeways.
C: None.
D: N/A.
E: No ITS to detect wrong-way drivers. Our population does not warrant the cost of installation and monitoring.
F: We have DPS Troopers posted in the TOC; they work with the TOC Dispatchers and the DPS Dispatch Center.
G: We don't track trajectory yet.
H: TMC operators only if we know about it. Most of the time, we don't unless it's on our specific corridor where we have detection and we know what ramp was triggered.
I: Highway Patrol Dispatch.
J: Tracked by Enforcement
K: We don't.

Table B4: Responses for the Steps Adopted when a WWD is Detected and Real-Time Notification to the Public and Media

State	District / Agency:	**Q6.** What **steps** does your agency take when a **wrong-way driver is detected** on the freeway? (Please select all that apply)				**Q7.** How does your agency **notify the public and media in real time** about a wrong-way driving incident on freeways? (Please select all that apply)				
		Alert right-way drivers on the freeway through dynamic message signs	Alert right-way drivers through smartphone apps (e.g., Google Maps, Waze, Apple Maps)	Dispatch law enforcement to the scene	Other (please specify)	Use of dynamic (changeable) message signs	Use of social media (e.g., Twitter)	Highway Advisory Radio (HAR) releases	Smartphones applications (e.g., Google Maps, Waze, Apple Maps)	Other (please specify)
Arizona	Arizona Department of Transportation (ADOT)	X		X		X	X			
Arkansas	Arkansas Department of Transportation			X		X			X	
Delaware	Delaware Department of Transportation (DelDOT)	X		X	A	X				
Florida	Florida Department of Transportation (FDOT)	X		X	P	X				
Florida	Florida Department of Transportation (FDOT) / District 1	X		X		X				
Florida	Florida Department of Transportation (FDOT) / District 2	X		X		X				
Florida	Florida Department of Transportation (FDOT) / District 3	X		X		X	X		X	
Florida	Florida Department of Transportation (FDOT) / District 4	X	X		B	X				
Florida	Florida Department of Transportation (FDOT) / District 5	X		X		X				
Florida	Florida Department of Transportation (FDOT) / District 6	X		X	C	X				
Florida	Florida Department of Transportation (FDOT) / District 7	X		X		X				
Florida	Florida Turnpike Enterprise (FTE)	X		X	R	X		X		

Table B4, Continued: Responses for the Steps Adopted when a WWD is Detected and Real-Time Notification to the Public and Media

State	District / Agency:	**Q6.** What **steps** does your agency take when a **wrong-way driver is detected** on the freeway? (Please select all that apply)				**Q7.** How does your agency **notify the public and media in real time** about a wrong-way driving incident on freeways? (Please select all that apply)				
		Alert right-way drivers on the freeway through dynamic message signs	Alert right-way drivers through smartphone apps (e.g., Google Maps, Waze, Apple Maps)	Dispatch law enforcement to the scene	Other (please specify)	Use of dynamic (changeable) message signs	Use of social media (e.g., Twitter)	Highway Advisory Radio (HAR) releases	Smartphones applications (e.g., Google Maps, Waze, Apple Maps)	Other (please specify)
Georgia	Georgia Department of Transportation (GDOT)			X		X				E
Hawaii	Hawaii Department of Transportation (HDOT)									
Iowa	Iowa Department of Transportation (IDOT)	X		X	Q	X				
Kansas	Kansas Department of Transportation (KDOT)	X		X		X				
Maine	Maine Department of Transportation (MaineDOT)		X							F
Michigan	Michigan Department of Transportation	X		X		X	X			G
Minnesota	Minnesota Department of Transportation (MnDOT)			X						H
Montana	Montana Department of Transportation (MDT)				D					I
Nebraska	Nebraska Department of Transportation (NDOT)			X						J
North Carolina	North Carolina Department of Transportation (NCDOT)	X		X		X				
Ohio	Ohio Department of Transportation (ODOT)			X						K
Pennsylvania	Pennsylvania Department of Transportation (PennDOT)	X		X		X				

Table B4, Continued: Responses for the Steps Adopted when a WWD is Detected and Real-Time Notification to the Public and Medi

State	District / Agency:	**Q6.** What **steps** does your agency take when a **wrong-way driver is detected** on the freeway? (Please select all that apply)				**Q7.** How does your agency **notify the public and media in real time** about a wrong-way driving incident on freeways? (Please select all that apply)				
		Alert right-way drivers on the freeway through dynamic message signs	Alert right-way drivers through smartphone apps (e.g., Google Maps, Waze, Apple Maps)	Dispatch law enforcement to the scene	Other (please specify)	Use of dynamic (changeable) message signs	Use of social media (e.g., Twitter)	Highway Advisory Radio (HAR) releases	Smartphones applications (e.g., Google Maps, Waze, Apple Maps)	Other (please specify)
Rhode Island	Rhode Island Department of Transportation (RIDOT)	X		X		X				
South Carolina	South Carolina Department of Transportation (SCDOT)			X						L
Texas	Texas Department of Transportation (TxDOT)	X		X		X				
Utah	Utah Department of Transportation (UDOT)			X			X			
Vermont	Vermont Agency of Transportation (VTrans)			X						M
Virginia	Virginia Department of Transportation (VDOT)			X						N
Washington	Washington State Department of Transportation (WSDOT)	X		X		X				O
Wyoming	Wyoming Department of Transportation (WYDOT)	X	X	X		X	X	X	X	

A: Our wrong-way detection system is a pilot and just began a couple of months ago.
B: We dispatch road rangers and advise FHP.
C: Alert service patrol via radio.
D: Nothing yet tied to ITS.
E: We currently do not notify motorists of an active wrong-way driving vehicle. When and if the wrong way driving vehicle crashes, details of the incident are shared on the dynamic message signs, Waze, on social media, and iPAWS.
F: We don't.

G: MiDrive/511 website.
H: No notifications.
I: Nothing yet tied to ITS.
J: N/A
K: N/A
L: No notifications.
M: N/A
N: Has to be confirmed before any activation of real-time notification is made in coordination with law enforcement.
O: Nothing at this time.
P: In terms of "steps," the operators verify all WWD alerts before acting on them
Q: When the TMC is notified, they create an event that is sent out to internal staff. Post WWD, we investigate each WWD event to determine the point of entry.
R: Road Rangers dispatched to the scene/location, if law enforcement not available.

Table B5: Responses for Interagency Real-Time Coordination and Evaluation Methods of Countermeasures

State	District / Agency:	**Q8.** How does your agency **coordinate in real time with other agencies and organizations** (e.g., law enforcement, emergency responders, transportation agencies) during a wrong-way driving incident on freeways? (Please specify)	**Q9.** How does your agency **analyze and evaluate** the effectiveness of its wrong-way driving **countermeasures** on freeways? (Please select all that apply)						
			Crash data analysis	Public feedback	Evaluation of warning and detection systems	Analysis of wrong-way driving incidents	Surveys of motorists	Analysis of traffic flow data	Other (please specify)
Arizona	Arizona Department of Transportation (ADOT)	A	X			X		X	
Arkansas	Arkansas Department of Transportation	B	X			X			
Delaware	Delaware Department of Transportation (DelDOT)	C	X		X	X			
Florida	Florida Department of Transportation (FDOT)	AI	X		X	X			
Florida	Florida Department of Transportation (FDOT) / District 1	D	X		X	X			
Florida	Florida Department of Transportation (FDOT) / District 2	E	X		X				
Florida	Florida Department of Transportation (FDOT) / District 3	F	X			X			
Florida	Florida Department of Transportation (FDOT) / District 4	G			X	X			
Florida	Florida Department of Transportation (FDOT) / District 5	H	X		X	X			
Florida	Florida Department of Transportation (FDOT) / District 6	I	X		X	X			AC
Florida	Florida Department of Transportation (FDOT) / District 7	J	X		X	X			
Florida	Florida Turnpike Enterprise (FTE)	AL	X	X	X	X			
Georgia	Georgia Department of Transportation (GDOT)	K	X		X	X		X	AD

Table B5, Continued: Responses for Interagency Real-Time Coordination and Evaluation Methods of Countermeasures

State	District / Agency:	**Q8.** How does your agency **coordinate in real time with other agencies and organizations** (e.g., law enforcement, emergency responders, transportation agencies) during a wrong-way driving incident on freeways? (Please specify)	**Q9.** How does your agency **analyze and evaluate** the effectiveness of its wrong-way driving **countermeasures** on freeways? (Please select all that apply)						
			Crash data analysis	Public feedback	Evaluation of warning and detection systems	Analysis of wrong-way driving incidents	Surveys of motorists	Analysis of traffic flow data	Other (please specify)
Hawaii	Hawaii Department of Transportation (HDOT)								
Iowa	Iowa Department of Transportation (IDOT)	AJ	X		X	X			AK
Kansas	Kansas Department of Transportation (KDOT)	L						X	
Maine	Maine Department of Transportation (MaineDOT)	M	X			X			
Michigan	Michigan Department of Transportation	N			X	X			
Minnesota	Minnesota Department of Transportation (MnDOT)	O							AE
Montana	Montana Department of Transportation (MDT)	P	X		X				
Nebraska	Nebraska Department of Transportation (NDOT)	Q	X			X			AF
North Carolina	North Carolina Department of Transportation (NCDOT)	R				X			
Ohio	Ohio Department of Transportation (ODOT)	S	X		X	X			
Pennsylvania	Pennsylvania Department of Transportation (PennDOT)	T	X		X	X			
Rhode Island	Rhode Island Department of Transportation (RIDOT)	U	X		X	X			
South Carolina	South Carolina Department of Transportation (SCDOT)	V							AG
Texas	Texas Department of Transportation (TxDOT)	W	X	D	X	X			
Utah	Utah Department of Transportation (UDOT)	X			X	X			
Vermont	Vermont Agency of Transportation (VTrans)	Y	X	X		X			

Table B5, Continued: Responses for Interagency Real-Time Coordination and Evaluation Methods of Countermeasures

State	District / Agency:	**Q8.** How does your agency **coordinate in real time with other agencies and organizations** (e.g., law enforcement, emergency responders, transportation agencies) during a wrong-way driving incident on freeways? (Please specify)	**Q9.** How does your agency **analyze and evaluate** the effectiveness of its wrong-way driving **countermeasures** on freeways? (Please select all that apply)						
			Crash data analysis	Public feedback	Evaluation of warning and detection systems	Analysis of wrong-way driving incidents	Surveys of motorists	Analysis of traffic flow data	Other (please specify)
Virginia	Virginia Department of Transportation (VDOT)	Z	X						
Washington	Washington State Department of Transportation (WSDOT)	AA	X			X			AH
Wyoming	Wyoming Department of Transportation (WYDOT)	AB	X	X		X	X	X	

A: DPS officer is located in the traffic operations center.
B: Use of ITS elements: CCTV, DMS.
C: Once a concern is detected or received, our Transportation Management Center will notify law enforcement and emergency responders in the area.
D: see previous SOP language.
E: Our RTMC is co-located with FHP and the local sheriff's office in Jacksonville.
F: telephone, computer, radio
G: Over phone calls and radio.
H: Coordinate through dispatch via telephone, shared video via Teams/Mutual link
I: Via telephone, TMC operators to Law Enforcement (FHP) dispatch. Via Radio, TMC Operator to Service Patrol personnel, Via email, FDOT Executive Leadership, and District personnel.
J: FHP is on the same floor as the RTMC operators; therefore, the information is coordinated immediately, Face to Face. Local agency contacts receive emails and phone calls.
K: Currently, all communication with other emergency agencies is via phone calls, Rave mobile notification emails, or text messages during an active wrong-way driving event.
L: Radio dispatch and law enforcement also use video on the web prior to heading to scenes
M: TMC would call if we found out

N: Only one operation center in Michigan has the best coordination. The operation center is housed with other agencies and organizations, such as law enforcement and emergency responders. Therefore in-person communication is possible. In addition, TMC-to-TMC communication is updated through an internal Microsoft team chat when the wrong way drives past into regions. The freeway courtesy patrol had radio communication with TMCs.
O: MnDOT Traffic Operations staff are co-located with Minnesota State Patrol Dispatch. State Patrol dispatchers have access to MnDOT traffic cameras to track wrong-way drivers.
P: We have a pilot-type project to address wrong-way crashes using active warning systems, but we don't yet have specific plans for automated coordination.
Q: If we are aware of them prior to a crash, law enforcement would be notified.
R: Phone calls or VIPER radios.
S: We contact the appropriate law enforcement for where the incident is located. / Usually, we only know of a WW driver in real time if one of our detection sensors gets triggered on an exit ramp. Currently, we only have this on about 25 ramps in the state. So a very small portion compared to the overall number of freeway ramps in the state. If drivers encounter a WW driver on the freeways, they usually directly call the Police, so our TMC typically isn't involved.
T: Most of the incidents happen so fast that the hazardous driving scenario runs its course before manual notification can be made to partners. Automated alerting or messaging to the drivers in harm's way would be the most effective, but traditional installations have only been installed at "hot spots".
U: Through phone and our state police (E 911) has access to the WWD cameras/System
V: Via radio/phone communications with traffic control centers
W: TMC is where all relevant parties get informed of and coordinated on responding to wrong-way driving incidents.
X: Coordinate through our TOC (TMC) and UHP dispatch
Y: Generally, we do not coordinate during the active event.
Z: In real time, VDOT coordinates with Virginia State Police and its other public safety responders when notified of a situation via its Transportation Operations Centers holistically in any incident. However, until law enforcement, VDOT Safety Service Patrol, or confirmed via CCTV coordination, wrong-way driver incidents do not begin until confirmation.
AA: TMC operator verifies and then notifies state patrol location and description of the vehicle. / See procedure section. Our camera server also has the capability to program cameras to turn automatically based on the wrong-way notification from our system.
AB: WY Highway Patrol is a part of WYDOT. Law enforcement uses Wyo-Link digital radio to set up a talk channel to coordinate a unified response.
AC: We are still in the early stages of deployment.
AD: Probe Data, event data
AE: Only countermeasures we have are on the freeway on-ramps at select locations. For a pilot project, we did evaluate the number of incidents where drivers started the wrong way but turned around.
AF: IDK, Infrequent event.
AG: No formal evaluation.
AH: None at this time.

AI: FDOT coordinates with FHP. Other transportation agencies, such as toll roads and expressway authorities, may have their own WWD detection systems that communicate with FDOT.
AJ: We are on the receiving end of good (reliable) WWD information. Our 62 cameras that can detect WWD and NOT good enough to dispatch from. (too many false calls from shadows, reflections, clouds, headlights, raindrops, etc.).
AK: As mentioned in the previous question, we have 62 cameras that do good job detecting WWD. We use these to see what countermeasures work and what do not. We are in year 2 of the data collection and have a few treatments that are extremely useful.
AL: Phone calls Co-location with FHP Dispatch

Table B6: Responses for the Content, Extension of Display, and Display Duration of Dynamic Message Signs

State	District / Agency:	**Q10.** What **content** does your agency display on **dynamic message signs** during an active wrong-way driving incident to alert right-way drivers on freeways? (Please specify)	**Q11.** How does your agency determine **which dynamic message signs** shall **display** the warning message during an active wrong-way driving incident? (Please specify)	**Q12.** For **how long** do you usually post messages on **dynamic message signs** during active wrong-way driving incidents on freeways? (Please specify)
Arizona	Arizona Department of Transportation (ADOT)	DMS	TOC	Check
Arkansas	Arkansas Department of Transportation	/	Location	/
Delaware	Delaware Department of Transportation (DelDOT)	This technology has not yet been deployed, however, it is in progress. We anticipate something along the lines of "WRONG WAY VEHICLE / PROCEED WITH CAUTION"	As of right now, it is the message board closest to the ramp. There are no other message boards in the vicinity.	Until law enforcement or transportation management center operators can clear the incident (whether they determine no threat exists, i.e., false detection or the wrong-way driving has terminated).
Florida	Florida Department of Transportation (FDOT)	WRONG WAY DRIVER REPORTED USE EXTREME CAUTION	All DMS within 10 miles upstream of the side of the road the wrong-way driving report was initiated or from alert from ramp with wrong-way vehicle detection system (WWVDS) installed.	TMC staff terminates the WWD event if it has been confirmed that the driver turned around, was stopped by law enforcement, crashes or there has not been any sign of or communication of a vehicle of interest for at least 10 minutes.
Florida	Florida Department of Transportation (FDOT) / District 1	WRONG WAY DRIVER ALERT USE EXTREME CAUTION	all DMS within a 15-mile radius of detection.	When a reported WWD cannot be found or confirmed after 15 minutes or when a confirmed WWD self-corrects or is intercepted and there is no longer any danger to the motoring public.
Florida	Florida Department of Transportation (FDOT) / District 2	Phase I WRONG WAY DRIVER AHEAD Phase II USE CAUTION	Geofenced in SunGuide™	Approximately 10 minutes
Florida	Florida Department of Transportation (FDOT) / District 3	Type of event Warning to Drivers	Based on Miles, 50-mile radius	20 minutes

Table B6, Continued: Responses for the Content, Extension of Display, and Display Duration of Dynamic Message Signs

State	District / Agency:	**Q10.** What **content** does your agency display on **dynamic message signs** during an active wrong-way driving incident to alert right-way drivers on freeways? (Please specify)	**Q11.** How does your agency determine **which dynamic message signs** shall **display** the warning message during an active wrong-way driving incident? (Please specify)	**Q12.** For **how long** do you usually post messages on **dynamic message signs** during active wrong-way driving incidents on freeways? (Please specify)
Florida	Florida Department of Transportation (FDOT) / District 4	WRONG WAY DRIVER REPORTED USE CAUTION	Part of messaging plan in SunGuide^{TM}.	Until the event is over
Florida	Florida Department of Transportation (FDOT) / District 5	Wrong Way Driver Reported Use Caution	Radius 15 miles	Until resolved
Florida	Florida Department of Transportation (FDOT) / District 6	General message advising of Wrong Way Driver.	Based on the information at the time of the incident upstream DMS (from known point of entry or wrong way vehicle spotted at location).	Until the wrong-way-driving vehicle is stopped.
Florida	Florida Department of Transportation (FDOT) / District 7	Please see the attached file: QRG Wrong Way Drivers 08-04-22	It is based on the location of the WDD and also coordination with local agencies QRG Wrong Way Drivers 08-04-22	"IF notified by FHP the RTMC keeps the WWD DMS messages for 10 minutes or if FHP reports back that they did not find any WWD where reported.
Florida	Florida Turnpike Enterprise (FTE)	Activate closest 10 miles of signs in both directions (or closest DMS sign if no devices within 10 miles) with the following message: WRONG WAY DRIVER REPORTED USE CAUTION	Activate closest 10 miles of signs in both directions (or closest DMS sign if no devices within 10 miles)	If the vehicle is not found in 15 minutes, call FHP to verify status of the WWD, then the signs can be blanked and the event "False Alarmed". If the vehicle is confirmed as a wrong way driver and/or self-corrects, send an email to TPKTMCMANAGER and TPKTMCATIS to advise on the status.
Georgia	Georgia Department of Transportation (GDOT)	Currently, no information is displayed on the DMS regarding the moving wrong way driving vehicle. (We can provide a better explanation via phone call.)	Currently, no information is displayed on the DMS regarding the moving wrong way driving vehicle. (We can provide a better explanation via phone call.)	Currently, no information is displayed on the DMS regarding the moving wrong way driving vehicle. (We can provide a better explanation via phone call.)

Table B6, Continued: Responses for the Content, Extension of Display, and Display Duration of Dynamic Message Signs

State	District / Agency:	**Q10.** What **content** does your agency display on **dynamic message signs** during an active wrong-way driving incident to alert right-way drivers on freeways? (Please specify)	**Q11.** How does your agency determine **which dynamic message signs** shall **display** the warning message during an active wrong-way driving incident? (Please specify)	**Q12.** For **how long** do you usually post messages on **dynamic message signs** during active wrong-way driving incidents on freeways? (Please specify)
Hawaii	Hawaii Department of Transportation (HDOT)	/	/	/
Iowa	Iowa Department of Transportation (IDOT)	We do not post this message in every metro area... but using more and more. Cedar Rapids, Iowa was our 1st metro to start We display for 10 minutes and use all DMS in a 10 mile radius of the approx location of the call... and in both directions. Assuming the caller knows where they are and the direction they are traveling is unreliable. WARNING WRONG WAY DRIVER REPORTED With enough time, we could probably evaluate the effectiveness of the message, but have not done yet.	Answered on previous	10 min. it is very rare that a WWD event lasts more than 10 min.... and we starting the message after the 911 caller calls the 911 center, and then they call the Iowa DOT TMC. So 3 to 5 minutes have already lapsed.
Kansas	Kansas Department of Transportation (KDOT)	Wrong way driver reported. Use Caution	Case by case	The approximate time between the wrong way driver and sign
Maine	Maine Department of Transportation (MaineDOT)	we don't	We don’t currently	N/A
Michigan	Michigan Department of Transportation	Wrong Way Driver Reported in Area Use Extreme Caution.	As soon as the agency is notified about a wrong way driver, the agency signs for a distance of two DMS signs.	Generally 10 -15 minutes.
Minnesota	Minnesota Department of Transportation (MnDOT)	None	N/A	N/A
Montana	Montana Department of Transportation (MDT)	Not yet applicable	Not yet applicable	Not yet applicable

Table B6, Continued: Responses for the Content, Extension of Display, and Display Duration of Dynamic Message Signs

State	District / Agency:	**Q10.** What **content** does your agency display on **dynamic message signs** during an active wrong-way driving incident to alert right-way drivers on freeways? (Please specify)	**Q11.** How does your agency determine **which dynamic message signs** shall **display** the warning message during an active wrong-way driving incident? (Please specify)	**Q12.** For **how long** do you usually post messages on **dynamic message signs** during active wrong-way driving incidents on freeways? (Please specify)
Nebraska	Nebraska Department of Transportation (NDOT)	NA	I don't believe DMS signs are used.	NA
North Carolina	North Carolina Department of Transportation (NCDOT)	WRONG WAY DRIVER | REPORTED IN AREA | STAY ALERT	It's the same message unless there's a crash.	20 minutes; after 10 minutes, we're contacting law enforcement for updates.
Ohio	Ohio Department of Transportation (ODOT)	None as of yet...currently exploring this possibility.	N/A	N/A
Pennsylvania	Pennsylvania Department of Transportation (PennDOT)	Wrong Way Driver Ahead, Pull Over (this rarely has been used because it many times isn't caught in time, or there aren't DMS to support in the area).	any in the travel direction	Until the wrong way driver has been stopped or exits the expressway
Rhode Island	Rhode Island Department of Transportation (RIDOT)	Flashing Lights on rectangle signs	There is list of DMS associated with each WWD signs.	All depends on the duration of the WWD vehicle. This we have never used, because of the duration of the WWD incident (15 sec or less)
South Carolina	South Carolina Department of Transportation (SCDOT)	no policy or procedures	we do not activate	n/a
Texas	Texas Department of Transportation (TxDOT)	WRONG WAY DRIVER REPORTED --- USE EXTREME CAUTION WRONG WAY DRIVER DETECTED USE CAUTION	Wrong-way driver warning messages are displayed to DMS on the potential impact routes that the WWD could have an impact on.	Displayed until (1) WWD stopped, (2) crash located, or 3) Police department cancels the alert.
Utah	Utah Department of Transportation (UDOT)	We have not used our dynamic message signs for WWD incidents to this point	N/A	N/A

Table B6, Continued: Responses for the Content, Extension of Display, and Display Duration of Dynamic Message Signs

State	District / Agency:	**Q10.** What **content** does your agency display on **dynamic message signs** during an active wrong-way driving incident to alert right-way drivers on freeways? (Please specify)	**Q11.** How does your agency determine **which dynamic message signs** shall **display** the warning message during an active wrong-way driving incident? (Please specify)	**Q12.** For **how long** do you usually post messages on **dynamic message signs** during active wrong-way driving incidents on freeways? (Please specify)
Vermont	Vermont Agency of Transportation (VTrans)	Typically none.	Law Enforcement and TMC Operators would discuss the specific incident	Varies / N/A
Virginia	Virginia Department of Transportation (VDOT)	None at this time	Response plans via the Advanced Traffic Management System (ATMS) for any incident.	N/A
Washington	Washington State Department of Transportation (WSDOT)	Wrong Way Vehicle Use Caution	If the wrong way driver is verified to be downstream of the DMS that faces traffic in the correct direction.	until the vehicle has stopped or pass the DMS.
Wyoming	Wyoming Department of Transportation (WYDOT)	Wyoming Highway Patrol assesses the situation and determines the content on the DMS	They try to estimate the location and try to get out in front of the wrong way driver. Wyoming Highway Patrol assesses the situation and determines the content on the DMS	Until the WY Highway Patrol reports the driver is no longer on the given Interstate system. Wyoming Highway Patrol assesses the situation and determines the content on the DMS

Table B7: Responses for the Information Documented in a WWD Incident

State	District / Agency:	**Q13.** Which of the following **information is documented** in a wrong-way driving incident on the freeway? (Please select all that apply)						
		Final location of the wrong-way driver	Location where the wrong-way driver entered the freeway	Direction of travel of the wrong-way driver	Vehicle description	Detection method/information	Event result (e.g., crash, intercept, WWD left the freeway)	Other (please specify)
Arizona	Arizona Department of Transportation (ADOT)	X	X	X	X	X	X	A
Arkansas	Arkansas Department of Transportation	X		X	X			
Delaware	Delaware Department of Transportation (DelDOT)	X	X	X	X		X	B
Florida	Florida Department of Transportation (FDOT)	X	X	X	X	X	X	I
Florida	Florida Department of Transportation (FDOT) / District 1	X	X	X	X	X	X	
Florida	Florida Department of Transportation (FDOT) / District 2	X	X	X	X	X	X	
Florida	Florida Department of Transportation (FDOT) / District 3		X	X			X	
Florida	Florida Department of Transportation (FDOT) / District 4	X	X	X	X	X	X	C
Florida	Florida Department of Transportation (FDOT) / District 5							
Florida	Florida Department of Transportation (FDOT) / District 6	X		X		X	X	D
Florida	Florida Department of Transportation (FDOT) / District 7	X	X	X	X	X	X	E
Florida	Florida Turnpike Enterprise (FTE)	X	X	X	X	X	X	
Georgia	Georgia Department of Transportation (GDOT)	X	X	X	X	X	X	F
Hawaii	Hawaii Department of Transportation (HDOT)							

Table B7, Continued: Responses for the Information Documented in a WWD Incident

State	District / Agency:	**Q13.** Which of the following **information is documented** in a wrong-way driving incident on the freeway? (Please select all that apply)						
		Final location of the wrong-way driver	Location where the wrong-way driver entered the freeway	Direction of travel of the wrong-way driver	Vehicle description	Detection method/information	Event result (e.g., crash, intercept, WWD left the freeway)	Other (please specify)
Iowa	Iowa Department of Transportation (IDOT)	X	X	X	X	X	X	J
Kansas	Kansas Department of Transportation (KDOT)		X				X	
Maine	Maine Department of Transportation (MaineDOT)		X					
Michigan	Michigan Department of Transportation	X	X	X			X	
Minnesota	Minnesota Department of Transportation (MnDOT)		X	X				
Montana	Montana Department of Transportation (MDT)	X	X	X	X	X	X	
Nebraska	Nebraska Department of Transportation (NDOT)	X	X	X	X		X	
North Carolina	North Carolina Department of Transportation (NCDOT)	X	X	X	X	X	X	
Ohio	Ohio Department of Transportation (ODOT)	X	X	X	X		X	
Pennsylvania	Pennsylvania Department of Transportation (PennDOT)		X	X		X	X	
Rhode Island	Rhode Island Department of Transportation (RIDOT)	X	X	X	X	X	X	
South Carolina	South Carolina Department of Transportation (SCDOT)							G
Texas	Texas Department of Transportation (TxDOT)	X	X	X	X	X	X	
Utah	Utah Department of Transportation (UDOT)		X	X	X		X	
Vermont	Vermont Agency of Transportation (VTrans)	X	X	X			X	
Virginia	Virginia Department of Transportation (VDOT)							H

Table B7, Continued: Responses for the Information Documented in a WWD Incident

State	District / Agency:	**Q13.** Which of the following **information is documented** in a wrong-way driving incident on the freeway? (Please select all that apply)						
		Final location of the wrong-way driver	Location where the wrong-way driver entered the freeway	Direction of travel of the wrong-way driver	Vehicle description	Detection method/information	Event result (e.g., crash, intercept, WWD left the freeway)	Other (please specify)
Washington	Washington State Department of Transportation (WSDOT)	X	X	X	X		X	
Wyoming	Wyoming Department of Transportation (WYDOT)	X	X	X	X		X	

A: This information is recorded on various reports, by ADOT and DPS. Also collect response time.
B: These are mostly captured in a crash report, only.
C: All this only if information is available.
D: Point of entry is very difficult to obtain.
E: If found on camera then will note in the incident report.
F: All the above information is documented in the crash report.
G: No specific documentation process.
H: N/A
I: Date and Time
J: I have a database of around 2,000 WWD events over the last 10 years.

Table B8: Responses for the Type of Data Collected and Analyzed in a WWD Incident

State	District / Agency:	**Q14.** What **type of data** does your agency **collect and analyze** in wrong-way driving incidents on freeways? (Please select all that apply)						
		Incident reports	Data from detection and warning systems	Video recordings	Reports from first responding agencies	Surveys of motorists	Wrong-way driving crash data	Other (please specify)
Arizona	Arizona Department of Transportation (ADOT)		X	X				A
Arkansas	Arkansas Department of Transportation						X	
Delaware	Delaware Department of Transportation (DelDOT)	X	X	X	X		X	
Florida	Florida Department of Transportation (FDOT)	X	X	X	X		X	C
Florida	Florida Department of Transportation (FDOT) / District 1	X	X		X		X	
Florida	Florida Department of Transportation (FDOT) / District 2	X	X		X		X	
Florida	Florida Department of Transportation (FDOT) / District 3	X					X	
Florida	Florida Department of Transportation (FDOT) / District 4	X	X		X		X	
Florida	Florida Department of Transportation (FDOT) / District 5							
Florida	Florida Department of Transportation (FDOT) / District 6	X	X		X		X	
Florida	Florida Department of Transportation (FDOT) / District 7	X	X		X		X	
Florida	Florida Turnpike Enterprise (FTE)	X	X		X		X	
Georgia	Georgia Department of Transportation (GDOT)	X	X	X	X		X	

Table B8, Continued: Responses for the Type of Data Collected and Analyzed in a WWD Incident

State	District / Agency:	**Q14.** What **type of data** does your agency **collect and analyze** in wrong-way driving incidents on freeways? (Please select all that apply)						
		Incident reports	Data from detection and warning systems	Video recordings	Reports from first responding agencies	Surveys of motorists	Wrong-way driving crash data	Other (please specify)
Hawaii	Hawaii Department of Transportation (HDOT)							
Iowa	Iowa Department of Transportation (IDOT)	X	X	X	X	X	X	D
Kansas	Kansas Department of Transportation (KDOT)	X		X	X		X	
Maine	Maine Department of Transportation (MaineDOT)	X	X				X	
Michigan	Michigan Department of Transportation	X	X		X		X	
Minnesota	Minnesota Department of Transportation (MnDOT)	X						
Montana	Montana Department of Transportation (MDT)	X			X	X	X	
Nebraska	Nebraska Department of Transportation (NDOT)	X					X	
North Carolina	North Carolina Department of Transportation (NCDOT)	X	X		X			
Ohio	Ohio Department of Transportation (ODOT)	X	X	X			X	
Pennsylvania	Pennsylvania Department of Transportation (PennDOT)	X		X	X		X	
Rhode Island	Rhode Island Department of Transportation (RIDOT)	X	X	X			X	
South Carolina	South Carolina Department of Transportation (SCDOT)							B
Texas	Texas Department of Transportation (TxDOT)	X	X		X		X	
Utah	Utah Department of Transportation (UDOT)	X	X	X	X		X	

Table B8, Continued: Responses for the Type of Data Collected and Analyzed in a WWD Incident

State	District / Agency:	**Q14.** What **type of data** does your agency **collect and analyze** in wrong-way driving incidents on freeways? (Please select all that apply)						
		Incident reports	Data from detection and warning systems	Video recordings	Reports from first responding agencies	Surveys of motorists	Wrong-way driving crash data	Other (please specify)
Vermont	Vermont Agency of Transportation (VTrans)	X			X		X	
Virginia	Virginia Department of Transportation (VDOT)	X					X	
Washington	Washington State Department of Transportation (WSDOT)	X		X	X		X	
Wyoming	Wyoming Department of Transportation (WYDOT)	X					X	

A: Dashboard to identify hotspots, locations, and trends.
B: No policy-specific data collected.
C: Advanced Traffic Management System (ATMS) Reports.
D: ANYTHING I can get, I store in an "WWD Event Folder" on our computer network.

Table B9: Responses for the Existence of Previous Studies and the Plans to Test New Technologies

State	District / Agency:	**Q15.** Has your agency conducted any studies or evaluations of the effectiveness of its policies, countermeasures, and response plans for addressing wrong-way driving incidents on freeways?	If yes. Please specify the agency studies or evaluations of the effectiveness of its policies, countermeasures, and response plans for addressing wrong-way driving incidents on freeways.	**Q16.** Is your agency planning to test new technologies to detect, prevent, or track wrong-way driving entries on freeways in the near future?	If yes. Please specify the agency planned tests of new technologies to detect, prevent, or track wrong-way driving entries on freeways in the near future.
Arizona	Arizona Department of Transportation (ADOT)	Yes	List	Yes	List
Arkansas	Arkansas Department of Transportation	No		Yes	Research Project to Test Wrong-Way Detection System
Delaware	Delaware Department of Transportation (DelDOT)	No		Yes	We have just deployed our wrong-way detection pilot system: https://www.wboc.com/news/deldot-implements-new-wrong-way-alert-system-to-reduce-deadly-crashes/article_b37983aa-c2c0-11ed-8779-ab7a4d0b5365.html

Table B9, Continued: Responses for the Existence of Previous Studies and the Plans to Test New Technologies

State	District / Agency:	**Q15.** Has your agency conducted any studies or evaluations of the effectiveness of its policies, countermeasures, and response plans for addressing wrong-way driving incidents on freeways?	If yes. Please specify the agency studies or evaluations of the effectiveness of its policies, countermeasures, and response plans for addressing wrong-way driving incidents on freeways.	**Q16.** Is your agency planning to test new technologies to detect, prevent, or track wrong-way driving entries on freeways in the near future?	If yes. Please specify the agency planned tests of new technologies to detect, prevent, or track wrong-way driving entries on freeways in the near future.
Florida	Florida Department of Transportation (FDOT)	Yes	SEPTEMBER 2014 Request to Experiment (RTE) - D3 Red Internally Illuminated Raised Pavement Markings, OCTOBER 2014 RTE - D7 Red Rectangular Rapid Flashing Beacon (RRFB), NOVEMBER 2015 (FSU) - Driving Simulator Studies on Human Factor, MARCH 2016 RTE- Florida Turnpike Red- RRFB, MARCH 2017 (CUTR) - Comparing Seven Countermeasures, NOVEMBER 2018 (CUTR)- Testing and Evaluation Video Detection Systems for Freeway Mainlines	Yes	The Department is open to receiving mainline or ramp detection products from suppliers at our Traffic Engineering Research Laboratory (TERL) for testing and evaluation if acceptable to install on the State Highway System. See: https://www.fdot.gov/traffic/traf-sys/traf-sys.shtm
Florida	Florida Department of Transportation (FDOT) / District 1	Yes	contact Edith Wong, PE in FDOT Central Office.	Yes	MVDS for main-line interstate detection.
Florida	Florida Department of Transportation (FDOT) / District 2	No		Yes	LiDAR and Video Analytics
Florida	Florida Department of Transportation (FDOT) / District 3	Yes	After Action Reviews, Dashboard Data, Data Comparison	Yes	Technology changes daily. Continued review and deployment is always considered.
Florida	Florida Department of Transportation (FDOT) / District 4	I am not sure		Yes	AI

Table B9, Continued: Responses for the Existence of Previous Studies and the Plans to Test New Technologies

State	District / Agency:	**Q15.** Has your agency conducted any studies or evaluations of the effectiveness of its policies, countermeasures, and response plans for addressing wrong-way driving incidents on freeways?	If yes. Please specify the agency studies or evaluations of the effectiveness of its policies, countermeasures, and response plans for addressing wrong-way driving incidents on freeways.	**Q16.** Is your agency planning to test new technologies to detect, prevent, or track wrong-way driving entries on freeways in the near future?	If yes. Please specify the agency planned tests of new technologies to detect, prevent, or track wrong-way driving entries on freeways in the near future.
Florida	Florida Department of Transportation (FDOT) / District 5				
Florida	Florida Department of Transportation (FDOT) / District 6	I am not sure		Yes	FDOT is currently deploying wrong way driving detection systems at various off-ramps, still learning from those deployments. FDOT is evaluating implementing other solutions such as illuminated pavement markers.
Florida	Florida Department of Transportation (FDOT) / District 7	Yes	Number of WWD, WWD correction on off-ramp by drivers due to the implementation of the WWD devices on the off ramps.	Yes	New WWD devices included on the APL.
Florida	Florida Turnpike Enterprise (FTE)	Yes	Wrong Way Driving Phase 1 BDV24 TWO 836-001 (2014-2015) Wrong Way Driving Phase 2 (BDV24 TWO 836-002)	Yes	Additional WWVDS deployment Turnpike-systemwide.
Georgia	Georgia Department of Transportation (GDOT)	Yes	Can be provided in follow up.	Yes	Event data from vehicles.

Table B9, Continued: Responses for the Existence of Previous Studies and the Plans to Test New Technologies

State	District / Agency:	**Q15.** Has your agency conducted any studies or evaluations of the effectiveness of its policies, countermeasures, and response plans for addressing wrong-way driving incidents on freeways?	If yes. Please specify the agency studies or evaluations of the effectiveness of its policies, countermeasures, and response plans for addressing wrong-way driving incidents on freeways.	**Q16.** Is your agency planning to test new technologies to detect, prevent, or track wrong-way driving entries on freeways in the near future?	If yes. Please specify the agency planned tests of new technologies to detect, prevent, or track wrong-way driving entries on freeways in the near future.
Hawaii	Hawaii Department of Transportation (HDOT)				
Iowa	Iowa Department of Transportation (IDOT)	Yes	I have published 1 official document that is out for distribution. (Low Cost WWD Counter measure for Parclo "B" Interchanges). In the near future, (like next week) can be found here: https://aii.transportation.org/Pages/Systemic-Approach-to-Wrong-Way-Driver-Safety.aspx Working on other summaries. It is a constant work in progress.	Yes	Always willing to test anything new. We have a camera from Axis right now that we are testing. Will be doing our own evaluation of LED blinker signs.... also, I have some questions with the 2017 study that Florida did and would LOVE to pick the brains of the researchers of that study of Red RRFBs. (which actually has now prevented their use, and I'm not happy about that!!!!)
Kansas	Kansas Department of Transportation (KDOT)	I am not sure		Yes	Sensor detection of where events occur
Maine	Maine Department of Transportation (MaineDOT)	No		No	
Michigan	Michigan Department of Transportation	Yes	Currently an RFP has been released to scan all wrong way countermeasure possibilities.	I am not sure	

Table B9, Continued: Responses for the Existence of Previous Studies and the Plans to Test New Technologies

State	District / Agency:	**Q15.** Has your agency conducted any studies or evaluations of the effectiveness of its policies, countermeasures, and response plans for addressing wrong-way driving incidents on freeways?	If yes. Please specify the agency studies or evaluations of the effectiveness of its policies, countermeasures, and response plans for addressing wrong-way driving incidents on freeways.	**Q16.** Is your agency planning to test new technologies to detect, prevent, or track wrong-way driving entries on freeways in the near future?	If yes. Please specify the agency planned tests of new technologies to detect, prevent, or track wrong-way driving entries on freeways in the near future.
Minnesota	Minnesota Department of Transportation (MnDOT)	No		No	
Montana	Montana Department of Transportation (MDT)	No		Yes	We plan on using existing technologies for active warning systems. Very specific information is not yet available on the system specs.
Nebraska	Nebraska Department of Transportation (NDOT)	No		No	
North Carolina	North Carolina Department of Transportation (NCDOT)	I am not sure		Yes	We're working on grant to install at pilot locations.
Ohio	Ohio Department of Transportation (ODOT)	No		Yes	We are currently looking at using more video analytics to detect wrong way drivers.

Table B9, Continued: Responses for the Existence of Previous Studies and the Plans to Test New Technologies

State	District / Agency:	**Q15.** Has your agency conducted any studies or evaluations of the effectiveness of its policies, countermeasures, and response plans for addressing wrong-way driving incidents on freeways?	If yes. Please specify the agency studies or evaluations of the effectiveness of its policies, countermeasures, and response plans for addressing wrong-way driving incidents on freeways.	**Q16.** Is your agency planning to test new technologies to detect, prevent, or track wrong-way driving entries on freeways in the near future?	If yes. Please specify the agency planned tests of new technologies to detect, prevent, or track wrong-way driving entries on freeways in the near future.
Pennsylvania	Pennsylvania Department of Transportation (PennDOT)	No		Yes	We're developing installations to consider around hot spot off ramps in the Pittsburgh metro that would use video analytics and automated DMS messaging when detected.
Rhode Island	Rhode Island Department of Transportation (RIDOT)	Yes	The effectiveness is determining by the numbers of corrected drivers capture on the video.	No	
South Carolina	South Carolina Department of Transportation (SCDOT)	No		No	
Texas	Texas Department of Transportation (TxDOT)	Yes	TxDOT Research Project 0-6769 Report: Assessment of the Effectiveness of Wrong Way Driving Countermeasures and Mitigation Methods.	Yes	Connected vehicle based wrong-way driving detection and warning applications

Table B9, Continued: Responses for the Existence of Previous Studies and the Plans to Test New Technologies

State	District / Agency:	**Q15.** Has your agency conducted any studies or evaluations of the effectiveness of its policies, countermeasures, and response plans for addressing wrong-way driving incidents on freeways?	If yes. Please specify the agency studies or evaluations of the effectiveness of its policies, countermeasures, and response plans for addressing wrong-way driving incidents on freeways.	**Q16.** Is your agency planning to test new technologies to detect, prevent, or track wrong-way driving entries on freeways in the near future?	If yes. Please specify the agency planned tests of new technologies to detect, prevent, or track wrong-way driving entries on freeways in the near future.
Utah	Utah Department of Transportation (UDOT)	No		Yes	Have researched and tested various "off-the-shelf" detection and alert systems for WWD. Did a pilot test of the TAPCO and Carmanah systems. Have decided to go with the Carmanah system for wider deployment. Received funding to deploy 20 of these systems at prioritized freeway offramp locations in various parts of Utah, but mostly concentrated in the Salt Lake City metro area along I-15.
Vermont	Vermont Agency of Transportation (VTrans)	No		No	

Table B9, Continued: Responses for the Existence of Previous Studies and the Plans to Test New Technologies

State	District / Agency:	**Q15.** Has your agency conducted any studies or evaluations of the effectiveness of its policies, countermeasures, and response plans for addressing wrong-way driving incidents on freeways?	If yes. Please specify the agency studies or evaluations of the effectiveness of its policies, countermeasures, and response plans for addressing wrong-way driving incidents on freeways.	**Q16.** Is your agency planning to test new technologies to detect, prevent, or track wrong-way driving entries on freeways in the near future?	If yes. Please specify the agency planned tests of new technologies to detect, prevent, or track wrong-way driving entries on freeways in the near future.
Virginia	Virginia Department of Transportation (VDOT)	I am not sure		I am not sure	
Washington	Washington State Department of Transportation (WSDOT)	No		I am not sure	
Wyoming	Wyoming Department of Transportation (WYDOT)	I am not sure		I am not sure	

APPENDIX C: FLYER

FLORIDA INTERNATIONAL UNIVERSITY

Research Participants Needed!

What is the Study About?

The purpose of the study is to evaluate drivers' understanding of Dynamic Message Signs (DMS) messages related to wrong-way driving (WWD).

Who is Eligible?

English Speaking Florida residents, 18+ years, with valid U.S. driver's license.

What will you do?

You will be scheduled for an appointment to participate in a driving simulation experiment involving different freeway scenarios.

How long will it take?

This experiment will take about 3 hours of your time

Where?

FIU Engineering Center, 10555 W Flagler St, Miami, FL 33174

Compensation?

$50 Gift Card!

Call us to schedule an appointment!

305-348-4103

APPENDIX D: DEMOGRAPHIC QUESTIONNAIRE

DEMOGRAPHIC QUESTIONNAIRE

Enhancing Wrong-Way Driving (WWD) Message Comprehension: A Driving Simulator Study

1. How long have you had a Florida driver's license?
a. Less than 5 years
b. 5-10 years
c. 11-15 years
d. 16-20 years
e. 21+

2. How old are you?
a. 18-24
b. 25-40
c. 40-64
d. 65+

3. Gender
a. Male
b. Female
c. Other

4. Race/Ethnicity
a. Caucasian
b. Black/African American
c. Asian
d. Hispanic
e. Other

5. What is your city of residence? ________________________

6. How far do you typically drive in one year?
a. 0-5000 miles
b. 5,000-10,000 miles
c. 10,000-15,000 miles
d. 15,000-20,000 miles
e. 20,000 miles+

7. What is your highest level of education?
a. High School
b. College

c. Bachelor’s Degree
d. Graduate School

8. What is your range of income?
a. 0-10,000
b. 10,000-25000
c. 25,000-40,000
d. 40,000-55,000
e. 55,000-70,000
f. 70,000+

9. Have you ever experienced a wrong-way driving incident in the last 5 years?
a. Yes
b. No

If yes, how were you notified about the incident (Dynamic Message Signs (DMS) or other means)?
If other means, what was it?

10. Are you a professional driver, like a taxi driver or truck driver?

a. Yes

b. No

11. Do you have a history of severe motion sickness or seizures?

a. Yes

b. No

12. Do you have experience with virtual reality games (such as simulators)?

a. Yes

b. No

APPENDIX E: EXIT SURVEY

EXIT SURVEY

Enhancing Wrong-Way Driving (WWD) Message Comprehension: A Driving Simulator Study

1. How did you respond to the wrong-way driving (WWD) incident messages on the dynamic message signs (DMS)?
a. Slowing down
b. Moving to slower lanes
c. Both a & b
d. Other ways

If other ways, how exactly did you respond to the WWD messages on DMS?

2. Which WWD message format got your attention quickly and easily?
a. Regular WWD message
b. WWD message with a “USE EXTREME CAUTION” phrase
c. Blinking/Flashing WWD message
d. Two-Phase WWD message

3. Do you have any suggestions as to what can be done to improve your response to the WWD messages on DMS?

4. Do you have any suggestions as to what can be done to make this driving simulation experiment better in the future?

APPENDIX F: CONSENT FORM

FIU IRB Approval:	01/29/2024
FIU IRB Expiration:	01/29/2027
FIU IRB Number:	IRB-24-0024

FIU | FLORIDA INTERNATIONAL UNIVERSITY

ADULT CONSENT TO PARTICIPATE IN A RESEARCH STUDY

Enhancing Wrong-Way Driving (WWD) Message Comprehension: A Driving Simulator Study

SUMMARY INFORMATION

Things you should know about this study:

- **Purpose:** The purpose of the study is to evaluate drivers' understanding of Dynamic Message Signs (DMS) messages related to wrong-way driving (WWD) on freeways.
- **Procedures**: If you choose to participate, you will be asked to engage in a driving simulation experiment. Please note that pictures will be taken for reporting purposes.
- **Duration:** This will take about 180 minutes of your time.
- **Risks**: Simulator sickness can happen in the form of nausea, headache, drowsiness, and eye discomfort.
- **Benefits**: Participants in the driving simulation study will not receive any direct benefits.
- **Alternatives:** There are no known alternatives available to you other than not taking part in this study.
- **Participation:** Taking part in this research project is voluntary.

Please carefully read the entire document before agreeing to participate.

PURPOSE OF THE STUDY

This study is centered on evaluating drivers' understanding of DMS messages related to WWD. The research team will execute a driving simulator study to gauge how well drivers comprehend WWD-related DMS messages. The task will take place in a driving simulator environment to analyze how quickly and easily a diverse group of drivers in Florida comprehend these messages.

NUMBER OF STUDY PARTICIPANTS

If you decide to be in this study, you will be one of at least 50 people participating in this research study. The team will verify participants' qualifications for study inclusion, such as having a valid U.S. driver's license.

DURATION OF THE STUDY

Your involvement in the driving simulation experiment will require approximately 180 minutes of your time. Your feedback will remain confidential, and only authorized personnel will be able to access your responses.

FIU IRB Approval:	01/29/2024
FIU IRB Expiration:	01/29/2027
FIU IRB Number:	IRB-24-0024

PROCEDURES

If you agree to be in the study, we will ask you to do the following things:

1. Read, complete, and sign this Informed Consent Form.
2. At a minimum, you will then be asked the following demographic questions:
   - City of residence,
   - Gender,
   - Age,
   - Ethnicity,
   - Level of education, and
   - Years of driving in the U.S.
3. Participate in at least two freeway driving simulation scenarios. The first scenario will familiarize you with the driving simulation environment, which might not be used in the study's data analysis. You will then participate in at least one more scenario, which will be included in the data analysis.
4. Fill out an exit survey at the end of the driving simulation experiment.

   Note: Still pictures will be taken for reporting purposes.

RISKS AND/OR DISCOMFORTS

Simulator sickness can develop during the simulation experiment in the form of nausea, headache, drowsiness, and eye discomfort. On such occasions you will be provided with water and a break time to reduce the effects of such sickness symptoms. For your safety, you can quit the experiment anytime you feel any form of sickness or discomfort.

BENEFITS

- There are no known benefits to you for participating in this study.
- Your input will aid the research team in pinpointing the most effective and beneficial ways of utilizing DMSs during WWD events.

ALTERNATIVES

There are no known alternatives available to you other than not taking part in this study. As previously mentioned, participation is voluntary, and there are no repercussions for deciding not to take part. Any significant new findings developed during the course of the research that may relate to your willingness to continue participation will be provided to you.

CONFIDENTIALITY

The records of this study will be kept private and will be protected to the fullest extent provided by law. In any sort of report we might publish, we will not include any information that will make it possible to identify you. Research records will be stored securely, and only the researcher team will have access to the records. However, your records may be inspected by authorized University or other agents who will also keep the information confidential.

FIU IRB Approval:	01/29/2024
FIU IRB Expiration:	01/29/2027
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USE OF YOUR INFORMATION

Not Applicable. This research does not involve collecting identifiable private information and/or biospecimens.

COMPENSATION & COSTS

At the conclusion of the driving simulation experiment, you will be compensated with a $50 Amazon gift card. There are no charges associated with your participation in this study.

RIGHT TO DECLINE OR WITHDRAW

Your participation in this study is voluntary. You are free to participate in the study or withdraw your consent at any time during the study. You will not lose any benefits if you decide not to participate or if you quit the study early. The investigator reserves the right to remove you without your consent at such time that he/she feels it is in the best interest.

RESEARCHER CONTACT INFORMATION

If you have any questions about the purpose, procedures, or any other issues relating to this research study you may contact the Principal Investigator, Dr. Priyanka Alluri at FIU Engineering Center, 305-348-3485, or by email at palluri@fiu.edu.

IRB CONTACT INFORMATION

If you would like to talk with someone about your rights of being a subject in this research study or about ethical issues with this research study, you may contact the FIU Office of Research Integrity by phone at 305-348-2494 or by email at ori@fiu.edu.

PARTICIPANT AGREEMENT

I have read the information in this consent form and agree to participate in this study. I have had a chance to ask any questions I have about this study, and they have been answered for me. I understand that I will be given a copy of this form for my records.

_______________________________ _______________

Signature of Participant Date

____

Printed Name of Participant

_______________________________ _______________

Signature of Person Obtaining Consent Date

APPENDIX G: CITI COMPLETION CERTIFICATE

CITI PROGRAM

Completion Date	20-Nov-2023
Expiration Date	N/A
Record ID	59769481

This is to certify that:

Abdallah Kinero

Not valid for renewal of certification through CME.

Has completed the following CITI Program course:

Responsible Conduct of Research for Engineers
(Curriculum Group)
Responsible Conduct of Research for Engineers
(Course Learner Group)
1 - RCR
(Stage)

Under requirements set by:

Florida International University

CITI
Collaborative Institutional Training Initiative

101 NE 3rd Avenue, Suite 320
Fort Lauderdale, FL 33301 US
www.citiprogram.org

Verify at www.citiprogram.org/verify/?w2e9369e6-bfb9-4b93-98f2-fdcac361b65c-59769481