CUTR
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BDV25-977-29

Final Report

Comparing Countermeasures for Mitigating Wrong-Way Entries onto Limited Access Facilities

March 2017

PREPARED FOR

Florida Department of Transportation

Center for Urban Transportation Research
University of South Florida
4202 E. Fowler Ave., CUT100, Tampa, FL 33620-5375

Comparing Countermeasures for Mitigating Wrong-Way Entries onto Limited Access Facilities

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Final Report

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March 2017

DISCLAIMER

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

UNIT CONVERSION TABLE

APPROXIMATE CONVERSIONS TO SI UNITS

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

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

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

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

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

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

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

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16. Abstract

Wrong-way crashes are a major cause for safety concerns along freeways and limited-access facilities. Although wrong-way crashes account for a relatively small portion of total crashes, the impact between two cars crashing into each other at high speeds in opposite directions often results in severe injuries or fatalities compared to any other type of crash. Despite providing the necessary “DO NOT ENTER” and “WRONG WAY” signs and pavement markings (wrong-way arrows, etc.), as per the *Manual on Uniform Traffic Control Devices* (MUTCD), wrong-way entry onto limited-access facilities is still occurring. To seek solutions for mitigating wrong-way driving (WWD), tests involving a number of countermeasures using Intelligent Transportation Systems (ITS) technologies have been conducted through FDOT pilot projects. This project looked to evaluate these WWD countermeasures developed through these pilot projects and come up with recommendations of the most effective and informing WWD countermeasures through analysis of existing data and studies, field testing using focus groups, a public opinion survey, and a human factors approach using driving simulation. The results proved that red Rectangular Rapid Flashing Beacons (RRFBs) is the top countermeasure for mitigating WWD at freeway off-ramps, with wigwag flashing beacons as the second best, and detection-triggered blank-out signs and detection-triggered LED lights around “WRONG WAY” signs (tie) as third best WWD countermeasures. Red flush-mount Internally Illuminated Raised Pavement Markers (IIRPMs) could be considered as a supplemental countermeasure for mitigating WWD at freeway off-ramps. The countermeasure of delineators along off-ramps is the least effective and is not recommended to be used for deterring WWD at freeway off-ramps. This study further confirms that the newly-developed signing and pavement marking standards by FDOT is a very positive countermeasure on arterials to mitigate wrong-way entries onto freeway off-ramps.

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EXECUTIVE SUMMARY

Wrong-way crashes are a major cause for safety concerns along freeways and other limited-access facilities. Although wrong-way crashes account for a relatively small portion of total crashes, the impact between two vehicles crashing into each other at high speeds in opposite directions often result in severe injuries or fatalities as well as a large amount of monetary damage compared to any other type of crash. Despite providing the necessary "DO NOT ENTER" and "WRONG WAY" signs and pavement markings (arrows, etc.), as per the *Manual on Uniform Traffic Control Devices* (MUTCD), wrong-way entry on to limited-access facilities is still occurring. According to the Statewide Wrong-way Crash study published by the Florida Department of Transportation (FDOT) in April 2015 (Project No. 12274.03), there were 280 wrong-way crashes on Florida highways between 2009 and 2013, resulting in 75 fatalities. The majority of these wrong-way crashes (71%) occurred in dark conditions, and at least 45% of drivers in wrong-way crashes were impaired. Wrong-way countermeasures using ITS technologies have emerged in the past several years, and new technologies continue to expand opportunities to reduce crashes and wrong-way driving (WWD) events.

To seek solutions for mitigating WWD, tests involving a number of countermeasures using Intelligent Transportation Systems (ITS) technologies have been conducted through FDOT pilot projects and approved requests for experiments (RFEs) from the Federal Highway Administration (FHWA). However, it is not clear which countermeasures (or combination of countermeasures) are more promising for widespread implementation in Florida.

Before the completion of FDOT's RFE's and final approval of the proposed countermeasures by FHWA, guidance needs to be provided to FDOT districts, Florida's Turnpike Enterprise, and expressway authorities to implement the most effective and accepted traffic control devices to reduce WWD in the near future. In addition, if FDOT is given the choice to prioritize among WWD countermeasures, the selection of a countermeasure is very important. Therefore, a comprehensive evaluation of identified WWD countermeasures used in FDOT pilot projects and RFEs is essential for the development of such guidance.

Section 1 of this final report details the project background and objectives. In short, the major objective of this research was to compare the countermeasures currently used in pilot projects or RFEs and recommend the appropriate measures for future deployment consideration by FDOT. The countermeasures tested and evaluated included:

1. Newly-developed signing and pavement marking standards (FDOT *Plans Preparation Manual*, Figures 7.1.1. and 7.1.2)
2. Red Rectangular Rapid Flashing Beacons (RRFBs)
3. Red flush-mount Internally Illuminated Raised Pavement Markers (IIRPMs)
4. Detection-triggered light-emitting diode (LED) lights around "WRONG WAY" signs
5. Detection-triggered blank-out signs that flash "WRONG WAY"
6. Delineators along off-ramps
7. Wigwag flashing beacons

Section 2 addresses the first task of this project and includes a literature review conducted by Dr. Priyanka Alluri of Florida International University and a cost data summary prepared by Larry Hagen of Hagen Consulting Services, LLC. This section also includes a cost analysis for each countermeasure with detailed information from FDOT Districts 3 and 7 and Florida's Turnpike Enterprise about the cost of the implemented WWD countermeasure equipment obtained.

Section 3 provides a brief description regarding the following four methodologies used in the WWD countermeasures evaluation for this project: analysis of existing data and studies, field testing using focus groups, a public opinion survey, and a human factors approach using driving simulation.

Section 4 summarizes the analysis of existing data and studies using the literature review and cost data.

Section 5 addresses the effort and results of the field testing and evaluation of the seven identified WWD countermeasures using focus groups. Based on the results of the driver focus group survey, focus group discussions, and consensus of five core focus group members, the top three most effective WWD countermeasures are (1) red RRFBs, (2) detection-triggered blank-out signs, and (3) wigwag flashing beacons. The effectiveness of the detection-triggered blank-out signs countermeasure was found to be very close to that of the red RRFBs countermeasure.

Section 6 summarizes the assessment and comparison of the perceived effectiveness of the identified WWD countermeasures obtained through a public opinion survey using pre-recorded field videos. A video was recorded for each countermeasure at a selected site. The videos were recorded from the driver's perspective to maximize the feeling of survey participants driving the vehicle themselves. After the videos were edited using video editing software, a set of survey questions was designed and pilot-tested. A total of 250 participants in different age groups (16–29, 30–59, 60+) and genders were recruited to review pre-recorded field videos and participate in a public opinion survey with the goal of attaining a representative group that replicates the general public. The survey participants reviewed the pre-recorded videos, answered survey questions, and provided rankings regarding their perceived effectiveness and acceptance of the countermeasures.

According to the average of the rankings by the public opinion survey participants, red RRFBs were found to be the most effective and informative countermeasure for freeway off-ramps to deter WWD, followed by wigwag flashing beacons, detection-triggered LED lights around "WRONG WAY" signs, and detection-triggered blank-out signs that flash "WRONG WAY." Red flush-mount IIRPMs could be considered as a supplemental countermeasure. The countermeasure of delineators along off-ramps was found to be the least effective and informative. The above results were also confirmed from statistical tests. No statistically-significant difference was found between red RRFBs and wigwag flashing beacons on their perceived effectiveness for deterring WWD.

Based on nonparametric tests, red RFRBs were ranked as being significantly more effective than detection-triggered LEDs and detection-triggered blank-out signs at the 5% and 1% levels, respectively. Detection-triggered LEDs and wigwag flashing beacons were ranked as significantly more effective than detection-triggered blank-out signs at the 10% and 1% levels, respectively. Results from the public opinion survey confirmed that the newly-developed signing and pavement marking standards for arterials near freeway off-ramps provide a significant improvement to mitigate WWD.

Section 7 summarizes the analysis and comparison of the effectiveness of identified WWD countermeasures via a human factors approach using driving simulation. This task was conducted by Dr. Walter Boot of the Florida State University. Based on the simulation results, it was determined that countermeasure #1 (newly-developed signing and pavement markings) should be implemented to reduce confusion regarding freeway entry points. In addition, the implementation of dynamic “WRONG WAY” signs, including red RRFBs (countermeasure #2), detection-triggered LED lights around “WRONG WAY” signs (countermeasure #4), and wigwag flashing beacons (countermeasure #7) should be considered to mitigate wrong-way crashes. Last, detection triggered blank-out signs that flash “WRONG WAY”(countermeasure #5) when a driver is approaching may not effectively warn drivers in time that they are going the wrong-way and are not recommended.

Section 8 summarizes the evaluation results of selected WWD countermeasures. The top countermeasures are (1) red RRFBs, (2) wigwag flashing beacons, and (3) detection-triggered blank-out signs and detection-triggered LED lights around “WRONG WAY” signs (tie).

Finally, Section 9 summarizes the conclusions and recommendations of this research project:

- Countermeasure #1, newly-developed signing and pavement marking standards, was confirmed throughout the study as a very positive countermeasure on arterials to mitigate wrong-way entries onto freeway off-ramps.
- Countermeasure #2, red RRFBs, is the top countermeasure for mitigating WWD at freeway off-ramps and informing the Traffic Management Center (TMC) and is strongly recommended to be installed at off-ramps.
- Countermeasure #7, wigwag flashing beacons, is the second-best countermeasure for mitigating WWD at freeway off-ramps and informing the TMC.
- Countermeasure #5, detection-triggered blank-out signs that flash “WRONG-WAY,” is an effective countermeasure for mitigating WWD at freeway off-ramps and informing the TMC. However, if implemented, it is not recommended as a stand-alone device without other static “WRONG WAY” signs.
- Countermeasure #4, detection-triggered LED lights around “WRONG WAY” signs, is an effective countermeasure for mitigating WWD at freeway off-ramps and informing the TMC and has a relatively low cost.
- Countermeasure #3, Red flush-mount IIRPMs could be considered a supplemental countermeasure for mitigating WWD at freeway off-ramps.
- Countermeasure #6, delineators along off-ramps, is the least effective countermeasure and is not recommended to be used for deterring WWD at freeway off-ramps.
- Further examination of increasing the length of WWD detection zones in Countermeasures #2, #4, #5 and #7 is recommended so wrong-way drivers will have longer time to see and react to the WWD warnings.
- Further examination of adjusting the area covered by the radar detection zones of Countermeasures #2, #4, #5 and #7 is recommended to minimize false WWD detection.

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1 INTRODUCTION

1.1 Background

Wrong-way crashes are a major cause for safety concerns along freeways and limited-access facilities. Although wrong-way crashes account for a relatively small portion of total crashes, the impact between two cars crashing into each other at high speeds in opposite directions often results in severe injuries or fatalities. Despite providing the necessary “DO NOT ENTER” and “WRONG WAY” signs and pavement markings (wrong-way arrows, etc.) as per the *Manual on Uniform Traffic Control Devices* (MUTCD), wrong-way entry onto limited-access facilities is still occurring. According to the Statewide Wrong-way Crash study published by the Florida Department of Transportation (FDOT) in April 2015 (Project No. 12274.03), there were 280 wrong-way crashes on Florida highways between 2009 and 2013, resulting in 75 fatalities. The majority of these wrong-way crashes (71%) occurred in dark conditions, and at least 45% of drivers in wrong-way crashes were impaired. Wrong-way countermeasures using ITS technologies have emerged in the past several years, and new technologies continue to expand opportunities to reduce crashes and wrong-way driving (WWD) events.

To seek solutions for mitigating wrong-way driving, tests involving a number of countermeasures using Intelligent Transportation Systems (ITS) technologies have been performed through FDOT pilot projects and approved RFEs from the Federal Highway Administration (FHWA). However, it is not clear which countermeasures (or combination of countermeasures) are more promising for widespread implementation in Florida.

The FDOT pilot projects and RFEs comprise the following:

- FDOT District 3 – Four locations on I-10 in Tallahassee, with installations that include detection triggered blank-out signs that flash “WRONG WAY” as well as four locations on I-10 and I-110 in Holmes, Washington, and Escambia counties with red flush-mount Internally Illuminated Raised Pavement Markers (IIRPMs).
- FDOT District 7 – Fifteen locations in high risk areas, with installations that include but are not limited to microwave vehicle detectors, red Rectangular Rapid-Flashing Beacon (RRFB) assemblies coupled with “WRONG WAY” signs, etc.; experimentation is being analyzed by the Center for Urban Transportation Research (CUTR) at the University of South Florida.
- Florida’s Turnpike Enterprise (FTE) – Fifteen locations in South Florida, with installations that include but are not limited to light-emitting diode (LED)-illuminated blinking “WRONG WAY” signs activated by forward radar, etc.
- Central Florida Expressway Authority (CFX) – Five locations on SR-408 in Orlando, with installations that include but are not limited to combinations of two manufacturer devices, two sets of LED-illuminated signs on both sides of road and activated by detection devices, etc.; focus is on lost or confused drivers (e.g., tourists and older adult population); University of Central Florida analyzing data for one year.

Before completion of FDOT’s requests for experiments and (RFEs) final approval of the proposed countermeasures by FHWA, guidance needs to be provided to FDOT Districts, Florida’s Turnpike

Enterprise, and expressway authorities to implement the most effective and accepted traffic control devices to reduce WWD in the near future. In addition, if FDOT is given the choice to prioritize among the WWD countermeasures, the countermeasure selection is very important. Therefore, a comprehensive evaluation of identified WWD countermeasures used in the FDOT pilot projects and RFEs was essential for the development of such guidance.

1.2 Project Objectives

The major objective of this research was to compare the countermeasures currently used in the pilot projects or RFEs and recommend the appropriate measures for future deployment consideration by FDOT. The countermeasures tested and evaluated included:

1. Newly-developed signing and pavement marking standards (*FDOT Plans Preparation Manual*, Figures 7.1.1. and 7.1.2)
2. Red rectangular rapid flashing beacons (RRFBs)
3. Red flush-mount Internally Illuminated Raised Pavement Markers (IIRPMs)
4. Detection-triggered LED lights around “WRONG WAY” signs
5. Detection-triggered blank-out signs that flash “WRONG WAY”
6. Delineators along off-ramps
7. Wigwag flashing beacons

This project comprised several major objectives:

1. Compare the available results from each pilot study, including the RFEs.
2. Evaluate WWD countermeasures via simulation and considering human psychology factors.
3. Conduct field evaluation on WWD countermeasures at each selected site.
4. Assess public perception of WWD countermeasures via public opinion surveys.
5. Develop recommendations for statewide uniform implementation of the most effective and accepted wrong-way countermeasures to reduce WWD.

Specifically, the major tasks of this project include the following:

1. Collect detailed information, available data, and analysis results of each pilot project and request for experiments.
2. Examine available data from pilot projects and RFEs, compare analysis results and costs for implementation, and assess the effectiveness of the seven identified WWD countermeasures.
3. Develop field testing methodology and conduct field testing and evaluation to compare the seven identified WWD countermeasures noted above.
4. Assess the perception and acceptance from the general public on seven identified WWD countermeasures via public opinion surveys.
5. Evaluate the identified WWD countermeasures using driving simulators.
6. Using results from Task 5, identify human factors testing on elements that need further evaluation.
7. Recommend the most promising countermeasure(s) for statewide uniform implementation to reduce WWD in Florida.

1.3 Report Organization

This final report is organized into nine sections along with an executive summary, references, and appendices:

1. Introduction
2. Literature Review of Wrong-Way Driving and Selected Countermeasures
3. Methodology for Countermeasure Evaluations
4. Evaluation of Countermeasures via Analysis of Existing Data and Studies
5. Evaluation of Countermeasures via Field Testing using Focus Groups
6. Evaluation of Countermeasures via a Public Opinions Survey
7. Evaluation of Countermeasures via a Human Factors Approach using Driving Simulation
8. Summary of Evaluation Results
9. Conclusions and Recommended Countermeasures for Future Implementation

2 LITERATURE REVIEW OF WWD AND SELECTED COUNTERMEASURES

A WWD crash is one in which a vehicle traveling in a direction opposing the legal flow of traffic on a high-speed divided highway or access ramp collides with a vehicle traveling on the same roadway in the proper direction (FHWA, 2016). Because wrong-way crashes typically involve head-on or side-swipe opposite direction crashes, they tend to result in more severe injuries. Over the past five decades, national, state, and local agencies have been working toward mitigating WWD instances and have been implementing countermeasures focusing on all the 4 E's of roadway safety—Engineering, Education, Enforcement, and Emergency Medical Services. Table 1 lists some of these countermeasures.

Table 1: Countermeasures for Mitigating WWD Incidents and Crashes

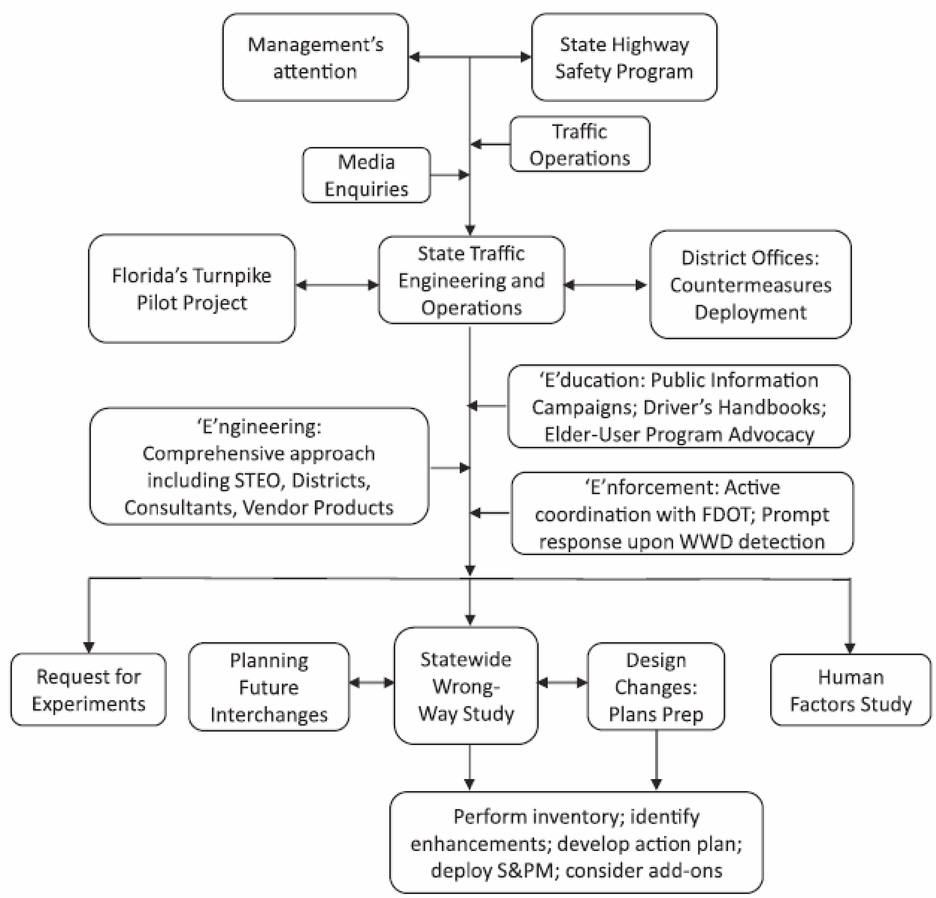
Engineering			
Signing	***Pavement Marking***	***Geometric Improvement***	***ITS Technologies***
• Standard "WRONG-WAY" sign package • Improved static signs • Lowered sign height • Oversized signs • Multiple signs on same post • Red retro-reflective tape on vertical posts • "FREEWAY ENTRANCE" signs for all on-ramps to ensure right-way driving	• Stop bar • Wrong-way arrow • Turn/through lane-only arrow • Raised pavement markers • Short dashed lane to delineate through turns	• Entrance/off-ramp separation • Raised curb median • Longitudinal channelizer • Changed ramp geometrics: – Obtuse angle – Sharp corner radii	• LED-illuminated signs • Dynamic signs to warn other drivers • Existing GPS navigation technologies to provide wrong-way movement alerts • Consistent messages/alerts that are intuitive to driver
Enforcement			
• Alerting of law enforcement agency • Enforcement of driving under influence (DUI) laws • Dynamic message sign (DMS) to warn right-way drivers • Portable spike barriers to stop wrong-way drivers; implemented by Harris County Toll Road Authority, Texas			
Education			
• Public awareness and understanding of basics of road designs and interchange types and proactive behaviors (witnessing a wrong-way driver) • Focus groups involving older drivers, DUI drivers, and young drivers			

Source: Zhou and Rouholamin, 2014

With an average of 28 annual WWD fatalities from 2004–2011, Florida ranks 3rd in the nation, behind only Texas and California (Baratian-Ghorghi et al., 2014). FDOT has increased its focus on mitigating WWD incidents through a holistic approach focusing on continual consultation, coordination, and communication among all stakeholders. On the research front, FDOT has focused on several aspects, including studying wrong-way crashes and citations and striving to increase understanding of the role of human cognition in driver decision-making. One of FDOT's main objectives is to step beyond conventional countermeasures and apply technologies for minimizing WWD crashes. As such, FDOT has initiated several pilot projects and RFEs to install innovative countermeasures to mitigate WWD incidents in the state. This report describes these countermeasures in detail.

2.1 Policy-oriented Approaches to Mitigate WWD Incidents in Florida

Ponnaluri (2016) presented a "policy-oriented framework toward addressing WWD incidents in a systematic manner and suggested a systemic discipline for transforming policy objectives to actionable outcomes." Figure 1 presents this framework with the backdrop of leadership-supported institutionalization to strategize road safety improvements.



Source: Ponnaluri, 2016

Figure 1: FDOT's Framework to Mitigate WWD Incidents

As illustrated, the holistic approach taken by the FDOT leadership includes:

- Implementing pilot projects.
- Conducting a statewide study with crash evaluation and field reviews, identifying interchange types, and developing countermeasures.
- Evaluating and deploying experimental devices specifically approved by FHWA.
- Conducting a human factors study.
- Transforming recommendations to design guidance.
- Discussing with planners on interchange types susceptible to WWD incidents.
- Retrofitting off-ramps with the recommended countermeasures.
- Leveraging the media to promote awareness and educate the public about the dangers of driving under the influence.

2.2 Statistical Analysis of WWD Crashes

Kittelson & Associates (2015) conducted a detailed statewide study of WWD crashes in Florida focusing on analyzing trends and contributing factors surrounding WWD incidents on limited access facilities. Some of the most relevant statistics include the following:

- From 2009–2013, the most recent five-year period for which data are available, approximately 280 WWD crashes occurred on Florida's freeways and expressways, resulting in more than 400 injuries and 75 fatalities.
- Weekends and early morning hours (12:00–6:00 AM) were found to be more susceptible to WWD crashes.
- Impaired drivers were involved in 45% of WWD crashes.
- Approximately 71% of WWD crashes occurred in dark conditions.
- Approximately 75% of WWD crashes occurred in urban areas and 25% in rural areas.
- The majority of WWD movements are entering the freeway/expressway from an off-ramp.
- Diamond/partial diamond, partial cloverleaf, and trumpet interchange types experienced the highest number of WWD crashes; the full cloverleaf interchange type experienced the lowest. However, this information is not normalized by the level of exposure.

2.3 Impact of Human Factors on WWD Crashes

Boot et al. (2015) conducted a human factor study to understand the role of human cognition in the driver decision-making process and focused primarily on nighttime crashes involving impaired drivers and daytime crashes involving older drivers. The authors concluded that a combination of cues help drivers pursue safe driving options; no particular sign or a lane marking but a combination of cues provide sensory inputs to drivers for making decisions. Based on an extensive literature review, the authors developed a decision-making process related to wrong-way entries and crashes. A recommendation from this study is that WWD crashes could be reduced at problematic interchanges by increasing the number and diversity of countermeasures.

2.4 Education Efforts to Reduce WWD Incidents

The Florida Department of Highway Safety and Motor Vehicles (DHSMV) has been leading extensive education efforts to reduce WWD incidents. The "StayRightatNight" campaign urges drivers to avoid a crash with a wrong-way driver and has generated significant interest on social media. On its website and through several avenues, DHSMV offers the following safety tips to avoid WWD crashes (DHSMV, 2016):

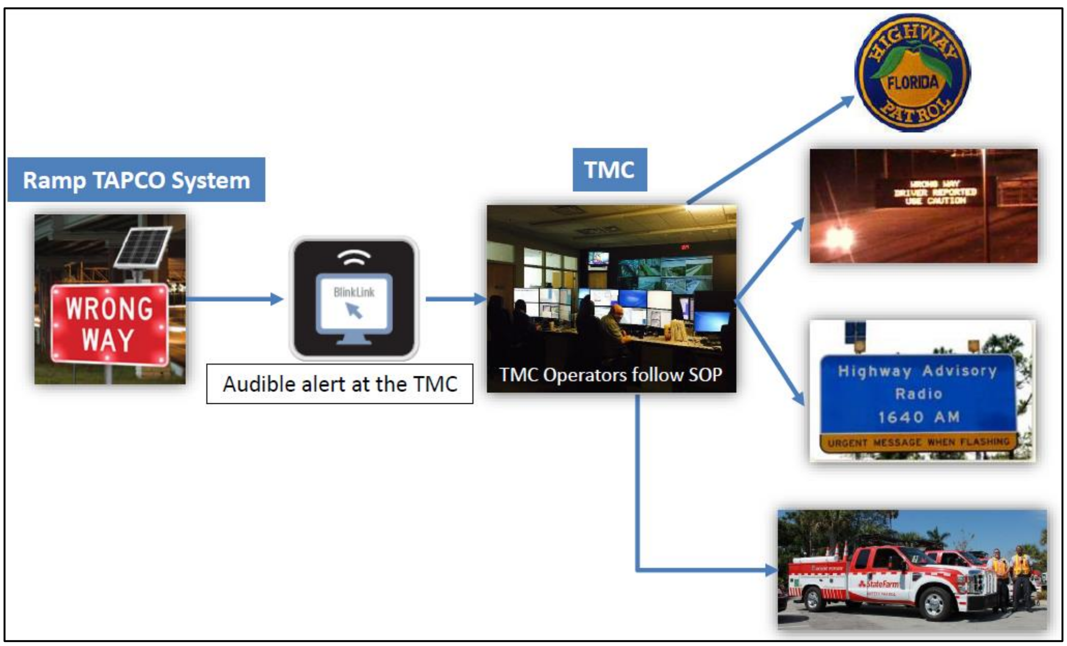
- "Stay Right at Night" to avoid crashes with wrong-way drivers.
- Call 911 immediately to report wrong-way drivers. If you see a wrong-way driver approaching, immediately reduce your speed and pull off the roadway.
- Learn and obey all traffic signs. If you drive past a "WRONG WAY" sign, turn around as soon as it is safe to do so.
- Look for FDOT dynamic messaging signs for wrong-way driver alerts.
- When you see a posted red sign, think: "Stop, do not enter, wrong way."
- Stay alert – do not drive distracted or impaired.

2.5 Real-time Procedure to Mitigate WWD Incidents

The main objective related to WWD for FDOT or any agency is to first mitigate drivers from making the wrong-way maneuver and, next, to deal with wrong-way maneuvers before they turn into wrong-way crashes. If a wrong-way driver misses all the cues on an arterial and the off-ramp, and enters the freeway from the off-ramp, the last and final resort is to alert the traffic on the freeway and the police to prevent a crash.

A real-time procedure to mitigate WWD incidents involves the following typical stages:

- Detect the vehicle traveling in the wrong direction.
- Record a video.
- Send the video to the Traffic Management Center (TMC) to verify that the incident is a WWD incident (Figure 2).
- Once confirmed, alert the public about the potential wrong-way driver through a message on Dynamic Message Sign (DMS) (Figure 3) and the Highway Advisory Radio (HAR).
- Coordinate with the Florida Highway Patrol (FHP) and dispatch personnel to the location.



Source: Gordin and Kinney, 2016

Figure 2: Typical WWD Detection Notification Process

Figure 3: Wrong-way Driver Alert on Dynamic Message Sign in Florida

2.6 Innovative Countermeasures in Florida

As part of a comprehensive effort to mitigate WWD incidents, FDOT has been conducting pilot studies and RFEs to evaluate the following seven innovative countermeasures:

1. Newly-developed S&PM standards (FDOT's *Plans Preparation Manual*, Figures 7.2.1. and 7.2.2)
2. Red RRFBs
3. Red flush-mount IIRPMs
4. Detection-triggered LED lights around "WRONG WAY" signs
5. Detection-triggered blank-out signs that flash "WRONG WAY"
6. Delineators along off-ramps
7. Wigwag flashing beacons

Test locations are identified based on the information gathered from prior crash history obtained from the FDOT Crash Analysis Reporting System (CARS), 911 call information (if any), available details from TMCs, and FHP's citation information. Table 2 provides the statewide summary of WWD projects in Florida.

Table 2: Statewide Summary of WWD Projects in Florida

FDOT District	# of Inter-changes	# of Off-ramps	# Inventoried for WWD	# of Already Implemented per New S&PM Standards (1)	# of Ramps with TAPCO, Unipart Dorman type LED-lit "WRONG WAY" signs (2)	# of Ramps with Red RRFBs (3)	# of Ramps with Red In-Pavement RPMs (4)	Dollars Invested in WWD Counter-measures on (1) thru (4)
1	55[a]	96[a]	96	0	0	0	0	$0[b]
2[c]	175	350	0	N/A	N/A	N/A	N/A	N/A
3	40	86	7	0	7	0	6	$481,346
4	67	134	13	11[d]	0	0	0	$181,000
5	85	170	51	0	0	0	0	$0
6	59	107	7	0	0	0	0	$0
7[e]	78[f]	118	107	118	0	6	0	$793,622
FTE	131	249	104[g]	27[h]	17	0[i]	0	$235,000
Total	690	1,310	385	156	24	6	6	$2,875,968

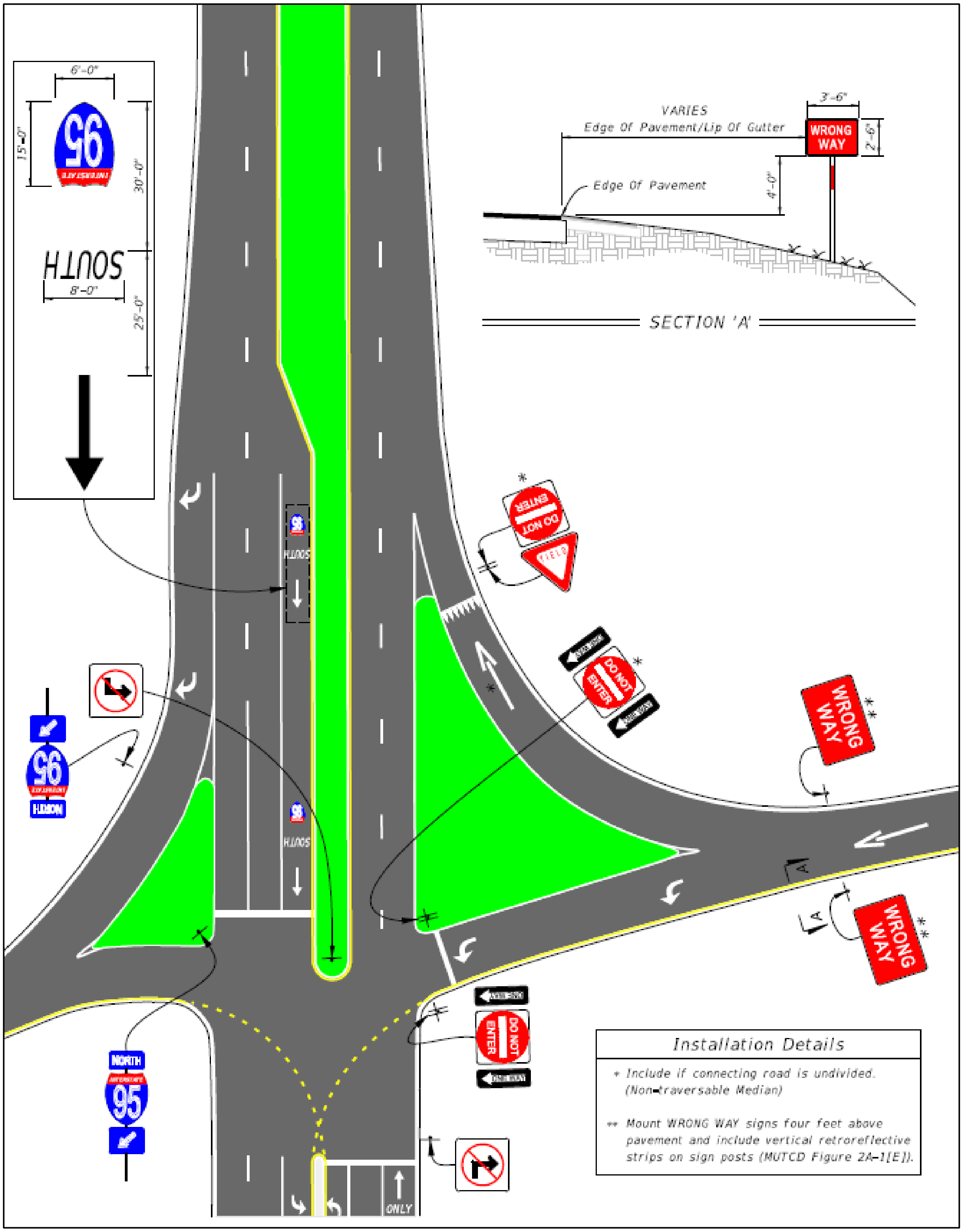
[a] Rest areas, service roads, recreation areas, and weigh stations included.
[b] FDOT District 1 planning to invest $1,185,000 in WWD countermeasures; includes cost estimate for implementation only.
[c] Project in work program to update interchanges to new standard, but unfunded at this time. No additional inventory completed.
[d] In addition to 11 interchanges with new S&PM, 14 interchanges received new S&PM through planned construction projects.
[e] Other treatments include i) upgraded 3 wrong-way detection devices - $46,027; ii) installed upper/lower red flashing beacons at 7 off-ramps - $283,879.50; iii) upgraded Wavetronix microwave vehicle detectors - $19,000.00; total cost in other treatments is $348,907.00.
[f] Total of 11 off-ramps not included in original inventory (under construction). New WWD S&PM added to projects.
[g] Ramps planned to be addressed via design contract.
[h] In progress of implementation through construction projects.
[i] Additional 417 expansion using RRFBs at 18 ramps not included in count.
Source: FDOT, 2016

2.7 Newly-Developed S&PM Standards

On April 15, 2015, FDOT released a bulletin introducing new minimum signing and pavement marking (S&PM) standards for interstate off-ramp intersections to complement the 2009 *Manual on Uniform Traffic Control Devices* (MUTCD) requirements (FHWA, 2009a). The new S&PM standards at diamond interchange off-ramps (Figure 4) and partial cloverleaf/trumpet interchange off-ramps (Figure 5) are described below:

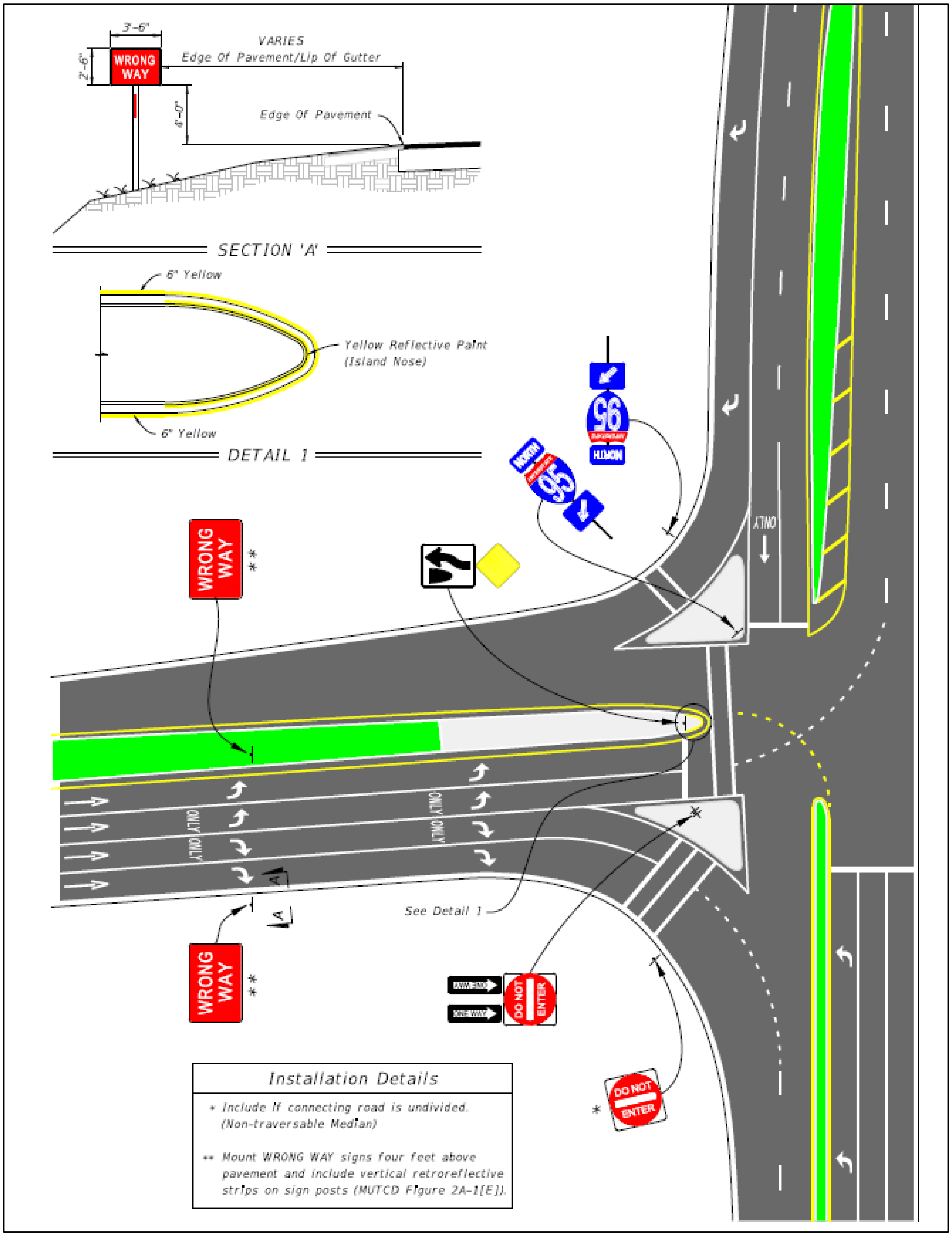
- Include MUTCD "optional" signs:
    - Second "DO NOT ENTER" sign
    - Second "WRONG WAY" sign
    - "ONE WAY" signs
- Include "NO RIGHT TURN" and "NO LEFT TURN" signs
- Use 3.5 ft × 2.5 ft "WRONG WAY" signs mounted at 4' height with retroreflective strip on sign supports
- Include 2–4 dotted guideline striping for left turns between ramps entrances/exits and cross-streets
- Include retroreflective paint (yellow) on ramp median nose where applicable
- Include straight arrow and route interstate shield pavement markings in left-turn lanes extending from far-side ramp intersection through near-side ramp intersection to mitigate premature left turns
- Include straight arrow and "ONLY" pavement message in outside lane approaching ramp exit

Note that these requirements complement the design requirements established by the *Traffic Engineering Manual* (TEM) (February 2015 edition), Section 4.2.4, "Route Shields for Wrong-way Treatment" (FDOT, 2015). Figure 6 shows the pavement markings for wrong-way treatment on arterials adjoining limited access facilities. It should be noted that this particular countermeasure is preventative in nature and it provides positive guidance to "mitigate" wrong-way entries.



Source: Figure 7.2.1, FDOT *Plans Preparation Manual*, 2016

Figure 4: Typical Layout for Diamond Interchange Off-Ramp



Source: Figure 7.2.2, FDOT *Plans Preparation Manual*, 2016

Figure 5: Typical Layout for Partial Cloverleaf/Trumpet Interchange Off-Ramp

Source: FDOT, 2015

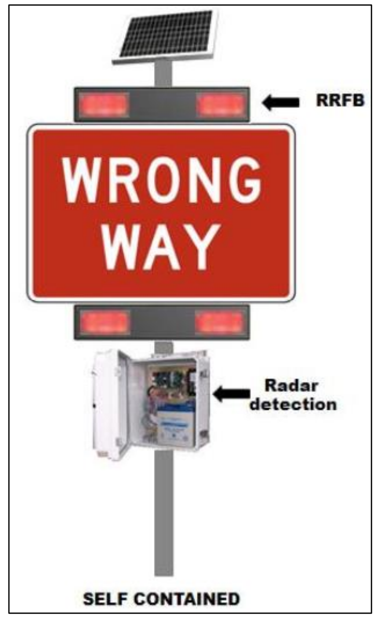
Figure 6: Newly-developed Signing and Pavement Markings (S&PM) on Arterials for Wrong-way Treatment

2.8 Red Rectangular Rapid Flashing Beacons (RRFBs)

RRFBs are rectangular, high-intensity, LED-based indications that were developed to improve safety at uncontrolled pedestrian crossings. RRFBs are mounted immediately between the "PEDESTRIAN CROSSING" sign and the sign's supplemental arrow plaque. When activated, RRFBs flash rapidly in an alternating "pulsing" flash pattern that is similar to emergency flashers on police vehicles (FHWA, 2009b). These are effective in improving drivers' yielding to pedestrians crossing streets.

Red RRFBs are a relatively new application of this technology, placed at freeway off-ramps in an attempt to correct WWD. These signs are equipped with dual radar sensors to detect vehicles traveling in the wrong direction. Red RRFBs were installed in the Tampa Bay area on I-275 in early 2015. When activated, the red RRFBs flash rapidly to notify the driver of the wrong-way driving action, and, simultaneously, a message is sent to the Tampa Bay SunGuide TMC. Law enforcement is then dispatched, and other drivers on the freeway are warned through DMS. Figures 8(a) and 8(b) show solar-powered yellow and red RRFB systems that alert drivers yielding to pedestrians and wrong-way drivers, respectively. Figure 8 shows the equipment used to detect WWD incidents using red RRFBs. As can be seen, the typical installation on off-ramps to detect wrong-way driving includes the following (Lattimer, 2015):

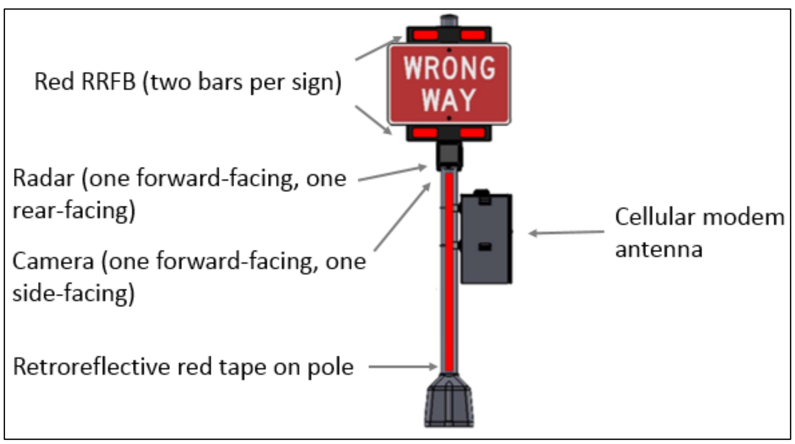
- Two red RRFB bars per "WRONG WAY" sign
- Two radar units (one front-facing, one rear-facing)
- Two cameras (one front-facing, one side-facing)
- Retroreflective red tape on pole
- Cellular modem antenna
- Solar power



(a) Yellow RRFBs at pedestrian crossings (b) Red RRFBs on "WRONG WAY" sign

Source: Ozkul et al., 2015

Figure 7: Yellow and Red RRFBs



Source Lattimer, 2015

Figure 8: Equipment to Detect Wrong-Way Driving Using Red RRFBs

The Center for Urban Transportation Research (CUTR) at the University of South Florida conducted a public opinion survey to study the different settings of red RRFBs and their perceived effectiveness on reducing WWD incidents. Of the 296 survey participants, a large majority (69.5%) selected the combination of placing "WRONG WAY" signs on both the left and right sides of an interstate off-ramp with red RRFBs activated at the top and bottom as the method that most gets their attention at night and informs them of wrong-way driving. Figure 9 shows this scenario during night condition. Initial results of the study show that the device was able to attract a wrong-way driver's attention and, in several instances, were found to turn the driver around (Lin and Ozkul, 2016). Based on before and after data, the authors concluded that red RRFBs have no impact on driving behaviors on the arterials adjacent to the off-ramp and that the red RRFBs can effectively alert wrong-way drivers while not adversely impacting driver behavior on adjacent arterials.

Photo source: CUTR

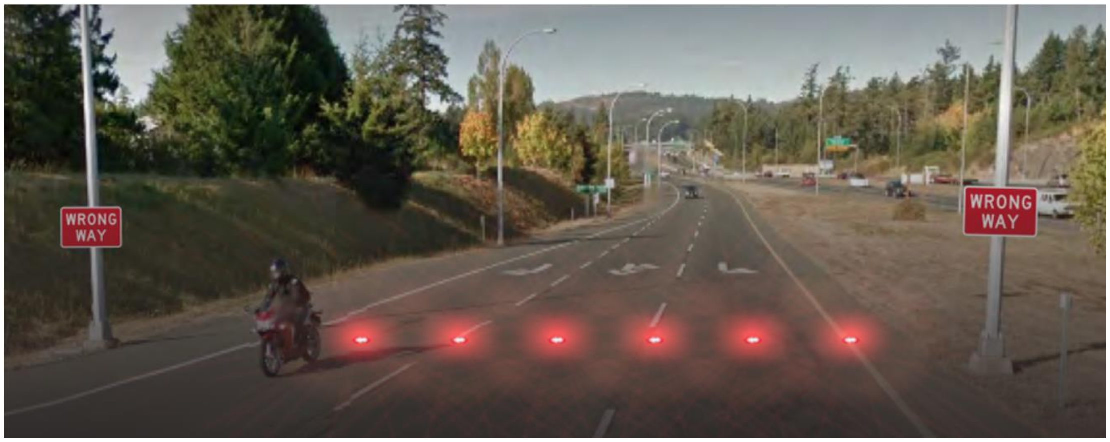
Figure 9: Red RRFBs Activated on Both Sides of Ramp

2.9 Red Flush-Mount IIRPMs

Red flush-mount IIRPMs and red in-roadway warning lights are solar-powered, red-flashing internally-illuminated LED in-roadway pavement markers that are placed to face drivers traveling in the wrong direction on off-ramps. Figure 10 provides the conceptual idea of an off-ramp location installed with these devices. The fast flashing operation provides a flickering red LED light effect that faces a wrong-way driver and alerts him/her of a wrong-way entry. Figure 11 shows the spacing of the flashing and steady red lights on 12 ft and 15 ft lanes.

As can be seen, the treatment includes three rows of lights 100 ft apart. The main advantages of these IIRPMs are that they are noticeable only during nighttime, are seen in red by a wrong-way driver to attract attention to the incorrect direction of traffic flow, and discourage traveling in the wrong direction. They typically would not be noticeable during daylight, as they do not flash during the day. Furthermore, they are in the direct view and cone of vision of drivers. Since alcohol-impaired drivers tend to look less to the left and right and more at the pavement in front of the vehicle, it is believed that these could be effective in reducing WWD incidents.

Table 3 summarizes locations installed with red in-roadway warning lights on off-ramps in FDOT D3.



Source: LaneLight, Inc., 2016

Figure 10: Red Flush-Mount IIRPMs

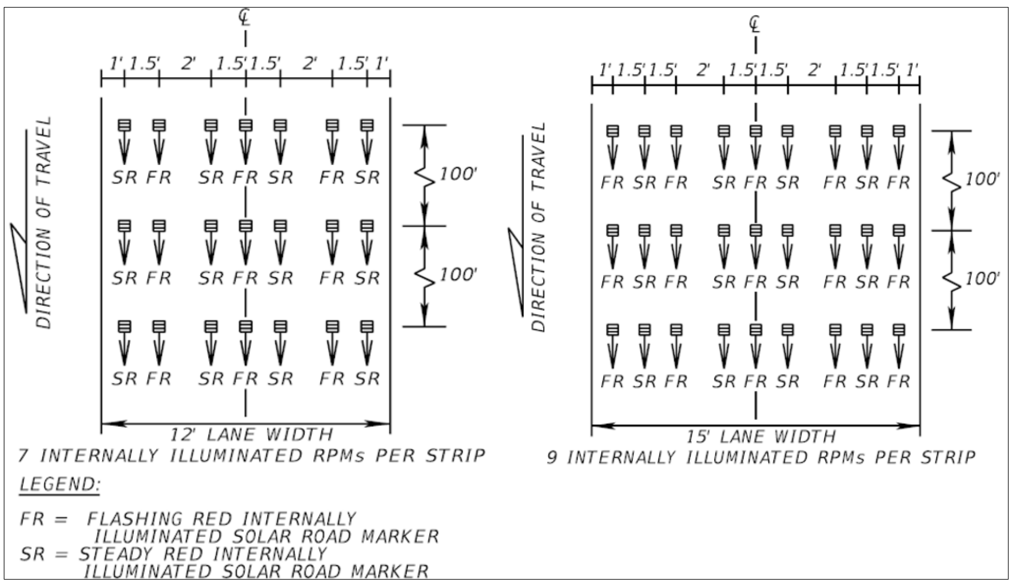


Figure 11: Red Flush-Mount IIRPM Lane Placement Detail

Table 3: Locations with IIRPMs on Off-ramps, FDOT District 3

County	Roadway ID	Milepost	Location	Total Ramps
Washington	61001000	1.017 & 1.404	SR 8 (I-10) at CR 279 off-ramps	2
Holmes	52002000	16.986 & 17.468	SR 8 (I-10) at SR 79 off-ramps	2
Escambia	48270000	1.600	SR 8A (I-110) at Maxwell Street off-ramp	1
Escambia	48270000	2.478 (Davis Hwy) & 2.980 (Fairfield)	SR 8A (I-110) at Fairfield Drive off-ramps	1
Total number of off-ramps				6

Note: Off-ramp locations are conventional diamond or partial modified diamond configurations.

2.10 Detection-triggered LED Lights

Figure 12 shows a location with detection-triggered LED "WRONG WAY" signs. As shown, sensors detect the wrong-way vehicle, and the "WRONG WAY" sign is triggered. The LED lights around the "WRONG WAY" sign start blinking, attracting the attention of the wrong-way driver. Figure 13 shows a blank-out sign that flashes only when a wrong-way vehicle is detected. Figures 14 (a) and 14 (b) show an off-ramp location on Sawgrass Expressway in Florida that is installed with detection-triggered LED-illuminated "WRONG WAY" sign. Another variation of this concept is using blank-out signs that flash "WRONG-WAY."

Source: Ponnaluri, 2013

Figure 12: Detection-triggered LED Lights around "WRONG WAY" Signs

Figure 13: Detection-triggered Blank-out Sign that Flashes "WRONG WAY"

(a) Off-ramp with LED-illuminated “WRONG WAY” sign location

(b) LED-illuminated “WRONG WAY” sign details

Source: Gordin & Kinney, 2016

Figure 14: LED-illuminated “WRONG WAY” Signs Installed on Sawgrass Expressway in Florida

2.10.1 Detection-triggered LED Lights around “WRONG WAY” signs

As part of a Florida’s Turnpike Enterprise (FTE) pilot project, detection-triggered LED lights around “WRONG WAY” signs were installed on 10 off-ramps on the Homestead Extension in South Florida (SR-821) and 5 off-ramps on the Sawgrass Expressway (SR-869). This pilot project consisted of four separate phases, as described in Table 4.

Table 4: Status of FTE Pilot Projects

Phase	Description	Status	Next Steps
1 – Signing & Pavement Marking	Signing and pavement markings installed at each off-ramp in pilot project	Complete (Oct. 2013)	
2 – Mainline Detection	Wavetronix SmartSensor (SS-126) devices and Click 512 devices installed at specific locations along mainline of HEFT	Complete (Feb. 2014)	• Continue to monitor wrong-way-generated alerts through intermediate system (Command Monitor) provided by Wavetronix • Coordinate integration with SunGuide
3 – Ramp Detection	Ramp technology (TAPCO “WRONG-WAY” LED blinker signs with vehicle detection) installed at 15 off-ramps along FTE pilot project corridor	Deployment & testing completed (Oct. 2014)	• Continue to monitor wrong-way-generated alerts through TAPCO-provided BlinkLink web-based software application • Relocate selected signs that provide excessive flashing operation • Coordinate integration with SunGuide
4 – SunGuide Software Enhancements	SunGuide development to enable communication between mainline and ramp technologies and TMC software so further automation can be incorporated into pilot project	In progress	• Review and comment on revised SunGuide Concept of Operations • Coordinate installation through next major release of SunGuide

Source: FTE, 2014

The installations on the off-ramps on the Turnpike and Sawgrass Expressway in South Florida include the following (FTE, 2014):

- LED-illuminated “WRONG WAY” signs activated by forward radar
- Two radar units (one front-facing, one rear-facing)
- Camera (rear-facing to confirm wrong-way activity and license plate capture)
- TAPCO communication software with ability to provide both notification via SunGuide and/or TAPCO BlinkAlert software, which can be configured for cellular communications and solar power; device also includes still-image capture that will provide visual verification of a wrong-way detection.

Based on the pilot study on the Turnpike, it was found that site selection for radar sensors is critical and is dependent on interchange geometry. Foundation installation also was found to be critical, requiring more attention during the installation process. Monitoring the locations on a regular basis is recommended to identify sign knockdowns. Also, semi-annual calibration of the devices needs to be performed to accurately detect wrong-way drivers (Gordin and Kinney, 2016).

2.10.2 Detection-triggered Blank-out Signs that Flash “WRONG WAY”

FDOT D3 installed detection-triggered LED “WRONG WAY” blank-out signs at four locations on I-10:

- SR 263 (Capital Circle NW)
- SR 63 (US 27/N Monroe St)
- SR 61 (Thomasville Rd)
- SR 261 US 319 (Capital Circle NE)

The installations of detection-triggered blank-out signs on the off-ramps on I-10 in Tallahassee include:

- Detection-triggered LED-illuminated "WRONG WAY" signs and vehicle detection
- Enhanced "DO NOT ENTER" and static "WRONG WAY" signage
- Overhead "WRONG WAY" signage
- Enhanced signage ("NO RIGHT TURN," "NO LEFT TURN," "NO U TURN") and pavement markings on cross streets
- Median curb extensions to discourage early left turns
- Wrong-way arrows (retroreflective raised pavement markers)

2.11 Delineators along Off-ramps

Figure 15 shows delineators along off-ramps on I-275 in Tampa. These devices provide two different colors—red to wrong-way drivers and yellow to drivers traveling in the correct direction.

Source: Luciol Systems, Inc., 2016

Figure 15: Delineators along Off-ramps

2.12 Wigwag Flashing Beacons

Figure 16 shows wigwag flashing beacons installed on a "WRONG WAY" sign, which recently were installed on I-275 in Tampa. Once a wrong-way driver is detected, these beacons begin flashing, notifying the driver of the wrong-way driving action.

Source*: Tampa Bay Times*, 2016

Figure 16: Wigwag Flashing Beacons

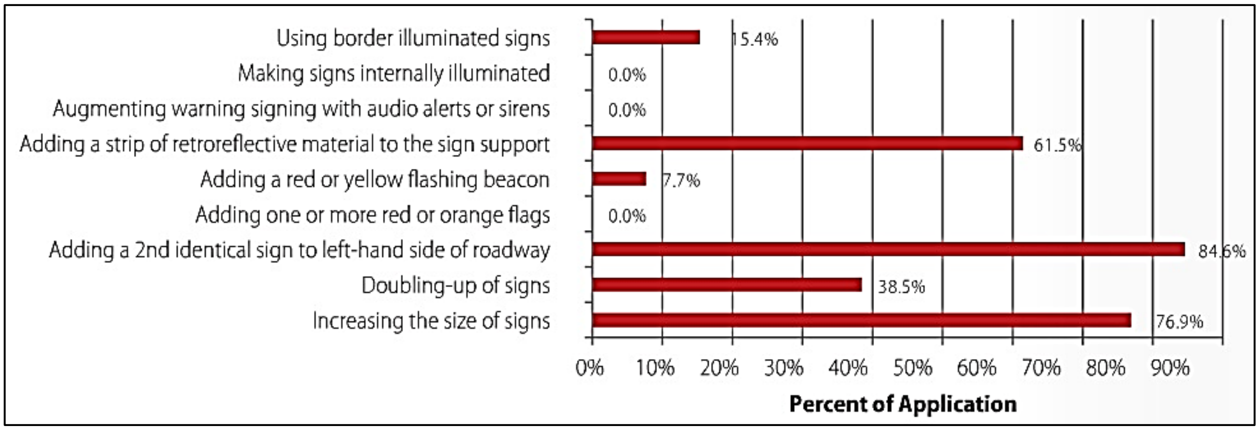
2.13 Other Countermeasures

This section provides information about the countermeasures that have been installed in other states, including:

- Additional signing and pavement markings
- Lower sign mounting height
- Directional traffic sensor system
- Flashing beacons

2.13.1 Additional Signing and Pavement Markings (S&PM)

Researchers confirmed that drivers with higher blood alcohol content (BAC) levels must be closer to a sign before they are able to identify the background color and read the legend, compared to drivers at lower BAC levels. In addition, alcohol-impaired drivers must be closer to signs with flashing red LEDs around the border before they can read the legend, compared to signs without flashing LEDs (Finley et al., 2014). Figure 17 shows the various methods of enhancing sign visibility along with their application percentages.

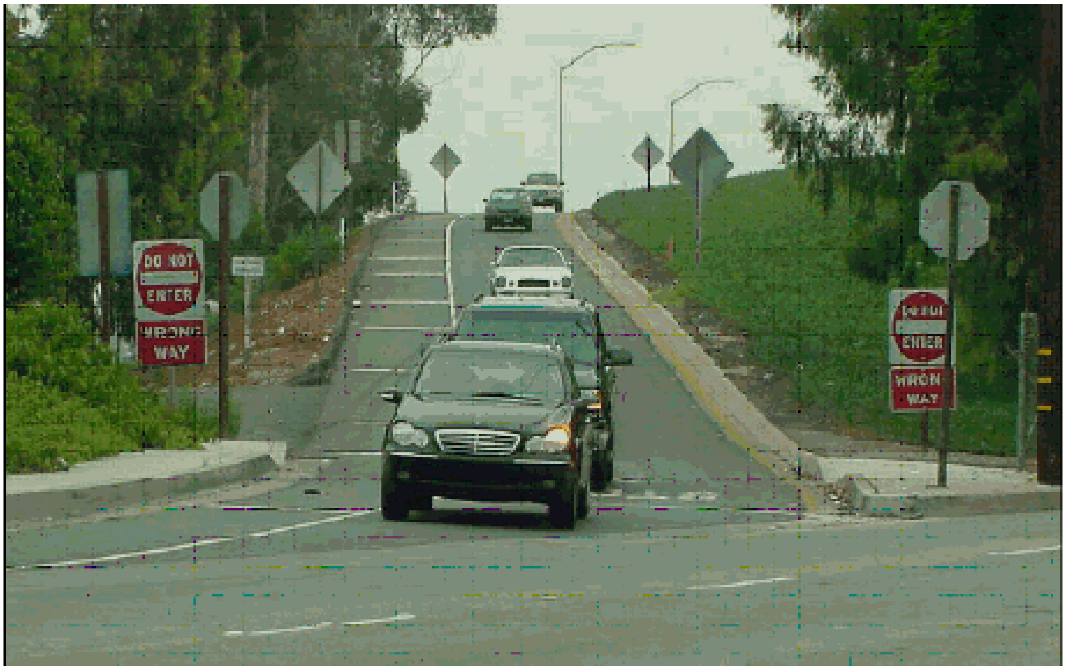


Source: Finley et al., 2014

Figure 17: Various Methods for Enhancing Sign Visibility with Application Percentage

2.13.2 Lower Sign Mounting Height

The MUTCD (FHWA, 2009) identifies the standard mounting height for road signs as 7 ft in urban areas and 5 ft in rural areas. However, the manual allows a lower mounting height of 3 ft for "DO NOT ENTER" and/or "WRONG WAY" signs along an off-ramp if an engineering study indicates that it would address WWD. Georgia, Virginia, and California have adopted minimum mounting height standards of 2 ft for their "DO NOT ENTER" and "WRONG WAY" signs (Leduc, 2008). Having the signs directly in the path of vehicle headlight beams was considered to be an effective way to improve safety. Figure 18 shows a location with lowered "DO NOT ENTER" and "WRONG WAY" signs in California.



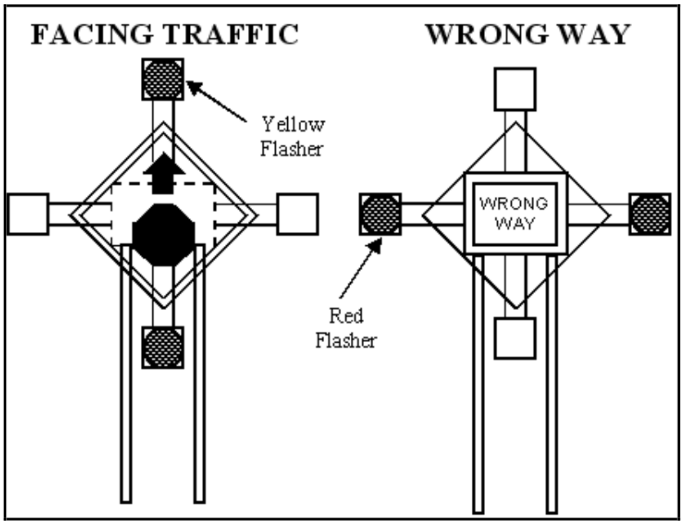
Source: Cooner et al., 2004

Figure 18: Lowered "DO NOT ENTER" and "WRONG WAY" Signs in California

Seitzinger et al. (2016) examined the effects of lower-mounted "WRONG WAY" signs (3 ft vs. 7 ft) on impaired drivers in a driving simulator setting. The authors found that the mounting height significantly affected participants only when making left-hand turns onto freeway ramps in the wrong direction. Participants were significantly less likely to miss 3-ft mounted "WRONG WAY" and "DO NOT ENTER" signs; only 3% of the left turners missed signs at 3ft mounting height, compared to 19% for signs mounted at the standard 7-ft height. The results showed when drivers make a right turn onto a freeway ramp, that there was no significant difference in reaction times between the two mounting heights. However, this study had a major limitation in that it used vision impairment goggles, which could simulate vision impairment but not decision impairment of intoxicated drivers.

2.13.3 Directional Traffic Sensor System

New Mexico installed a directional traffic sensor system (DTSS) in 1998 at an off-ramp of I-40 to detect wrong-way movement and alert oncoming traffic. The DTSS uses inductive loop sensors to detect the wrong-way movement. When a wrong-way movement is detected, the system activates two sets of warning lights that flash for one minute each. A set of red flashing lights is mounted on a traditional "WRONG WAY" sign facing the wrong-way driver. On the back of the sign, a set of yellow flashing lights is mounted on a "STOP AHEAD" sign facing the driver moving in the correct direction. The red flashing lights alert the wrong-way drivers, and the yellow flashing lights alert an oncoming car of potential danger ahead (Cooner et al., 2004). Figure 19 shows how a DTSS appears to drivers traveling in both directions.



Source: Cooner et al., 2004

Figure 19: New Mexico Directional Traffic Sensor System

2.13.4 Flashing Beacons

In 2006, FDOT installed a wrong-way notification system along the three-mile long Pensacola Bay Bridge that uses non-intrusive, low-power microwave technology to detect a vehicle traveling the wrong way as it approaches the bridge. The wrong-way vehicle activates the flashing beacons on the "WRONG WAY" signs, which are placed directly over the travel lanes near the bridge entrance. The system alerts the driver approximately 1,000 feet before the bridge, allowing approximately 15 seconds of reaction and decision time. The project has significantly reduced wrong-way crashes and secondary incidents and associated non-recurring congestion (Williams, 2006). Figure 20 is a Google Street View of the location.

Source: Google, 2016

Figure 20: Pensacola Bay Bridge Wrong-way Detection System

2.13.5 WWD Countermeasure Cost Data

FDOT contracted with CUTR to conduct an evaluation of seven countermeasures that have been installed at various locations throughout Florida that are intended to alert wrong-way drivers and mitigate their entry onto a high-speed limited access facility while driving in the wrong direction. The seven countermeasures evaluated in this study are as follows:

- **Countermeasure #1:** Newly-developed S&PMs
  Location: WB Fletcher Avenue at I-275 NB off-ramp, Tampa (FDOT District 7)
- **Countermeasure #2**: Red RRFBs
  Location: I-275 @Fletcher NB off-ramp, Tampa (FDOT District 7)
- **Countermeasure #3:** Red flush-mount IIRPMs
  Location: I-110 @ Maxwell Street SB off- ramp, Pensacola (FDOT District 3)
- **Countermeasure #4:** Detection-triggered LED lights around "WRONG WAY" signs
  Location: Sawgrass (SR-869 SB) Exit 11 – Sample Road (Florida Turnpike)
- **Countermeasure #5:** Detection-triggered blank-out signs that flash "WRONG WAY"
  Location: WB off-ramp at Capital Circle NW, Tallahassee (FDOT District 3)
- **Countermeasure #6:** Delineators along off-ramps
  Location: I-275 @ Busch SB off-ramp, Tampa (FDOT District 7)
- **Countermeasure #7:** Wigwag flashing beacons
  Location: I-275 @ Busch NB off-ramp, Tampa (FDOT District 7)

Each of these countermeasures is detailed more specifically in literature review provided previously. As part of the task of literature review, Hagen Consulting Services collected cost information on the countermeasures to be studied from each of the District offices that had installed them. The responses from the District offices varied widely in their scope and detail. The results are summarized in Table 5.

Table 5: Cost Summary for Each WWD Countermeasure

Countermeasure		Cost per Ramp	Notes
1	Newly-developed S&PM standards	$10,159.11	Cost shown is for ramp studied. Similar ramps would have similar cost, but if ramp geometry is significantly different, costs also could be significantly different. Cost based on District 7 Design-Build Push Button contract costs.
2	Red RRFBs	$42,000.00	Cost shown is approximate from District for studied ramp. Does not include cost for MOT or communications. Similar installations expected to have similar cost, regardless of number of lanes.[1]
3	Red flush-mount IIRPMs	$13,243.71	Cost shown based on installation on single-lane ramp locations. Two-lane ramps expected to cost significantly more. Cost includes approximately $4,000 for MOT costs during installation.
4	Detection-triggered LED lights around "WRONG WAY" signs	$12,722.23	Cost shown is typical for ramp with two signs per ramp. Similar installations expected to have similar cost, regardless of number of lanes.
5	Detection-triggered blank-out signs that flash "WRONG WAY"	$38,000.00	Cost shown is to furnish and install blank-out signs only (two per ramp). Estimate of $55,519.92 from District includes other signing and pavement marking improvements at ramp.
6	Delineators along off-ramps	$7,522.50	Cost shown is for purchase only – installation performed by FDOT Maintenance personnel.
7	Wigwag flashing beacons	$42,000.00	Cost shown is approximate from District for studied ramp. Does not include cost for MOT or communications. Number of lanes will impact cost estimate due to costs of loop detection in each lane.[1]

[1] Cost estimate shown based on total cost estimate of $50,000: Purchase of equipment and materials $25,000, MOT during installation $5,000, communications to SunGuide $3,000, installation & CEI $17,000, total $50,000.

3 METHODOLOGIES FOR COUNTERMEASURE EVALUATIONS

To evaluate the selected seven WWD countermeasures described in Section 2, four evaluation methods were used:

- Analysis of existing data and studies
- Field testing using focus groups
- Public opinions survey
- Human factors approach using driving simulation

Existing data and current FDOT studies on the selected countermeasures and their respective cost data were analyzed through a literature review and by reaching out to FDOT Districts for information on the WWD pilot studies and RFEs and associated and readily-available cost information. Through this analysis, insights for the WWD countermeasures and their cost to FDOT could be obtained.

Field testing using focus groups was used to determine the effectiveness of the WWD countermeasures via the naked eye. This was deemed necessary since it is important to obtain the insights of persons who experience the WWD countermeasures first hand in the field. Once the field testing was finished, the focus groups were given questionnaires to obtain their input on the effectiveness of the WWD countermeasure being tested. In addition, at the end of each focus group, all participants were involved in general discussions regarding their insights on the WWD countermeasure being tested.

To fully justify the selection of the most effective WWD countermeasures, public opinion also was sought. A survey was conducted of 250 people in three age group categories. Before the surveys were administered, videos of the WWD countermeasures from the field were recorded at driver eye height/vision and were shown to the participants along with a survey questionnaire to evaluate their selection of the most effective and informing WWD countermeasure.

To determine how people react to certain driving scenarios, driving simulator studies were conducted. Unlike a field evaluation, simulator studies can help isolate the impact of individual countermeasures holding all other variables constant (e.g., ramp geometry, traffic and weather conditions). This effort also examined a driver being under the influence of alcohol through specially-made glasses that simulated BAC levels. The simulator was coded to replicate each of the WWD countermeasures of analysis, and study participants drove the simulation course using the simulator.

Each of these methods and the specific evaluation methodologies are described in detail in the following sections.

4 EVALUTION OF COUNTERMEASURES VIA ANALYSIS OF EXISTING DATA AND STUDIES

The main objective of this general effectiveness assessment of selected WWD countermeasures was to determine how well WWD treatments have deterred and reduced the frequency of WWD incidents based on available data and reports. Countermeasure evaluations are important because they:

- Prove the effectiveness of agency investments
- Demonstrate the value of agency programs to decision-makers
- Add to the scientific knowledge base
- Improve agency decisions and optimize future investments in safety

A variety of study designs can be used to evaluate the safety effectiveness of a WWD treatment. One main consideration in selecting a study design is the type of data available and the time periods for which data are (or will be) available for the study locations.

If crash data at the study locations are available, observational before-and-after or cross-sectional studies can be conducted. Chapter 9 of the *Highway Safety Manual* provides more details about these methods, which use crash data at the locations at which treatments have been implemented. However, since WWD crashes are rare, analyzing crash data alone might not result in a comprehensive review of the performance of WWD countermeasures. In addition to crash data, citation data also can be used to determine the effectiveness of WWD treatments. However, even these data might not portray the entire picture since citations are given to wrong-way drivers only after they continue to drive the wrong way. Since the objective of the new WWD countermeasures is to mitigate drivers from making wrong-way movements, a comprehensive overview of the safety performance of WWD countermeasures could be obtained by:

- Reviewing crash and citation data for both before and after periods
- Analyzing real-time alerts generated by WWD treatments

4.1 New Countermeasures in Florida

As part of a comprehensive effort to mitigate WWD incidents, FDOT has been conducting pilot studies and RFEs to evaluate the following seven innovative WWD countermeasures, as illustrated in Figure 21:

1. Newly-developed S&PM standards (*Plans Preparation Manual,* Figures 7.2.1. and 7.2.2)
2. Red RRFBs
3. Red flush-mount IIRPMs
4. Detection-triggered LED lights around "WRONG WAY" signs
5. Detection-triggered blank-out signs that flash "WRONG WAY"
6. Delineators along off-ramps
7. Wigwag flashing beacons

Countermeasure #1

Countermeasure #2

Countermeasure #3

Countermeasure #4

Countermeasure #5

Countermeasure #6

Countermeasure #7

Figure 21: Seven Wrong-way Driving Countermeasures in Study

Table 6 summarizes the pilot projects and RFEs initiated by FDOT to mitigate WWD incidents and includes the cost estimate for each countermeasure.

Table 6: Pilot Projects and RFEs in Florida

FDOT District	General Location	Countermeasure	Deployment Timeframe	Cost Estimate
FTE	Homestead Extension in South Florida and Sawgrass Expressway	Detection–LED lights around "WRONG WAY" signs	September 2014	$12,722.23
D3	I-10 interchanges in Tallahassee area	New S&PM standards and detection-triggered blank-out signs that flash "WRONG WAY"	July 2014	$55,519.92 (total cost for 7 ramps: $388,639.44)[a, b]
D3	I-110 and I-10 interchanges in Pensacola and Bonifay, respectively	Red flush-mount IIRPMs	November 2015	$13,243.71 (total cost for 6 ramps: $92,706)[c]
D7	Tampa Bay area (I-275)	Red RRFBs	Early 2015	Approx. $50,000[d]
D7	Tampa Bay area (I-275)	Wigwag flashing beacons	Mid 2015	Approx. $50,000
D7	Tampa Bay area (I-275)	Delineators along off-ramps	July 2016	$7,522.50[e]
D7	Tampa Bay area (I-275)	Newly-developed S&PM standards	July 2014	$10,159.11[f]

[a] Estimated cost for both newly-developed S&PM and detection-triggered "WRONG WAY" blank-out signs.
[b] Estimated cost for detection-triggered "WRONG WAY" blank-out signs approximately $38,000.
[c] Estimated cost for Red flush-mount IIRPMs approximately $9,660 without Maintenance of Traffic (MOT) costs.
[d] Estimate includes cost associated with connection to Tampa Bay SunGuide Center.
[e] Estimated cost does not include installation by FDOT Maintenance.
[f] Estimate is per pay items at ramp location and Design-Build Push-Button master pay item list.

4.2 Safety Data

This section discusses the following types of safety data that potentially could be used in evaluating the safety effectiveness of WWD countermeasures:

- Crash data
- Citation data
- Real-time alerts generated by WWD treatments
- Return rate of wrong-way drivers

4.2.1 Crash Data

FDOT's Crash Analysis Reporting System (CARS) database has been a major source of crash data for safety studies in Florida and includes details about crashes such as crash location, crash type, roadway, environment, and vehicle factors as well as information about the vehicles and persons involved in a crash. Evaluating WWD crashes is not quick or simple, as there is no separate code to identify WWD crashes from the crash summary reports; the only way to identify WWD crashes is by reviewing police crash reports, which is not economically feasible. Thus, the first step in identifying potential wrong-way crashes that occurred on interstate freeways and expressways is based on review seeking the following information:

- Contributing Cause 1 or 2, coded as 21 (i.e., driving wrong side/way)
- Vehicular crash directions (i.e., VEH DIR 1, VEH DIR 2) not identical
- Harmful event coded as 02 (i.e., head-on collision)

The next step is downloading and reviewing police reports of all potential wrong-way crashes and identifying actual wrong-way crashes. Crashes are considered to involve a wrong-way driver if they involve wrong-way entry on a ramp, driving on a mainline opposite the direction of traffic, U-turns followed by wrong-way driving, or reversing on the mainline or on-ramps. Although this is a resource-intensive approach, there is no simpler or quicker way to identify wrong-way crashes.

4.2.2 Citation Data

A review of recent citations or arrests related to WWD on limited-access facilities provides additional helpful information to supplement the information gathered from crash records. Although there is no specific violation code for WWD, violations relating to driving on the wrong side of a road can be used to identify potential WWD incidents.

4.2.3 Real-time Alerts

WWD countermeasures can be categorized into two types: if they can communicate with a TMC or if they cannot. Low-cost treatments, including newly-developed S&PM standards and delineators along off-ramps, do not alert agencies of potential WWD incidents. On the other hand, several other innovative countermeasures, such as red RRFBs and wigwag flashing beacons, can record WWD incidents and alert agencies in real time. If a wrong-way driver misses all the cues on an arterial and off-ramp and enters a freeway from the off-ramp, the last and final resort to prevent a crash is to alert the police and the traffic on the freeway. This procedure involves the following five typical stages:

1. Detect the vehicle traveling in the wrong direction.
2. Record a video.
3. Send the video to the TMC to verify that the incident is a WWD incident.
4. Once confirmed, alert the public about the potential wrong-way driver through a message on a Dynamic Message Sign (DMS) and the Highway Advisory Radio (HAR).
5. Coordinate with Florida Highway Patrol (FHP) and dispatch personnel to the location.

As an initial step, some WWD treatments can generate an alert when a WWD is detected. Sometimes, false positives—devices incorrectly identifying and triggering a WWD incident—are reported. An efficient system not only can identify all WWD incidents, but also can minimize false positives. As such, when evaluating the performance of WWD countermeasures, it is imperative to identify the success rate by taking into consideration both false and true positives.

4.2.4 Return Rate of Wrong-Way Drivers

A WWD treatment is considered a success if a wrong-way driver turns around before entering a freeway. Therefore, in addition to generating real-time alerts, the treatments must be effective in alerting a driver that he/she is headed in the wrong direction. This measure can be calculated as the ratio of returned wrong-way drivers to total wrong-way drivers identified by the treatment.

4.3 WWD Countermeasure Evaluation Studies in Florida

FDOT has been conducting studies to document and evaluate the safety performance of WWD countermeasures implemented in its Districts, including the following that were obtained for this study:

- Red in-roadway warning lights in FDOT District 3 – "Technical Memorandum: Part I of II (Before Study): Red In-Road Warning Lights on Off-ramps"
- Detection-triggered LED lights around "WRONG WAY" signs in South Florida – Excel file listing alert frequency of detection-triggered LED lights around "WRONG WAY" signs
- Red RRFBs in FDOT District 7 – Excel files listing alert frequency of red RRFBs; final research report, "Evaluation on Impact of Red RRFB Implementation at Freeway Off-ramps on Driving Behaviors along Adjacent Arterials"

The following subsections summarize these documents. Only red RRFBs have been evaluated extensively; others are still being evaluated.

4.3.1 Red Flush-Mount IIRPMs

FDOT District 3 installed solar red-flashing internally-illuminated LED in-roadway pavement markers facing drivers traveling the wrong-way on off-ramps at the following four interchange off-ramp locations:

- SR 8 (I-10) at CR 279 (unsignalized) in Washington County
- SR 8 (I-10) at SR 79 (unsignalized) in Holmes County
- SR 8A (I-110) at Maxwell Street (signalized) (southbound off-ramp only; no northbound off-ramp) in Escambia County

- SR 8A (I-110) at Fairfield Drive (signalized) in Escambia County (southbound off-ramp only. Northbound off-ramp was not included due to ramp type configuration)

Phase 1 of the before-and-after analysis included a “before analysis” to assess baseline driver behavior, crash data, and facility operations at these four locations. The intent was to follow this baseline analysis with a second phase to conduct an “after analysis” after the installation of in-roadway warning lights. Only Phase 1 has been completed; District 3 currently is working on Phase 2 (“Technical Memorandum: Part I of II [Before Study]: Red In-roadway Warning Lights on Off-ramps”).

4.3.2 Detection-triggered LED Lights around “WRONG WAY” Signs

Florida’s Turnpike Enterprise recorded the number of alerts provided by detection-triggered LED lights around “WRONG WAY” signs from October 2014 through May 2016; the devices triggered the alerts 31 times. Table 7 provides more details about the ramp location, interchange type, and alert counts. The Turnpike analyzed this information by time-of-day, lighting condition (i.e., daytime vs. nighttime), day of week (i.e., Friday–Sunday vs. Monday–Thursday), crash severity, alcohol and/drug involvement, and driver age.

Table 7: Alert Counts of Detection- triggered LED lights around “WRONG WAY” signs

Ramp Location	Interchange Type	Alert Counts
821 SB OFF 29-NW 41	2-quadrant cloverleaf or partial cloverleaf	2
821 NB OFF 47-NW 27	Partial diamond	4
821 NB OFF 29-NW 41	2-quadrant cloverleaf or partial cloverleaf	4
869 SB OFF 1-Sunrise	Diamond	2
869 SB OFF 11-Sample	Diamond	4
869 SB OFF 5-Commerc	Diamond	3
821 NB OFF 34-NW 106	Trumpet	1
821 NB OFF 35-US 27	2-quadrant cloverleaf or partial cloverleaf	1
821 SB OFF 35-US 27	2-quadrant cloverleaf or partial cloverleaf	1
869 SB OFF 3-Oakland	Diamond	1
869 SB OFF 8-Atlantc	Diamond	3
821 NB OFF 31-NW 74 ST	Trumpet	0
821 SB OFF 31-NW 74 ST	Trumpet	0
821 SB OFF 34-NW 106	Trumpet	1
821 NB OFF 43-NW 57	2-quadrant cloverleaf or partial cloverleaf	3
821 SB OFF 47-Univer	Partial diamond	0

4.3.3 Red RRFBs

Red RRFBs installed in FDOT District 7 have been evaluated extensively by CUTR, which completed the examination on perceived effectiveness of various combinations of red RRFBs and “WRONG WAY” signs and evaluated the impact of red RRFB implementation on adjacent arterials in Tampa area.

Based on a public opinion survey of 296 participants who reviewed pre-recorded field videos with various red RRFB and “WRONG WAY” sign combinations, a large majority (69.5%) of participants selected the combination of placing “WRONG WAY” signs on both the left and right sides of an interstate off-ramp with red RRFBs activated at the top and bottom as the method that most got their attention at night and informed them of wrong-way driving. Additionally, the statistical analyses based on collected driving behavioral data demonstrated that there was no effect on arterial driving behaviors before and after the implementation of red RRFBs on freeway off-ramps. The implementation of red RRFBs are projected to effectively alert wrong-way drivers while not adversely impacting driving behaviors on adjacent arterials.

Table 8 summarizes a short-term evaluation of red RRFBs at five locations and wigwag flashing beacons at two locations based on the return rates of WWD vehicles. The return rate was computed as a percentage of wrong-way vehicles turning around due to the warning of the countermeasure over the number of total WWD vehicles. Note that the statistics at the different locations provided in Table 8 are not directly comparable since the number of WWD vehicles is small and the study durations are different. Based on the available data, red RRFBs provided 100% WWD vehicle return rate, and wigwag flashing beacons provided 75% WWD vehicle return rates, which demonstrates their effectiveness of deterring WWD vehicles.

Table 8: Performance of Red RRFBs and Wigwag Flashing Beacons

Location	Study Duration	WWD Cases			Return Rate
		WWD	*Returned*	*Uncertain*	
I-275 NB at Bearss Ave (Red RRFBs)	May–December 2016	0	0	0	N/A
I-275 SB at Bearss Ave (Red RRFBs)	June–December 2016	0	0	0	N/A
I-275 NB at Fletcher Ave (Red RRFBs)	May–December 2016	1	1	0	100%
I-275 SB at Fletcher Ave (Red RRFBs)	May–December 2016	1	1	0	100%
I-275 SB at Fowler Ave (Red RRFBs)	June–December 2016	0	0	0	N/A
I-275 NB at Busch Blvd (Wigwag flashing beacons)	October 2015–December 2016	8	6	2	75%
I-4 WB at Alexander St (Wigwag flashing beacons)	Mar–December 2016	4	3	1	75%

Notes:

- WWD – video showed red RRFBs or wigwag flashing beacons activated by actual wrong-way driving vehicles.
- Returned – vehicle stopped, came back in right direction; if vehicle did not come back in right direction within length of video, not considered returned case.
- Uncertain – vehicle observed driving in wrong direction; however, given circumstances, unclear in video if vehicle returned or not.
- Return Rate – ratio of number of returned wrong-way driving vehicles to number of total actual wrong-way driving vehicles.

4.4 Assessment Criteria

WWD countermeasures are considered effective if they are successful in alerting a wrong-way driver of his/her wrong-way movement and sending alerts of a potential wrong-way driver to the TMC in real time. In addition to these criteria, installation, maintenance, and operation costs must be considered in evaluating the WWD treatments.

4.4.1 Alerting a Wrong-Way Driver

The main goal of a WWD treatment is to alert a wrong-way driver that he/she is headed in the wrong direction. An effective treatment would result in the wrong-way driver turning around before entering the freeway. Of the six countermeasures for freeway off-ramps, the following four countermeasures proved to be relatively more effective in alerting a wrong-way driver of a wrong-way movement:

1. Red RRFBs
2. Detection-triggered LED lights around "WRONG WAY" signs
3. Detection-triggered blank-out signs that flash "WRONG WAY"
4. Wigwag flashing beacons

Delineators along off-ramps are considered not effective in alerting a wrong-way driver.

Based on the feedback from the general public, the newly-developed S&PM standards as a major arterial WWD countermeasure are effective countermeasures to direct drivers towards the right direction.

4.4.2 Sending Real-time Alerts to TMC

Sending alerts of a potential wrong-way driver to the TMC in real time is an effective way to mitigate WWD incidents. Of the seven countermeasures, the following four treatments can send alerts to TMC in real time:

1. Red RRFBs
2. Detection-triggered LED lights around "WRONG WAY" signs
3. Detection-triggered blank-out signs that flash "WRONG WAY"
4. Wigwag flashing beacons

For this study, the remaining two countermeasures (IIRPMs and off-ramp delineators) and the newly-developed S&PM standards on arterials do not have detection units to detect a wrong-way driver and, hence, cannot send real-time alerts to the TMC.

Additionally, the accuracy of real-time alerts plays a key role in determining the effectiveness of the countermeasures. Treatments that have the lowest rate of false positives and the highest rate of true positives are considered promising. However, since this information is not available for all countermeasures, no conclusion could be completely made at this time on the effectiveness of the countermeasures.

4.4.3 Cost

The seven countermeasures can be divided into two cost groups—low-cost (< $20,000 per ramp) and high-cost (> $30,000 per ramp):

- Low-cost countermeasures:
  - Newly-developed S&PM standards
  - Red flush-mount IIRPMs
  - Detection-triggered LED lights around "WRONG WAY" signs
  - Delineators along off-ramps

- High-cost countermeasures:
  - Red RRFBs
  - Detection-triggered blank-out signs that flash "WRONG WAY"
  - Wigwag flashing beacons

Table 9 compares the seven countermeasures based on cost and capabilities to alert a wrong-way driver and to send real-time alerts to the TMC.

Table 9: Comparison of WWD Countermeasures

Countermeasure	Cost[1]	Mitigate WWD or Alert Wrong-Way Driver[2]	Send Real-time Alerts to TMC[3]
Newly-developed S&PM standards	Low	Yes	No
Red RRFBs	High	Yes	Yes
Red flush-mount IIRPMs	Low	Yes	No
Detection-triggered LED lights around "WRONG WAY" signs	Low	Yes	Yes
Detection-triggered blank-out signs that flash "WRONG WAY"	High	Yes	Yes
Delineators along off-ramps	Low	No	No
Wigwag flashing beacons	High	Yes	Yes

[1] Cost includes initial installation, maintenance, and operation costs.

[2] Countermeasure effectiveness evaluated by its capability to mitigate WWD or alert wrong-way drivers to turn back on ramp prior to entering freeway.

[3] Assessment based on capability and accuracy to send real-time alerts.

5 EVALUATION OF COUNTERMEASURES VIA FIELD TESTING USING FOCUS GROUPS

This section presents evaluation of the seven WWD countermeasures selected by FDOT for evaluation and the corresponding field tests.

5.1 Site Locations

Field testing of the seven countermeasures was conducted as follows.

5.1.1 Newly-Developed S&PM Standards

As noted earlier, FDOT released a bulletin in April 2015 that introduced new minimum signing and pavement marking standards for interstate off-ramp intersections to complement the 2009 *Manual on Uniform Traffic Control Devices* (MUTCD) requirements (FHWA, 2009a). Figure 22 depicts the site selected for the S&PM countermeasure for this field testing and evaluation, a modified site in Tampa at the I-275 and E. Fletcher Avenue Interchange. It was selected due to its clarity in displaying the S&PM markings and its connection to a previous FDOT District 7 WWD study. Figure 23 shows an aerial view of this site.

Figure 22: Newly-developed S&PM on Arterials to Mitigate WWD

**Figure 23: Newly-developed S&PM Evaluation Site—
I-275 and E. Fletcher Avenue, Tampa**

5.1.2 Red RRFBs

Red RRFBs are rectangular-shaped high-intensity LED-based indications developed to improve safety at uncontrolled pedestrian crossings. They are mounted immediately between a pedestrian crossing sign and its supplemental arrow plaque. When activated, red RRFBs flash rapidly in a wigwag "flickering" flash pattern similar to emergency flashers on police vehicles (FHWA, 2009). These are effective in improving drivers yielding to pedestrians crossing streets.

Red RRFBs are a relatively new application of this technology and are placed at freeway off-ramps in an attempt to correct WWD. They are equipped with dual radar sensors to detect vehicles traveling in the wrong direction. Red RRFBs were installed in the Tampa Bay area on I-275 in early 2015. When activated, the red RRFBs flash rapidly alert the driver of the WWD action and, simultaneously, a message is sent to the Tampa Bay SunGuide TMC. Law enforcement is then dispatched, and other drivers on the freeway are warned through DMS.

Figure 24 depicts a site with red RRFBs mounted on "WRONG WAY" signs to deter wrong-way driving. The site selected for field testing and evaluation of this WWD countermeasure was the northbound off-ramp of the I-275 and E. Fletcher Avenue Interchange in Tampa. This site was selected due to its geometric characteristics and its connection to a previous FDOT District 7 WWD study. Figure 25 shows an aerial view of this site.

Figure 24: Red RRFBs

Figure 25: Red RRFBs Evaluation Site—NB Off-Ramp at I-275 and E. Fletcher Avenue

5.1.3 Red Flush-Mount IIRPMs

IIRPMs or red in-roadway warning lights are solar-powered, red, flashing, internally-illuminated LED in-roadway markers that are placed facing drivers traveling in the wrong direction on off-ramps. Figure 26 shows a site at a freeway off-ramp location installed with these IIRPMs. The fast flashing operation provides a flickering red LED light effect that faces wrong-way drivers and alerts them of a wrong-way entry. The spacing of the flashing and steady red lights on 12-ft and 15-ft lanes varies, as described in Section 2, but for both, the treatment includes three rows of lights 100 ft apart. The site selected for field testing and evaluation of this WWD countermeasure was the southbound off-ramp of the I-110 and E. Maxwell Street Interchange in Pensacola. This site was selected due to its narrow and short geometric characteristics. Figure 27 shows an aerial view of this site.

Figure 26: Red Flush-Mount IIRPMs

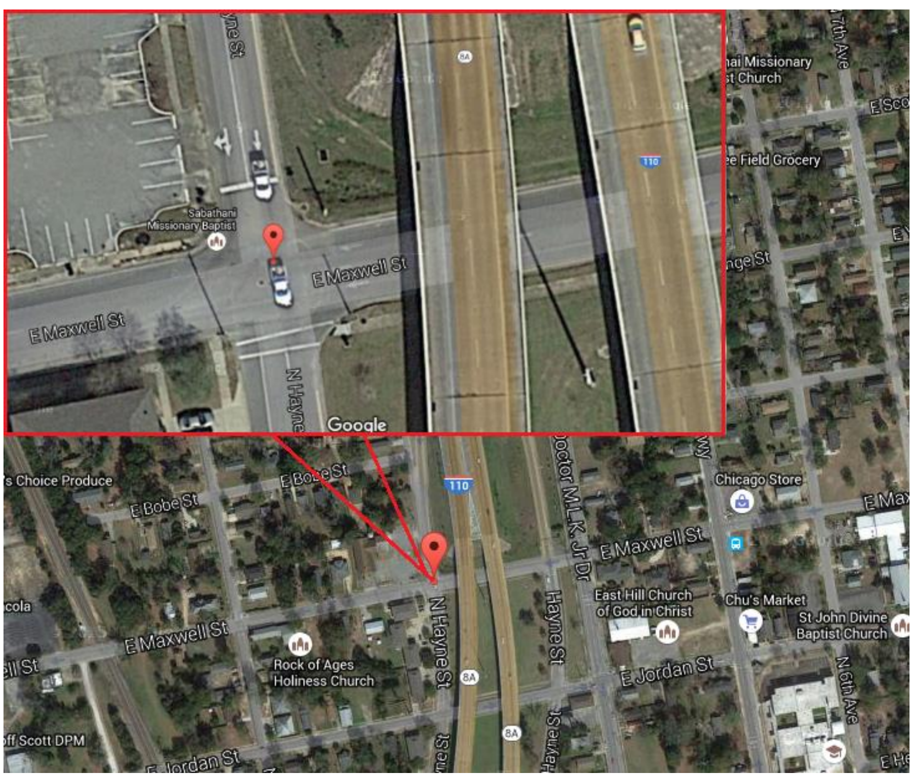


Figure 27: Red Flush-Mount IIRPM Evaluation Site—Southbound Off-Ramp at I-110 and E. Maxwell Street, Pensacola

5.1.4 Detection-triggered LED Lights around "WRONG WAY" Signs

Figure 28 shows a location with detection-triggered LED "WRONG WAY" signs. Sensors detect the wrong-way vehicle, and the "WRONG WAY" sign is triggered; the LED lights around the "WRONG WAY" sign start blinking, attracting the attention of the wrong-way driver. The site selected for field testing and evaluation of this WWD countermeasure was the southbound off ramp of the Sawgrass Expressway and W. Sample Road Interchange in Coral Springs, Florida. This site was selected due to its narrow and long geometric characteristics. Figure 29 shows an aerial view of this site.

Figure 28: Detection-Triggered LED Lights around "WRONG WAY" Signs

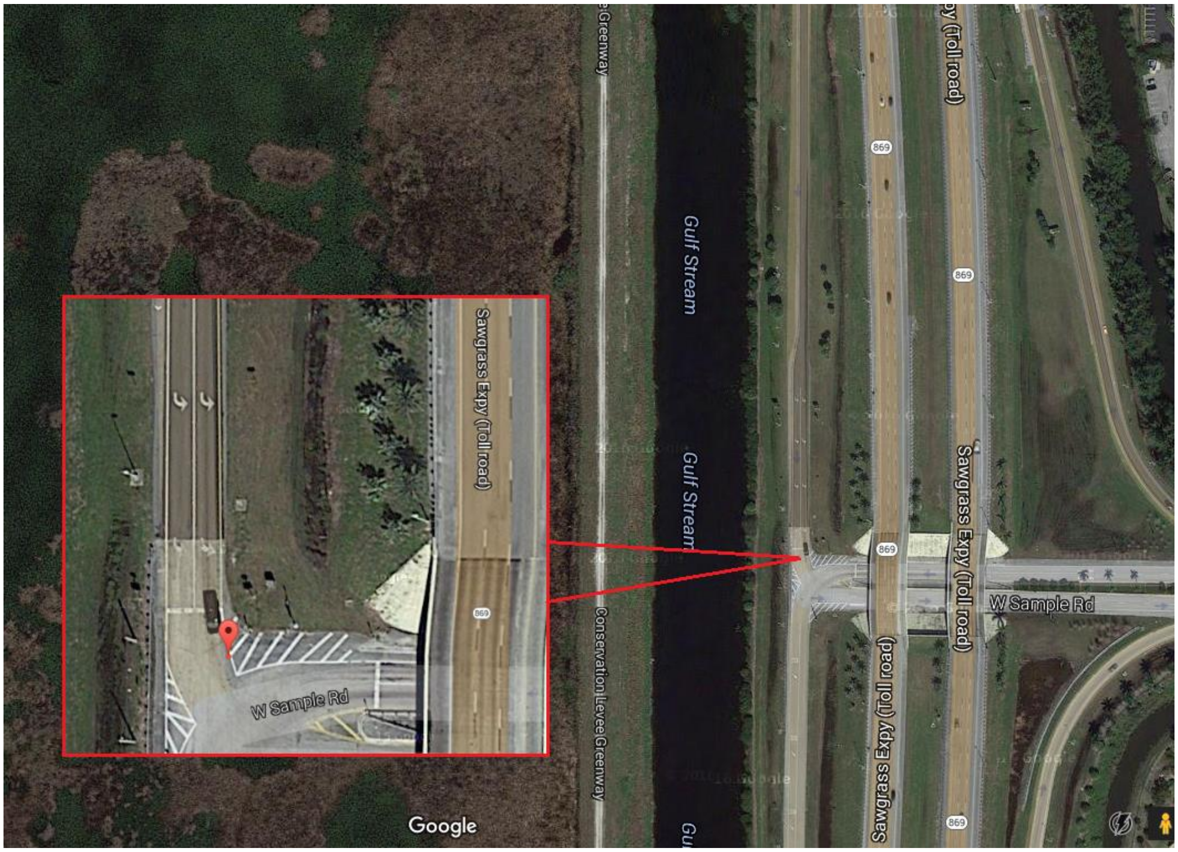


Figure 29: Detection-Triggered LED Lights around "WRONG WAY" Signs Evaluation Site—SB Off-Ramp at Sawgrass Expressway and W. Sample Road, Coral Springs

5.1.5 Detection-Triggered Blank-out Signs That Flash “WRONG WAY”

Another variation of the detection-triggered LED lights around the “WRONG WAY” sign concept is using blank-out signs that flash “WRONG WAY,” as shown in Figure 30. The site selected for field testing and evaluation of this WWD countermeasure was the westbound off ramp of the I-10 and Capital Circle NW Interchange in Tallahassee, Florida. This site was selected due to its wide and long off-ramp geometric characteristics. Figure 31 shows an aerial view of this site.

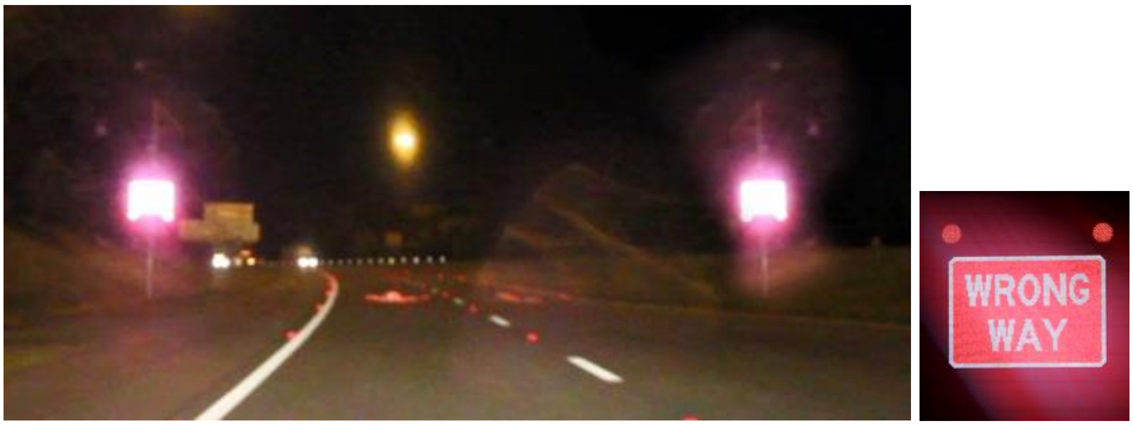


Figure 30: Detection-triggered Blank-Out Signs That Flash “WRONG WAY”

Figure 31: Detection-Triggered Blank-out Signs That Flash “WRONG WAY” Evaluation Site — WB Off-Ramp at I-10 and Capital Circle NW

5.1.6 Delineators along Off-ramps

Delineators along off-ramps provide two different colors of delineators—red for wrong-way drivers and yellow for those driving in the correct direction, as shown in Figure 32. The site selected for field testing and evaluation of this WWD countermeasure was the SB off-ramp of the I-275 and E. Busch Boulevard

Interchange in Tampa. This site was selected due to its availability to have delineators installed on short notice for field testing. Figure 33 shows an aerial view of this site.

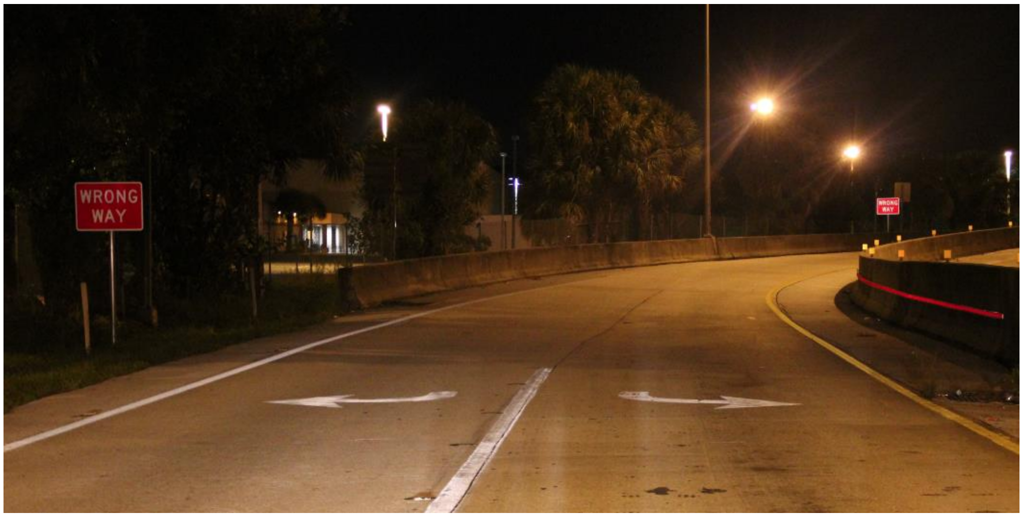


Figure 32: Delineators along Off-ramps

Figure 33: Delineators along Off-ramps Evaluation Site—
SB Off-Ramp at I-275 and E. Busch Boulevard, Tampa

5.1.7 Wigwag Flashing Beacons

Wigwag flashing beacons can be installed on "WRONG WAY" signs, as shown in Figure 34. Once a wrong-way driver is detected, the beacons begin flashing, alerting the driver of the WWD action. The site selected for field testing and evaluation of this WWD countermeasure was the off-ramp of the I-275 and E. Busch Boulevard Interchange in Tampa. This site was selected due to its wide and long off-ramp geometric characteristics. Figure 35 shows an aerial view of this site.

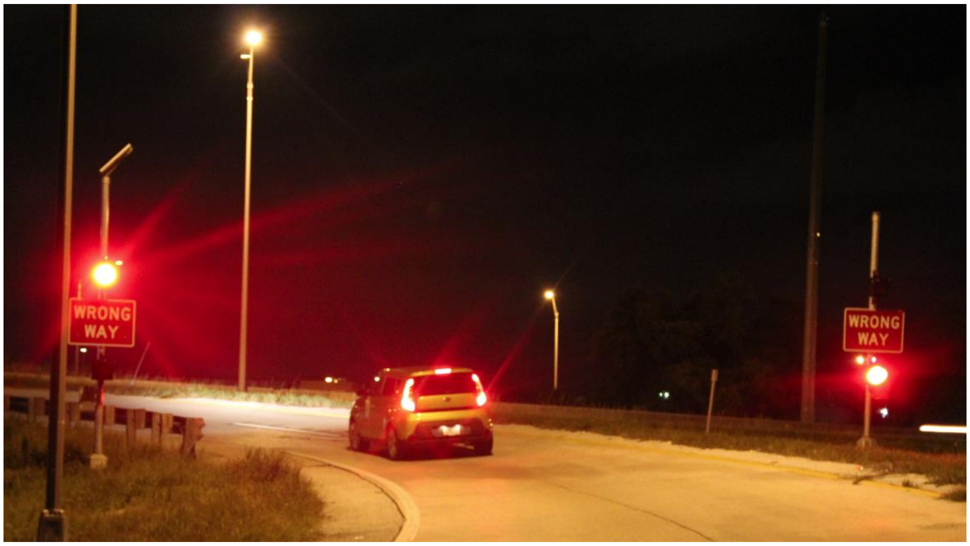


Figure 34: Wigwag Flashing Beacons

Figure 35: Wigwag Flashing Beacons Evaluation Site—Northbound Off-Ramp at I-275 and E. Busch Boulevard, Tampa

5.2 Methodology

The major work conducted for Task 4 of this project was field testing and evaluation of the identified countermeasures using focus groups. A focus group was assembled for each selected site, each comprising 8–10 members, including 5 key WWD engineers/researchers (permanent participants) and 3–5 local motorists (local participants). Their purpose was to compare and evaluate the effectiveness of the WWD countermeasures via actual physical driving and observation with the naked eye. This is in comparison to Task 5 of this study, in which a field recording of each countermeasure was obtained and video footage of all countermeasures was compiled to show their effectiveness. The evaluation results from the field testing focus groups are included in this section, and the evaluation results of the public opinion survey are included in the following section.

A field test and evaluation process was developed that entailed survey questionnaires (as shown in Appendix A) for each countermeasure. Each focus group member followed the evaluation process and completed the survey questionnaires and provided specific comments and feedback. Once all participants in a focus group completed the survey, the whole focus group assembled and discussed major points regarding that specific site and the WWD countermeasure being evaluated.

Each focus group visited each selected site at night to assess the corresponding countermeasures and was given the opportunity to drive and pass through the WWD countermeasure in the wrong-way direction three times to help with their field evaluation. Each site visit corresponded to a temporary ramp closure for several hours at night (11:00 PM–3:00 AM) to ensure the safety of the focus group members and public motorists. FDOT was responsible for coordinating and arranging the ramp closures with the Florida Highway Patrol (FHP).

5.3 Results

The results of the driver focus group surveys, nonparametric tests for participant ratings from the surveys, and focus group discussions of each countermeasure are presented in detail in this subsection.

5.3.1 Driver Focus Group Survey

The driver focus group surveys were completed by focus group members who evaluated the selected countermeasures. The following subsections present tables in which the numerical ratings for questions 3 and 4 are depicted for each participant along with an average rating received by that countermeasure. Question 3 was to rate how effectively each countermeasure warned the driver of WWD when compared to standard static "WRONG WAY" signs installed at a freeway off-ramp. Question 4 was to rate how effectively each WWD countermeasure the driver just experienced warned him/her of or stopped wrong-way driving. For both questions, a rating of 10 = "extremely well" and 0 = "there is no difference." Appendix B includes the detailed driver focus group survey responses by each countermeasure type for each specific question as well as pros and cons derived from each driver focus group survey for each corresponding countermeasure.

5.3.1.1 Newly-Developed S&PM Standards

Table 10 depicts the numerical ratings for questions 3 and 4 for each participant along with an average rating received by newly developed S&PM standards.

Table 10: Countermeasure #1 – Participant Ratings for Q3 and Q4

All Participants	Q3 Rating	Q4 Rating
Permanent Participant #1	8	6
Permanent Participant #2	6	7
Local Participant #1	9	9
Local Participant #2	3	4
Permanent Participant #3	9.5	9.5
Permanent Participant #4	9	9
Local Participant #3	7	7
Permanent Participant #5	9.5	7
Average rating	**7.6**	**7.3**
Permanent Participants	**Q3 Rating**	**Q4 Rating**
Permanent Participant #1	8	6
Permanent Participant #2	6	7
Permanent Participant #3	9.5	9.5
Permanent Participant #4	9	9
Permanent Participant #5	9.5	7
Average rating	**8.4**	**7.7**

5.3.1.2 Red RRFBs

Table 11 depicts the numerical ratings for questions 3 and 4 for each participant along with an average rating received by red RRFBs.

Table 11: Countermeasure #2 – Participant Ratings for Q3 and Q4

All Participants	Q3 Rating	Q4 Rating
Permanent Participant #1	7	8
Permanent Participant #2	8	9
Local Participant #1	10	10
Local Participant #2	10	10
Permanent Participant #3	9.5	9.5
Permanent Participant #4	9	9
Local Participant #3	9	9
Permanent Participant #5	10	10
Average rating	**9.1**	**9.3**
Permanent Participants	**Q3 Rating**	**Q4 Rating**
Permanent Participant #1	7	8
Permanent Participant #2	8	9
Permanent Participant #3	9.5	9.5
Permanent Participant #4	9	9
Permanent Participant #5	10	10
Average rating	**8.7**	**9.1**

5.3.1.3 Red Flush-Mount IIRPMs

Table 12 depicts the numerical ratings for questions 3 and 4 for each participant along with an average rating received by Red flush-mount IIRPMs.

Table 12: Countermeasure #3 – Participant Ratings for Q3 and Q4

All Participants	Q3 Rating	Q4 Rating
Permanent Participant #1	4	6
Local Participant #4	6	5
Permanent Participant #2	5	2
Permanent Participant #3	9	9
Local Participant #5	8	8
Local Participant #6	10	10
Permanent Participant #4	5	5
Permanent Participant #5	8	8
Local Participant #7	0	3
Average rating	**6.1**	**6.2**
Permanent Participants	**Q3 Rating**	**Q4 Rating**
Permanent Participant #1	4	6
Permanent Participant #2	5	2
Permanent Participant #3	9	9
Permanent Participant #4	5	5
Permanent Participant #5	8	8
Average rating	**6.2**	**6.0**

5.3.1.4 Detection-Triggered LED Lights around "WRONG WAY" signs

Table 13 depicts the numerical ratings for questions 3 and 4 for each participant along with an average rating received by detection-triggered LED lights around "WRONG WAY" signs.

Table 13: Countermeasure #4 – Participant Ratings for Q3 and Q4

All Participants	Q3 Rating	Q4 Rating
Permanent Participant #1	6	6
Permanent Participant #2	5	7
Local Participant #8	6	6
Permanent Participant #3	3	3
Permanent Participant #4	7	9
Local Participant #9	10	8
Permanent Participant #5	7.5	7.5
Local Participant #10	8	–
Average rating	**6.6**	**6.6**
Permanent Participants	**Q3 Rating**	**Q4 Rating**
Permanent Participant #1	6	6
Permanent Participant #2	5	7
Permanent Participant #3	3	3
Permanent Participant #4	7	9
Permanent Participant #5	7.5	7.5
Average rating	**5.7**	**6.5**

5.3.1.5 Detection-Triggered Blank-out Signs That Flash "WRONG WAY"

Table 14 depicts the numerical ratings for questions 3 and 4 for each participant along with an average rating received by detection-triggered blank-out signs that flash "wrong way."

Table 14: Countermeasure #5 – Participant Ratings for Q3 and Q4

All Participants	Q3 Rating	Q4 Rating
Permanent Participant #1	8	–
Permanent Participant #2	8	8
Permanent Participant #3	8	8
Local Participant #5	9	9
Local Participant #11	9	9
Local Participant #6	10	10
Permanent Participant #4	9	9
Permanent Participant #5	10	10
Local Participant #12	10	6
Local Participant #13	10	7
Average rating	**9.1**	**8.4**
Permanent Participants	**Q3 Rating**	**Q4 Rating**
Permanent Participant #1	8	–
Permanent Participant #2	8	8
Permanent Participant #3	8	8
Permanent Participant #4	9	9
Permanent Participant #5	10	10
Average rating	**8.6**	**8.8**

5.3.1.6 Delineators along Off-ramps

Table 15 depicts the numerical ratings for questions 3 and 4 for each participant along with an average rating received by delineators along off-ramps.

Table 15: Countermeasure #6 – Participant Ratings for Q3 and Q4

All Participants	Q3 Rating	Q4 Rating
Permanent Participant #1	1	1
Permanent Participant #2	1	1
Local Participant #1	2	0
Local Participant #14	2	5
Local Participant #2	2	0
Permanent Participant #3	2	2
Permanent Participant #4	1	1
Local Participant #3	1	2
Permanent Participant #5	0	1
Average rating	**1.3**	**1.4**
Permanent Participants	**Q3 Rating**	**Q4 Rating**
Permanent Participant #1	1	1
Permanent Participant #2	1	1
Permanent Participant #3	2	2
Permanent Participant #4	1	1
Permanent Participant #5	0	1
Average rating	**1.0**	**1.2**

5.3.1.7 Wigwag Flashing Beacons

Table 16 depicts the numerical ratings for questions 3 and 4 for each participant along with an average rating received by wigwag flashing beacons.

Table 16: Countermeasure #7 – Participant Ratings for Q3 and Q4

All Participants	Q3 Rating	Q4 Rating
Permanent Participant #1	7	8
Permanent Participant #2	8	8
Local Participant #1	7	8
Local Participant #14	8	8
Local Participant #2	7	10
Permanent Participant #3	9	9
Permanent Participant #4	8	8
Local Participant #3	7	7
Permanent Participant #5	8.5	8.5
Average rating	**7.7**	**8.3**
Permanent Participants	**Q3 Rating**	**Q4 Rating**
Permanent Participant #1	7	8
Permanent Participant #2	8	8
Permanent Participant #3	9	9
Permanent Participant #4	8	8
Permanent Participant #5	8.5	8.5
Average rating	**8.1**	**8.3**

5.3.2 Nonparametric Tests for Participant Ratings

Summarizing the ratings in Tables 10 through 16, Table 17 shows the descriptive statistics of participant ratings for driver focus group survey Questions 3 and 4. The nonparametric tests in this section determine if the Q3 and Q4 ratings were significantly different for the seven countermeasures.

Table 17: Descriptive Statistics of Participant Ratings for Q3 and Q4

Average Ratings	Q3 Rating		Q4 Rating	
	Mean	*Number of Participants*	*Mean*	*Number of Participants*
#1: Newly-developed S&PM standards	7.6	8	7.3	8
#2: Red RRFBs	9.1	8	9.3	8
#3: Red flush-mount IIRPMs	6.1	9	6.2	9
#4: Detection-triggered LED lights around “WRONG WAY” signs	6.6	8	6.6	7
#5: Detection-triggered blank-out signs that flash “WRONG WAY”	9.1	10	8.4	9
#6: Delineators along off-ramps	1.3	9	1.4	9
#7: Wigwag flashing beacons	7.7	9	8.3	9

The nonparametric tests were adopted for hypothesis tests regarding Q3 and Q4 ratings between the seven countermeasures because the data points of participant ratings (Tables 10–16) do not follow normal distribution or any evident shape. Specifically, the Kruskal-Wallis H test (a rank-based nonparametric test) was used to determine if there are statistically-significant differences between the seven groups of participant ratings. The Kruskal-Wallis H test is considered the nonparametric alternative to the one-way ANOVA (sometimes also called the "one-way ANOVA on ranks"), and an extension of the Mann-Whitney U test to allow the comparison of more than two independent groups (countermeasures in this study). The Kruskal-Wallis H test results showed that there was a statistically-significant difference in Q3 rating between the seven groups, with $\chi^2(6) = 33.791$ and $p = 0.0001$. Similarly, for the Q4 rating, the Kruskal-Wallis H test showed that there was a statistically-significant difference between the seven groups, with $\chi^2(6) = 32.966$ and $p = 0.0001$. As shown in Figure 36, the top three countermeasures for Q3 ratings are #5 (detection-triggered blank-out signs), #2 (red RRFBs), and #7 (wigwag flashing beacons).

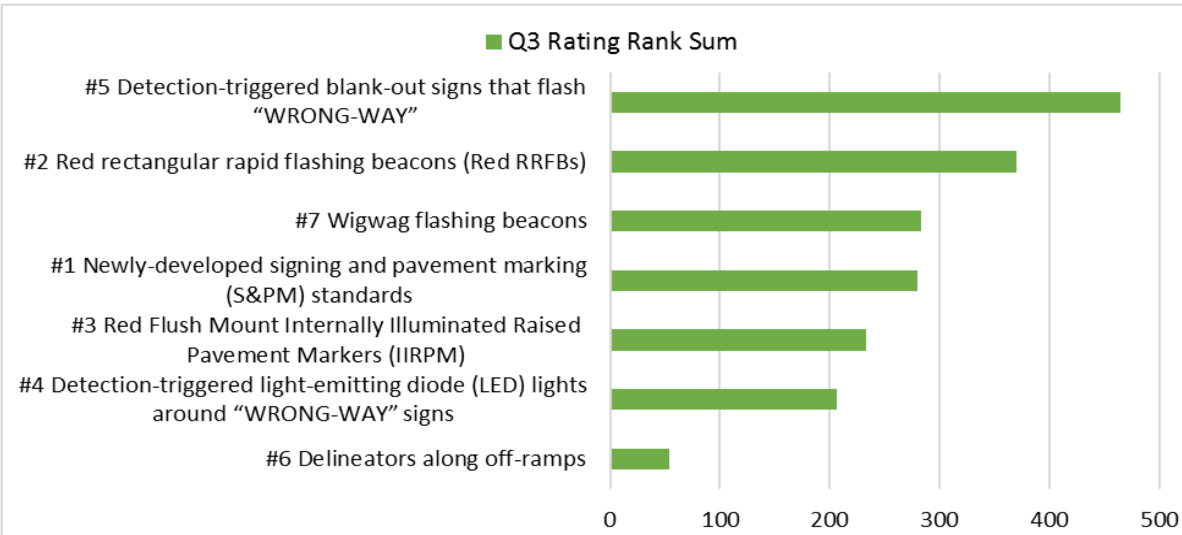


Figure 36: Results of Nonparametric Test for Q3 Rating

As shown in Figure 37, the top three countermeasures for Q4 ratings were #2 (red RRFBs), #5 (detection-triggered blank-out signs that flash "WRONG WAY"), and #7 (wigwag flashing beacons).

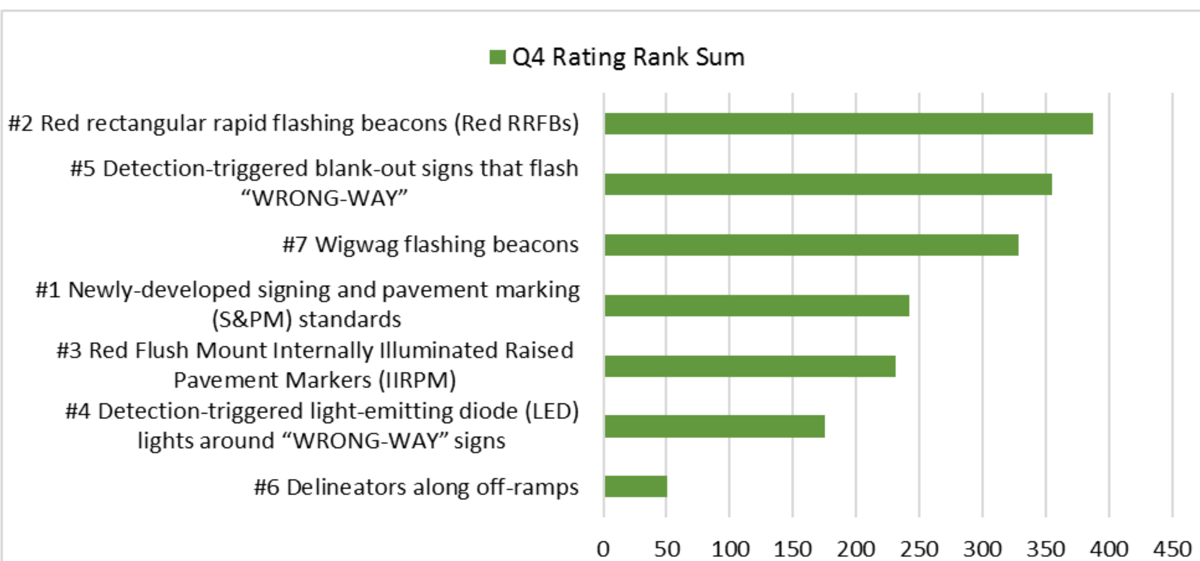


Figure 37: Results of Nonparametric Test for Q4 Rating

To further determine which of these countermeasures differ from each other, post hoc pairwise tests (Sidak method) were performed after significant effects for Q3 and Q4 ratings. As shown in Table 18, for Q3 ratings, both countermeasures #2 (red RFRBs) and #5 (detection-triggered blank-out signs that flash "WRONG WAY") were significantly higher than countermeasure #3 (red flush mount IIRPM) at the 5% level. Countermeasure #5 (detection-triggered blank-out signs that flash "WRONG WAY") was significantly higher than countermeasure #4 (detection-triggered LED) at the 10% level. Countermeasure #6 (delineators along off-ramps) was significantly lower than all the other countermeasures at the 1% level.

Table 18: Comparison of Q3 Rating by Countermeasure

Row Mean-Col Mean	#1	#2	#3	#4	#5	#6
#2	1.438 (0.904)					
#3	-1.514 (0.826)	-2.951 **(0.021**)**				
#4	-1.063 (0.996)	-2.500 (0.118)	0.451 (1.000)			
#5	1.475 (0.829)	0.038 (1.000)	2.989 **(0.010**)**	2.538 **(0.069*)**		
#6	-6.292 **(0.000***)**	-7.729 **(0.000***)**	-4.778 **(0.000***)**	-5.229 **(0.000***)**	-7.767 **(0.000***)**	
#7	0.097 (1.000)	-1.340 (0.932)	1.611 (0.699)	1.160 (0.983)	-1.378 (0.867)	6.389 **(0.000***)**

****, **, * ==> Significance at 1%, 5%, 10% levels.*

As shown in Table 19, for the Q4 rating, countermeasure #2 (red RFRBs) was significantly higher than countermeasures #3 (red flush-mount IIRPMs) and #4 (detection-triggered LED lights around "WRONG WAY" signs) at the 1% and 10% levels, respectively. Countermeasure #6 (delineators along off-ramps) was significantly lower than all the other countermeasures at the 1% level.

Table 19: Comparison of Q4 Rating by Countermeasure

Row Mean-Col Mean	#1	#2	#3	#4	#5	#6
#2	2.000 (0.360)					
#3	-1.090 (0.987)	-3.090 (0.008***)				
#4	-0.670 (1.000)	-2.670 (0.069*)	0.421 (1.000)			
#5	1.132 (0.981)	-0.868 (0.999)	2.222 (0.138)	1.802 (0.558)		
#6	-5.868 (0.000***)	-7.868 (0.000***)	-4.778 (0.000***)	-5.198 (0.000***)	-7.000 (0.000***)	
#7	0.965 (0.997)	-1.035 (0.993)	2.056 (0.228)	1.635 (0.721)	-0.167 (1.000)	6.833 (0.000***)

****, **, * ==> Significance at 1%, 5%, 10% levels.*

5.3.3 Driver Focus Group Discussions

As described in the methodology subsection, the driver focus group discussions were conducted as a whole group that evaluated the select countermeasures immediately after the group completed the field testing of each specific countermeasure. This discussion was conducted to capture any points that could otherwise not be captured through the focus group questionnaire the participants completed. A summary of the discussions for each countermeasure is included in this subsection.

5.3.3.1 Newly-Developed S&PM Standards

One participant stated that pavement markings tell drivers explicitly to go straight instead of turning into the wrong way, which was found to be a very clear and simple message. In addition, another participant mentioned that the interstate shield is effective, as it is a common logo that drivers will immediately recognize due to its colors being bright and the logo being large enough to be seen from a distance. A major point brought up during the discussion was that even though this is a very good countermeasure, it should be used to supplement standard regulatory signs but should not act as a replacement. A participant also mentioned that it is a very good improvement from previous left-turn arrow pavement markings, which were confusing to drivers. Another topic was that drivers might possibly miss this countermeasure if they are not looking on the ground. In addition, for the effectiveness of this countermeasure, it was mentioned that road lighting is very crucial.

5.3.3.2 Red RRFBs

One participant stated that the countermeasure is very prominent and nearly impossible to miss due to its prominent red color and rapid flashing frequency. The drivers also mentioned that the emergent flashing pattern suggests something dangerous is happening and commands immediate attention. Another participant mentioned that the red lights meant “emergency” to him, which grabbed his attention. In addition, the participants mentioned that the radar detection of the vehicle was quick and efficient. Some participants mentioned that the detection zone of the radar should be tweaked a little to give a longer reaction time for the wrong-way driver. Another participant mentioned that with the strong flashing lights, they were unable to read the “WRONG WAY” sign clearly, which potentially could be problematic. However, there are “WRONG WAY” signs before and after the red RRFB along the off-ramp, so drivers should quickly recognize they drive in the wrong direction.

5.3.3.3 Red Flush-Mount IIRPMs

One participant stated that this countermeasure was quite effective compared to static “WRONG WAY” signs since lights draw attention and get the driver’s attention at night. One participant mentioned that the device is right in front of the driver on the roadway, which gives it maximum effectiveness. However, other participants mentioned that the lights of the countermeasure are not bright or visible enough because of other lights that also fall on the roadway surface. Other participants stated that the message was ambiguous and not all drivers might understand that this is a wrong-way driving countermeasure. In addition, the participants mentioned that this countermeasure would have no impact in daylight conditions. Another participant mentioned that these could be good supplemental countermeasures as a secondary wrong-way driving countermeasure and might possibly be considered for all ramps if cost is low.

5.3.3.4 Detection-Triggered LED Lights around "WRONG WAY" signs

One participant stated that LEDs draw attention to the sign and seems effective in alerting the driver. Another participant mentioned that the LEDs accentuate the "WRONG WAY" sign clearly, directly relaying the countermeasure's message to the driver. On the other hand, some participants mentioned that the detection zone should be set so that the driver will not be able to accelerate quickly and pass the sign before he/she can understand the message being relayed. Other participants mentioned that the letters of the sign are not very visible while the LEDs are flashing and, also, the text is dull compared to LED lights. Some suggestions were to brighten the LEDs, make the sign bigger, etc. In addition, some participants mentioned that another set of lights downstream that trigger at the same time as the first set of lights will ensure drivers not missing the countermeasure.

5.3.3.5 Detection-Triggered Blank-out Signs that Flash "WRONG WAY"

One participant stated that this countermeasure was hard to miss and was very visible. The group agreed that the sign worked even when the driver was far away and since the sign says "WRONG WAY," it is familiar to drivers and easy to understand. A participant mentioned that there is a nice surprise factor, since all is dark and then suddenly the sign appears to grab the driver's attention fully. The group agreed that the countermeasure captures attention no matter how fast the driver is going and where they are looking. On the other hand, the group also agreed that perhaps a bigger sign/font will make the countermeasure more effective for more impaired drivers and drivers with eyesight problems. Another topic was the detection zone and how important it is to have enough time for the driver to process and understand the message. The group agreed that a mixture of in-pavement lights with this countermeasure would make a very effective combination to capture the wrong-way drivers' attention.

5.3.3.6 Delineators along Off-ramps

One participant stated that this countermeasure does not explicitly tell the driver that he/she is going in the wrong-way direction. Another point that was made was that these might be very cost-effective, and the red color might not get the driver's attention, but it does not carry a clear message. Some participants mentioned that this countermeasure is salient, and most drivers likely will not stop due to the message not being effective. It was agreed by the group that this might be more confusing to drivers than carrying out the WWD message and stopping them.

5.3.3.7 Wigwag Flashing Beacons

One participant stated that this countermeasure is prominent and hard to miss, since the red lights are bright. Another mentioned that the lights alert the driver immediately and the wigwag nature is attention-getting. The group also discussed that the detection zone is an important aspect for this type of countermeasure so the driver has enough time to reach the warning sign. Another participant stated that the steady flashing pattern is easy on the eyes of the driver while still clearly sending the "wrong-way" message. The group also discussed that the wigwag could be quicker, as with the red RRFBs, and the intensity could be heightened to warn the driver more effectively.

5.4 FIELD TESTING USING FOCUS GROUPS CONCLUSIONS

Field testing and driver focus group surveys were conducted to evaluate the seven selected WWD countermeasures. The rating scores obtained from survey questions 3 and 4 and the discussions from seven focus groups were used to evaluate the effectiveness of the selected WWD countermeasures.

Question 3 asked participants to score the effectiveness of a selected WWD countermeasure to mitigate wrong-way driving or warn a driver of wrong-way driving as compared to existing static signage or pavement marking treatment, with 10 being "extremely well" to 0 being "there is no difference."

Question 4 asked participants to score the effectiveness of a selected WWD countermeasure they just experienced to mitigate wrong-way driving or warn a driver of wrong-way driving without any comparison to the existing treatments, with 10 being "extremely well" and 0 being "there is no difference."

By analyzing the rating scores for questions 3 and 4 from the driver focus groups surveys, the top three most effective countermeasures were ranked by the focus group participants, as depicted in Table 20.

Table 20: Top Three Countermeasures – Average Participant Ratings for Driver Focus Group Survey Q3 and Q4

Average Ratings	Q3 Rating	Ranking based on Q3 Rating	Q4 Rating	Ranking based on Q4 Rating
Red RRFBs	9.1	1	9.3	1
Detection-triggered blank-out signs that flash "WRONG WAY"	9.1	1	8.4	2
Wigwag flashing beacons	7.7	3	8.3	3

Further nonparametric tests showed the following findings: (1) for the Q3 rating, red RRFBs and detection-triggered blank-out signs that flash "WRONG WAY" scored significantly higher than IIRPMs at the 5% level, and detection-triggered blank-out signs that flash "WRONG WAY" scored significantly higher than detection-triggered LED lights around "WRONG WAY" signs at the 10% level; (2) for the Q4 rating, red RFRBs scored significantly higher than IIRPMs and detection-triggered LEDs at the 1% and 10% levels, respectively; (3) delineators along off-ramps scored significantly lower than all the other countermeasures for both the Q3 and Q4 ratings. Based on the results of the nonparametric tests, the top three most effective countermeasures for the Q3 and Q4 rating scores are shown in Tables 21 and 22, respectively.

Table 21: Top Three Countermeasures Based on Nonparametric Tests on Ratings for Q3

Countermeasure	Ranking based on Q3 Rating
Detection-triggered blank-out signs that flash "WRONG WAY"	1
Red RRFBs	2
Wigwag flashing beacons	3

Table 22: Top Three Countermeasures Based on Nonparametric Tests on Ratings for Q4

Countermeasure	Ranking based on Q4 Rating
Red RRFBs	1
Detection-triggered blank-out signs that flash "WRONG WAY"	2
Wigwag Flashing Beacons	3

Additionally, the top three most effective WWD countermeasures based on the results of focus group discussions and the consensus of five core focus group members were (1) red RRFBs, (2) detection-triggered blank-out signs that flash "WRONG WAY," and (3) wigwag flashing beacons, as shown in Table 23.

Table 23: Top Three Countermeasures Based on Focus Group Discussions

Countermeasure	Ranking based on Q4 Rating
Red RRFBs	1
Detection-triggered blank-out signs that flash "WRONG WAY"	2
Wigwag Flashing Beacons	3

Based on the results of driver focus group survey, the discussions of focus group, and the consensus of five core focus group members, it was concluded that the top three most effective WWD countermeasures based on the field testing and evaluation are (1) red RRFBs, (2) detection-triggered blank-out signs that flash "WRONG WAY," and (3) wigwag flashing beacons. It also was concluded that the effectiveness of the detection-triggered blank-out signs is very close to that of red RRFBs.

6 EVALUATION OF COUNTERMEASURES VIA PUBLIC OPINION SURVEY

A major task for completing the comprehensive evaluation of identified WWD countermeasures was to obtain the public's perception regarding these countermeasures. Positive perception and acceptance from the general public of a new countermeasure implementation to reduce WWD is vital for the successful implementation of each countermeasure. This section summarizes the assessment and comparison of the perceived effectiveness of the identified WWD countermeasures obtained through a public opinion survey using pre-recorded field videos.

6.1 Site Selection

A total of 250 surveys were collected at 7 different locations around the Tampa Bay area:

- Muvico Theater, Highway Preserve Parkway, Tampa
- Center for Urban Transportation Research (CUTR), USF-Tampa campus
- USF Marshall Student Center, USF-Tampa campus
- USF Library, USF-Tampa campus
- Town 'N Country Senior Center, 7606 Paula Drive, Tampa
- Brandon Senior Center, 612 N. Parsons Avenue, Brandon,
- Riverview Senior Center, 101 E. Kirby Street, Tampa

These locations were selected to gain access to a larger and more diverse survey participant demographic. Figure 38 shows photos of sample locations at which the survey was administered. Table 24 shows the number of surveys conducted at each location, which correlates to the percentages depicted in Figure 39.

Figure 38: Sample Survey Administration Photos

Table 24: Number of Surveys Conducted at Each Location

Survey Location	Total
Brandon Senior Center	6
Muvico Theater	101
The Oaks at Riverview Senior Center	19
Town 'N Country Senior Center	23
USF Center for Urban Transportation Research	4
USF Library	48
USF Marshall Student Center	49
Total	**250**

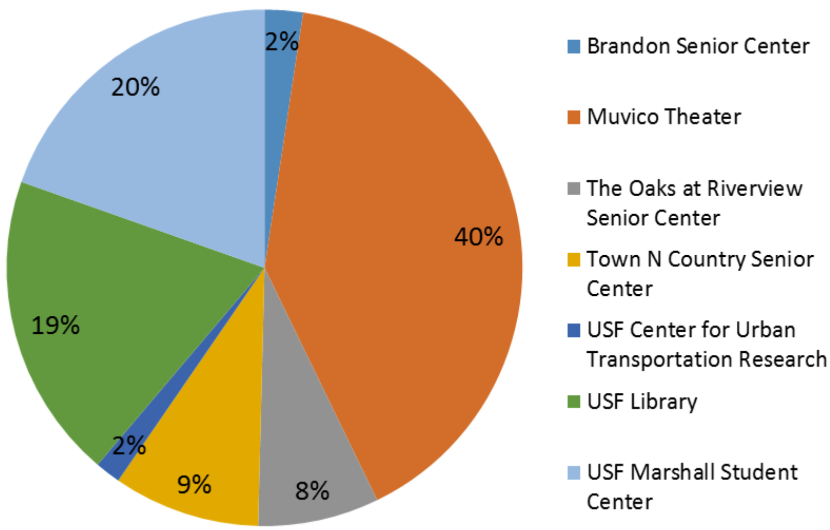


Figure 39: Number of Surveys Conducted at Each Location

6.2 Public Opinion Surveys

The public opinion survey was designed to collect participant perceptions of the most effective and informative WWD countermeasures (see Appendix C for survey instrument). In addition to participant demographics (gender, age, city, state, and race), the following participant perceptions were collected through this survey:

- Degree of improvement of the newly-developed signing and pavement markings over the previous left-turn arrow pavement markings.
- Effectiveness of four active and two passive signage countermeasures at off-ramps, from most effective to least effective.
- Effectiveness of top two countermeasure choices if used together and to what degree.

A field video was recorded for each countermeasure at each selected site, coinciding with the task group site visits performed under Task #4. The videos were recorded from the driver's perspective to maximize the feeling of survey participants driving the vehicle themselves. Once the videos were finalized, a set of survey questions was designed and pilot tested. In total, 250 participants in different age groups (16–29, 30–59, 60+) and genders were recruited to review the pre-recorded field videos and participate in the public opinion survey with a goal of attaining a representative group that replicates the general public. To generate interest in the study, an incentive ($5 gift card to a grocery store) was given to each participant who took the public opinion survey. Figures 41 through 43 show the gender, age and race split of the survey participants.

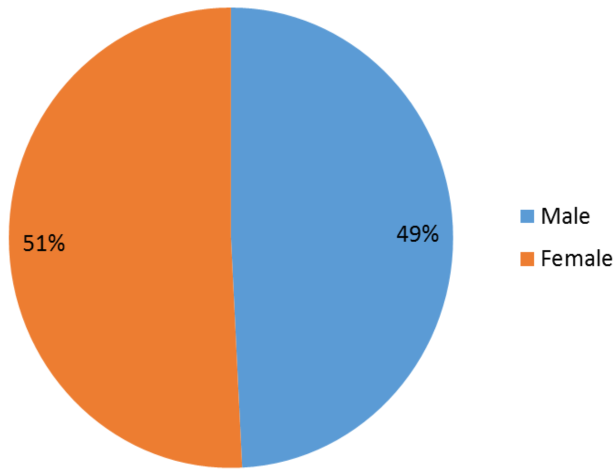


Figure 40: Gender Split of Survey Participants

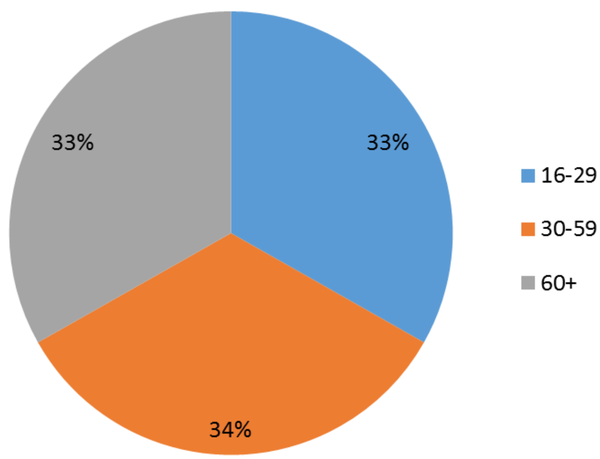


Figure 41: Age Split of Survey Participants

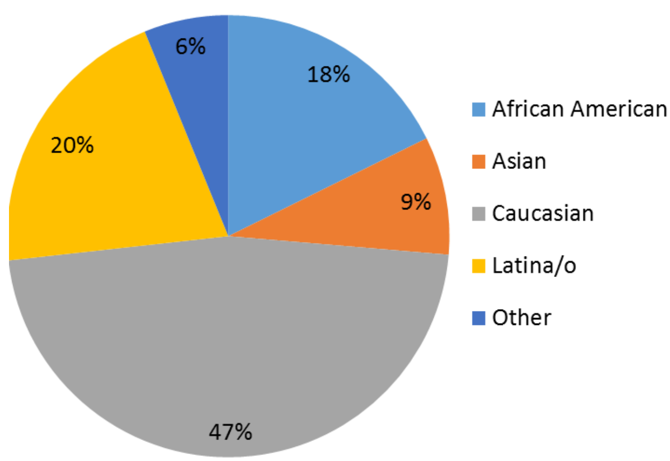


Figure 42: Race Split of Survey Participants

6.3 Public Opinion Survey Results and Analysis

The following questions were asked on the survey to collect data on the public's perception of the most effective and information WWD countermeasures. (Raw data for the following charts results can be found in Appendix D in tabulated format.)

6.3.1 Question 1

Q1. For the signing and pavement marking countermeasure (Countermeasure #1), to what degree does this countermeasure improve upon the previous condition to warn or mitigate wrong-way driving? Comparing the newly-developed in-pavement markings to the previous left-turn arrow markings, 59% of survey participants considered it a significant improvement, 28% considered it to be a moderate improvement, and 13% considered it a minor improvement, as depicted in Figure 43.

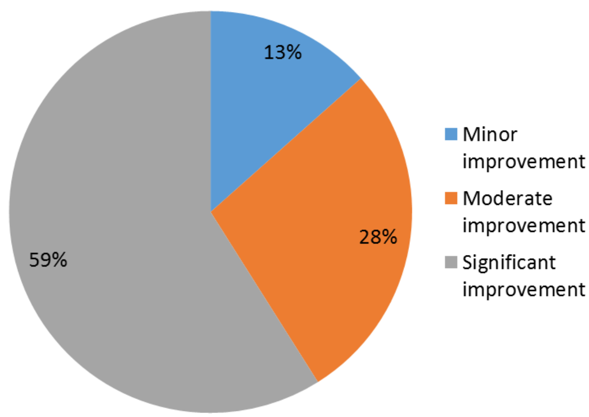


Figure 43: Question 1 Responses

6.3.2 Question 2

Q2. Please rank the effectiveness of the following four countermeasures at off-ramps from the most effective to the least effective, where 1 = most effective and 4 = least effective. For red RRFBs, 80 participants listed it as their first choice, 67 second, 54 third, and 45 fourth, as shown in Figure 44.

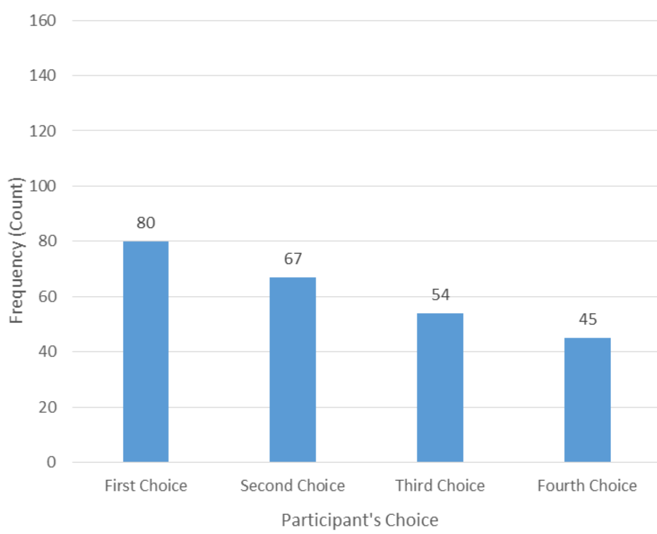


Figure 44: Question 2 Responses – RRFBs

For detection-triggered LED lights around “WRONG WAY” signs, 55 participants listed it as their first choice, 59 second, 69 third, and 59 fourth, as shown in Figure 45.

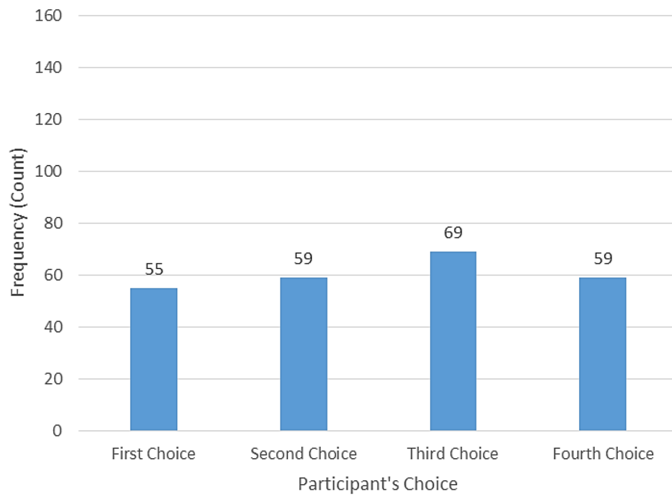


Figure 45: Question 2 Responses – Detection-Triggered LED Lights around “WRONG WAY” signs

For detection-triggered blank-out signs that flash “WRONG WAY,” 36 participants listed it as their first choice, 53 second, 81 third, and 73 fourth, as shown in Figure 46.

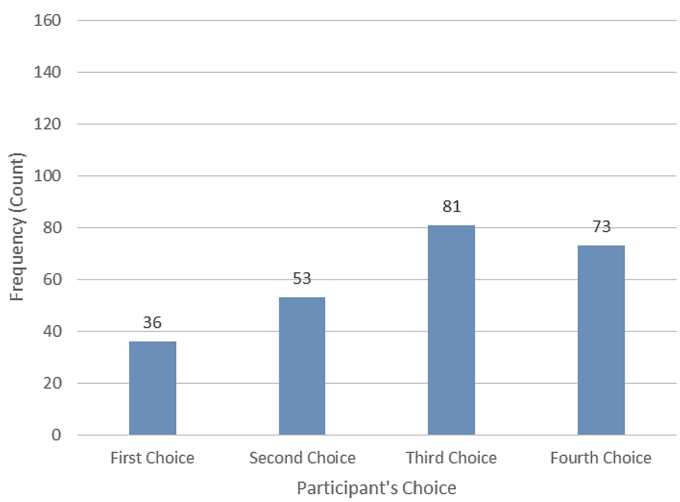


Figure 46: Question 2 Responses –Detection-triggered Blank-out Signs That Flash “WRONG WAY”

For wigwag flashing beacons, 79 participants listed it as their first choice, 63 second, 37 third, and 64 fourth, as shown in Figure 47.

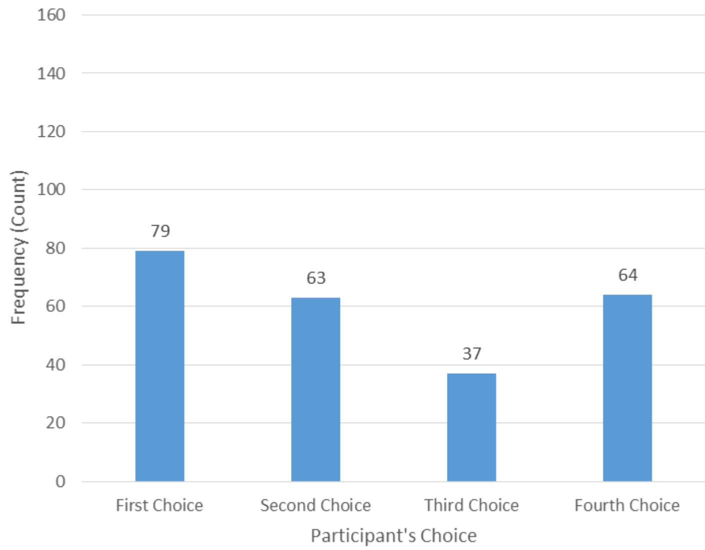


Figure 47: Question 2 Responses – Wigwag Flashing Beacons

Figure 48 shows the proportion of each countermeasure ranked as first choice. Both RRFBs and wigwag flashing beacons were selected first at 32%, detection-triggered LED lights around "WRONG WAY" signs were selected first at 22%, and detection-triggered blank-out signs were selected first at 14%.

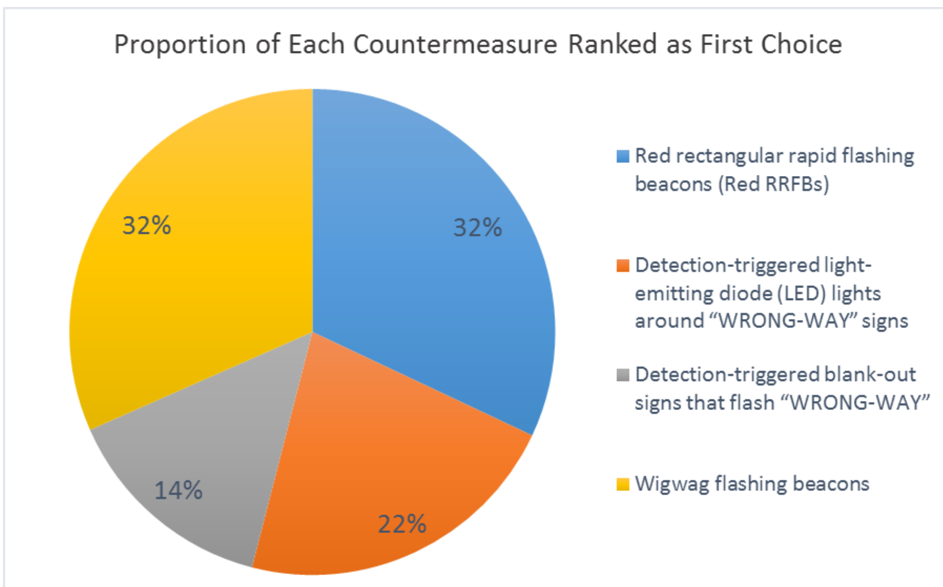


Figure 48: Question 2 Responses – Proportion of Each Countermeasure Ranked as First Choice

6.3.3 Question 3

Q3. Please compare Countermeasure #3 (Red Flush-Mount IIRPMs) and Countermeasure #5 (delineators along off-ramps). Which do you think is more effective? In total, 74% of participants chose red flush-mount IIRPMs as the more effective countermeasure, and the remaining 26% chose delineators along off-ramps, as shown in Figure 49.

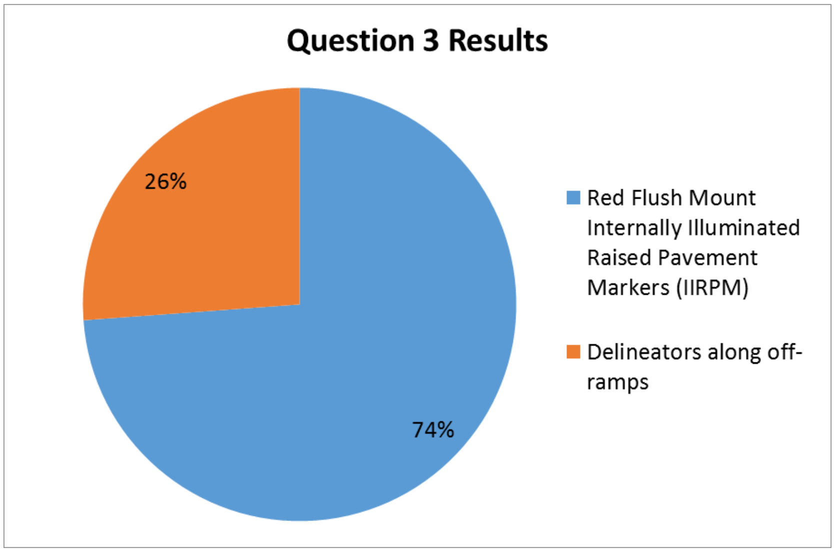


Figure 49: Question 3 Responses

6.3.4 Question 4

This question was divided into three sections—4A, 4B, and 4C—and is discussed below.

6.3.4.1 Question 4A

Q4A. Of your choice from question 2 and question 3, which is more effective?
In total, 74% of participants selected their answer choice from question 2 to be more effective, and 26% selected their answer choice from question 3, as shown in Figure 50.

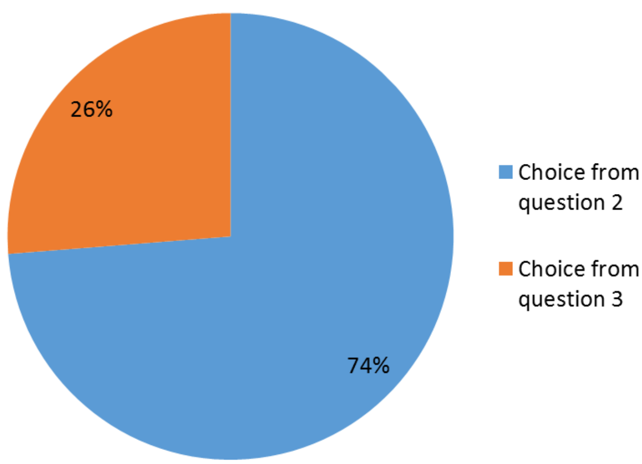


Figure 50: Question 4A Responses

6.3.4.2 Question 4B

Q4B. Do you think it would be beneficial to combine your choices from question 2 and question 3?
In total, 90% believed it would be beneficial to have both choices combined and 10% did not, as shown in Figure 51.

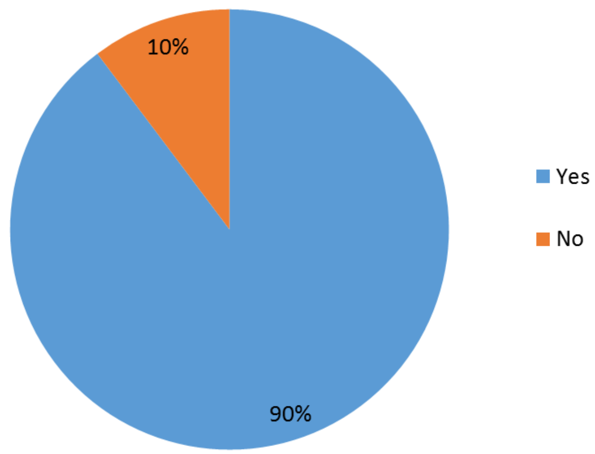


Figure 51: Question 4B Responses

6.3.4.3 Question 4C

Q4C. If yes, to what degree will the combination have on overall effectiveness? In total, 74% believed the combination would be a significant improvement, 23% believed it would be a moderate improvement, and 3% believed it would be a minor improvement, as shown in Figure 52.

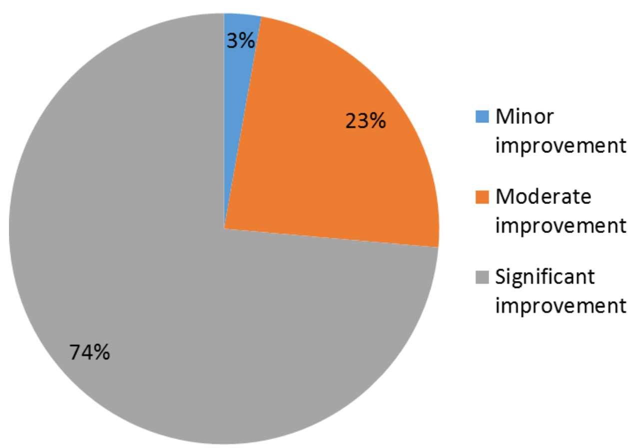


Figure 52: Question 4C Responses

6.3.5 Question 5

Q5. Please rank the effectiveness of all six countermeasures from the most effective to the least effective, where 1= most effective, 2 = second most effective, 3 = third most effective, 4 = fourth most effective, 5 = fifth most effective, and 6 = least effective. In total, 63 participants ranked red RRFBs as their first choice, 50 second, 49 third, 43 fourth, 24 fifth, and 11 sixth, as shown in Figure 53.

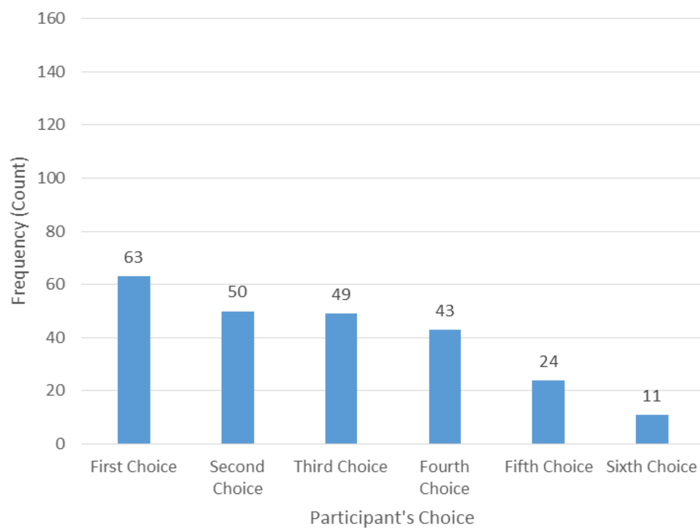


Figure 53: Frequency Count and Rankings of RRFBs

For detection-triggered blank-out signs that flash "WRONG WAY," 24 participants ranked it as their first choice, 49 second, 62 third, 63 fourth, 30 fifth, and 13 sixth, as shown in Figure 54.

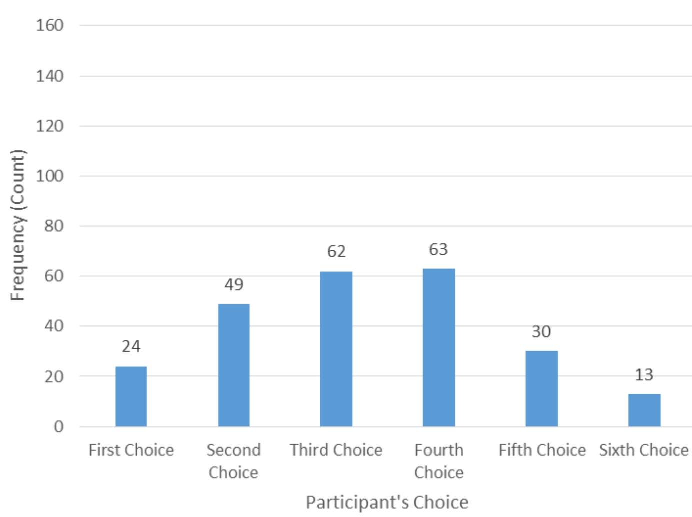


Figure 54: Frequency Count and Rankings of Detection-triggered Blank-out Signs That Flash "WRONG WAY"

For detection-triggered LED lights around "WRONG WAY" signs, 51 participants ranked it as their first choice, 47 second, 60 third, 51 fourth, 21 fifth, and 10 sixth, as shown in Figure 55.

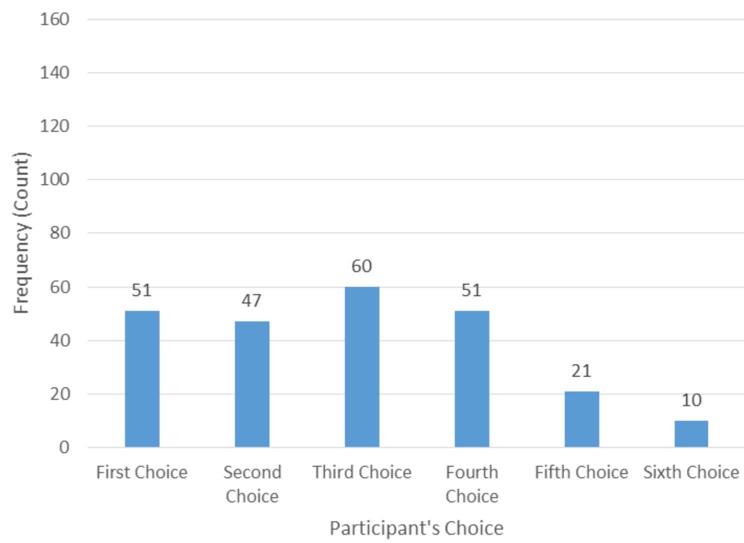


Figure 55: Frequency Count and Rankings of Detection-triggered LED Lights around "WRONG WAY" signs

For wigwag flashing beacons, 67 participants ranked it as their first choice, 50 second, 32 third, 45 fourth, 32 fifth, and 13 sixth, as shown in Figure 56.

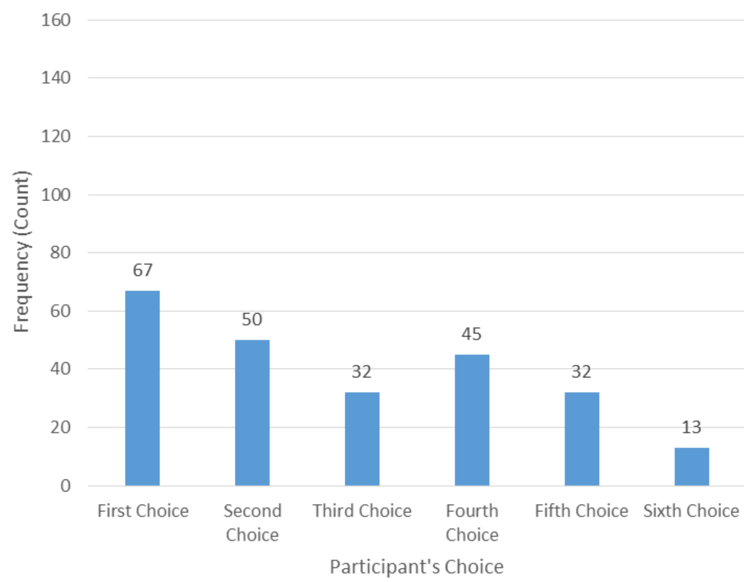


Figure 56: Frequency Count and Rankings of Wigwag Flashing Beacons

For red flush mount IIRPMs, 28 participants ranked it as their first choice, 29 second, 23 third, 25 fourth, 89 fifth, and 46 sixth, as shown in Figure 57.

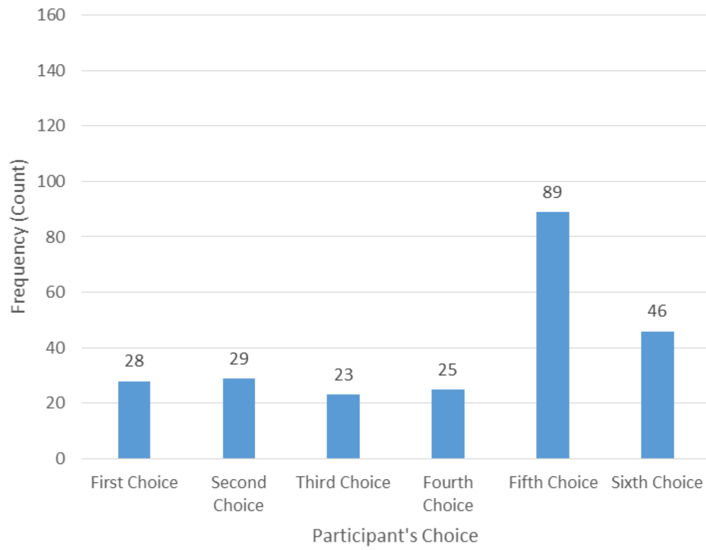


Figure 57: Frequency Count and Rankings of Red Flush Mount IIRPMs

For delineators along off-ramps, 9 participants ranked it as their first choice, 15 second, 13 third choice, 12 fourth, 42 fifth, and 149 sixth, as shown in Figure 58.

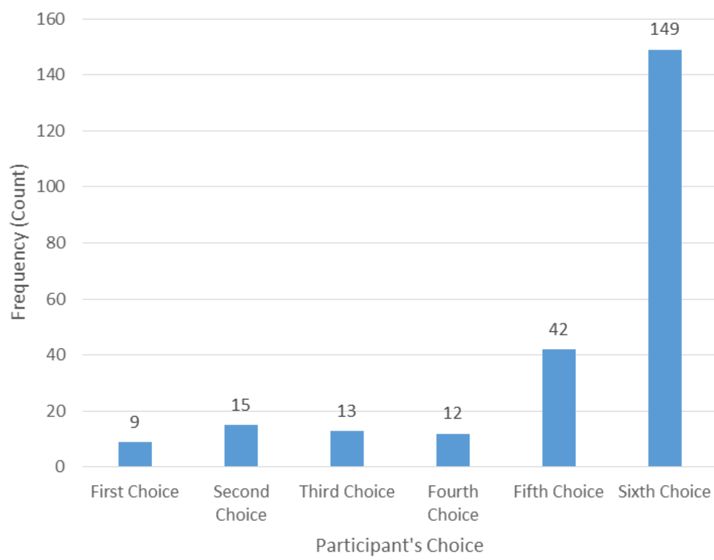


Figure 58: Frequency Count and Rankings of Delineators along Off-ramps

Figure 59 depicts the proportion of each countermeasure ranked as first choice. The highest proportion was wigwag flashing beacons at 28%, followed by red RRFBs at 26%, detection-triggered LED lights around "WRONG WAY" signs at 21%, red flush mount IIRPMs at 11%, detection-triggered blank-out signs that flash "WRONG WAY" at 10%, and delineators along off-ramps at 4%.

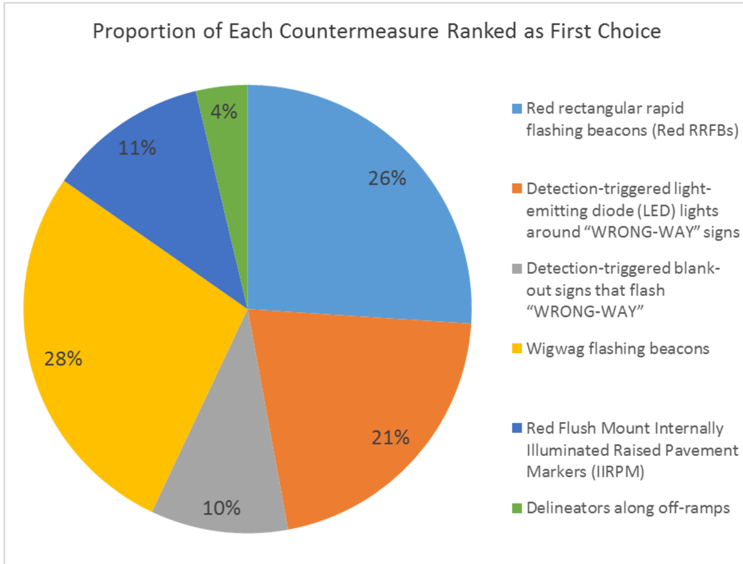


Figure 59: Question 5 Responses – Proportion of Each Countermeasure Ranked as First Choice

6.4 Statistical Tests for Q2 and Q5 Ranks

As described above, Question 2 ranked the effectiveness of the four countermeasures (Table 25) at off-ramps from the most effective to the least effective. Also, Question 5 ranked the effectiveness of all six countermeasures (Table 26). By summarizing the choices of the 250 participants from four major WWD countermeasures for freeway off-ramps, Tables 25 and 26 show descriptive statistics of participant ranks for Questions 2 and 5, respectively. The nonparametric tests in this section determined if the Questions 2 and Q5 ranks were significantly different for those countermeasures. The lower the mean is, the more effective and informative the countermeasure was determined to be.

Table 25: Descriptive Statistics of Participant Ranks for Question 2

Average Ranks	Q2 Rank	
	Mean	***Valid Number of Participants***
C2: Red RRFBs	2.26	246
C4: Detection-triggered LED lights around "WRONG WAY" signs	2.55	242
C5: Detection-triggered blank-out signs that flash "WRONG WAY"	2.79	243
C7: Wigwag flashing beacons	2.35	243

Table 26: Descriptive Statistics of Participant Ranks for Question 5

Average Ranks	Q5 Rank	
	Mean	***Valid Number of Participants***
C2: Red RRFBs	2.78	240
C3: Red flush-mount IIRPMs	4.07	240
C4: Detection-triggered LED lights around "WRONG WAY" signs	2.89	240
C5: Detection-triggered blank-out signs that flash "WRONG WAY"	3.27	241
C6: Delineators along off-ramps	5.13	240
C7: Wigwag flashing beacons	2.85	239

The nonparametric tests were adopted for hypothesis tests regarding Q2 and Q5 ranks between the four or six countermeasures because the data points of participant ranks (Figures 7–10 and Figures 16-21) do not follow normal distribution or any evident shape. Specifically, the Kruskal-Wallis H test (a rank-based nonparametric test) was used to determine if there were statistically-significant differences between the four or six countermeasures of participant ranks. The Kruskal-Wallis H test is considered the nonparametric alternative to the one-way ANOVA (sometimes also called the "one-way ANOVA on ranks") and an extension of the Mann-Whitney U test that allow the comparison of more than two independent groups (countermeasures in this study).

The Kruskal-Wallis H test results showed that there was a statistically-significant difference in Q2 ranks between the four groups, with $\chi^2(3)$ =31.462 and p = 0.0001. Similarly, for the Q5 ranks, the Kruskal-Wallis H test showed that there was a statistically-significant difference between the 6 groups, with $\chi^2(5)$ =353.315 and p = 0.0001.

As shown in Figure 60, the ranks of effectiveness of the four countermeasures in Q2 were the following: (1) C2 - red RRFBs, (2) C7 – wigwag flashing beacons, (3) C4 – detection-triggered LED lights around “WRONG WAY” signs, and (4) C5 – detection-triggered blank-out signs that flash “WRONG WAY.”

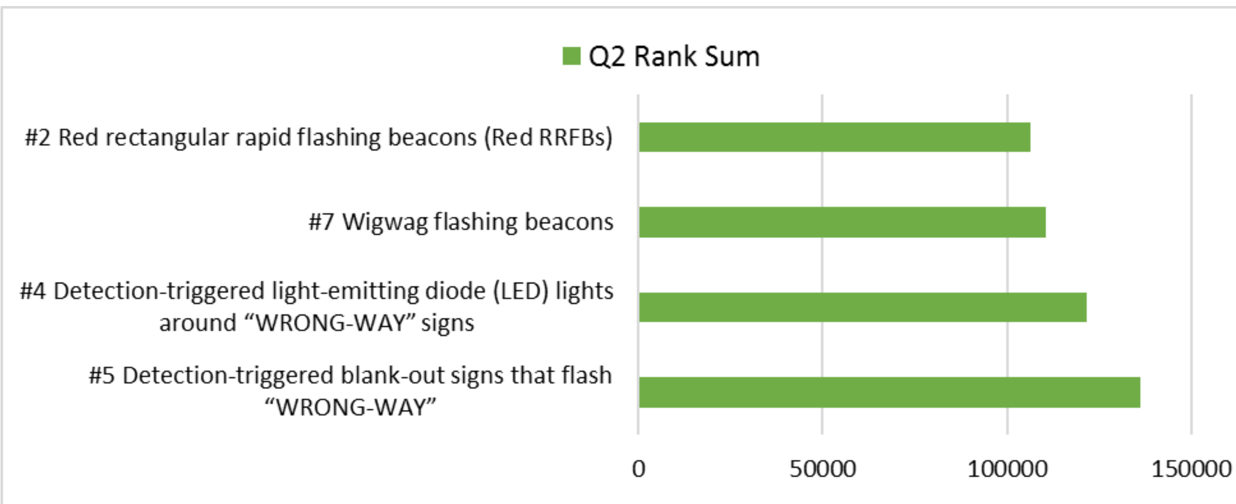


Figure 60: Results of Nonparametric Test for Question 2 Ranks

As shown in Figure 61, the rank of effectiveness of the six countermeasures in Question 5 were the following: (1) C2 – red RRFBs, (2) C7 – wigwag flashing beacons, (3) C4 – detection-triggered LED lights around “WRONG WAY” signs, (4) C5 – detection-triggered blank-out signs that flash “WRONGWAY,” (5) C3 – red flush-mount IIRPMs , and (6) C6 –delineators along off-ramps.

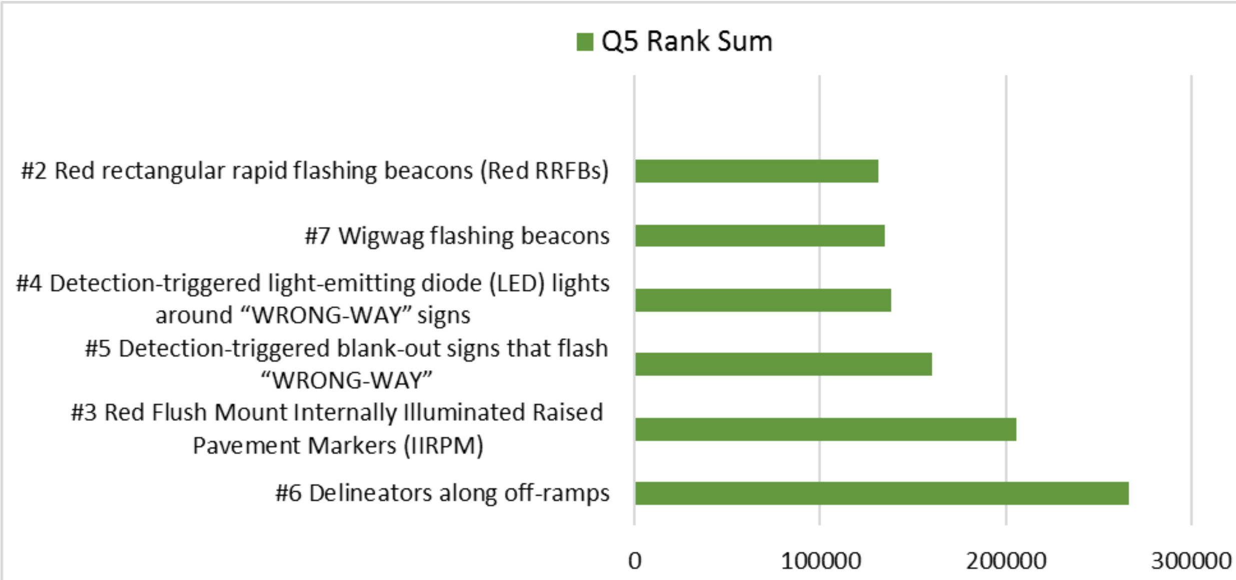


Figure 61: Results of Nonparametric Test for Question 5 Ranks

To further determine which of these countermeasures differ from each other, post hoc pairwise tests (Sidak method) were performed after significant effects for Question 2 and Question 5 ranks.

As shown in Table 27, for Question 2 ranks, C2 (red RFRBs) was ranked as being significantly more effective than C4 (detection-triggered LED lights around "WRONG WAY" signs) and C5 (detection-triggered blank-out signs that flash "WRONGWAY") at the 5% and 1% levels, respectively. C4 (detection-triggered LED lights around "WRONG WAY" signs) and C7 (wigwag flashing beacons) were ranked as significantly more effective than C5 (detection-triggered blank-out signs that flash "WRONGWAY") at the 10% level and 1% levels, respectively.

Table 27: Comparison of Question 2 Ranks for Four Countermeasures

Row Mean- Col Mean	C2: Red RRFBs	C4: Detection-Triggered LEDs	C5: Detection-triggered Blank-out Signs
C4: Detection-triggered LED lights around "WRONG WAY" signs	0.285 **(0.026**)**		
C5: Detection-triggered blank-out signs that flash "WRONG WAY"	0.526 **(0.000***)**	0.241 **(0.097*)**	
C7: Wigwag flashing beacons	0.094 (0.924)	-0.192 (0.296)	-0.432 **(0.000***)**

****, **, * ==> Significance at 1%, 5%, 10% levels.*

As shown in Table 28, for Question 5 ranks, C6 (delineators along off-ramps) was ranked as the least effective countermeasure than others at the 1% significance level. C2 (red RFRBs) was ranked significantly more effective than C5 (detection-triggered blank-out signs that flash "WRONG WAY") at the 5% level. C4 (detection-triggered LED lights around "WRONG WAY" signs) and C7 (wigwag flashing beacons) were ranked significantly more effective than C5 (detection-triggered blank-out signs that flash "WRONG WAY") at the 10% level and 5% levels, respectively.

Table 28: Comparison of Question 4 Rating by Countermeasures

Row Mean-Col Mean	C2	C3	C4	C5	C6
C3	1.283 (0.000***)				
C4	0.108 (1.000)	-1.175 (0.000***)			
C5	0.486 (0.005**)	-0.797 (0.000***)	0.378 (0.079*)		
C6	2.342 (0.000***)	1.058 (0.000***)	2.233 (0.000***)	1.855 (0.000***)	
C7	0.066 (1.000)	-1.217 (0.000***)	-0.042 (1.000)	-0.420 (0.030**)	-2.276 (0.000***)

****, **, * ==> Significance at 1%, 5%, 10% levels*

6.5 Major Findings of the Public Opinion Survey

This task conducted and analyzed a public survey to determine the most perceived effective and informative WWD countermeasure. The countermeasure(s) chosen as the most effective at informing wrong-way drivers about their WWD behavior was mainly based on the rankings provided in Questions 2 and 5. In Question 2 (in which only four detection-triggered countermeasures were included), red RRFBs were chosen as the most effective and informative WWD countermeasure, followed by the wigwag flashing beacons. The top two countermeasures were the same for Question 5 (when all six countermeasures for off-ramps were included). It should be noted that the rankings for these two WWD countermeasures were very close; there is no significant difference statistically between the red RRFBs and the wigwag flashing beacons on their perceived effectiveness on deterring wrong-way driving.

According to the average rankings by participants, red RRFBs were found to be the most informative and effective countermeasure for freeway off-ramps, followed by wigwag flashing beacons, detection-triggered LED lights around "WRONG WAY" signs, and detection-triggered blank-out signs that flash "WRONG WAY." Delineators along off-ramps were found to be the least effective countermeasure. These results were also confirmed from statistical tests.

In addition, from the survey responses analysis, it was determined that the older age group (60+), overwhelmingly preferred RRFBs as their first choice for being the most informative and effective WWD countermeasure compared to the other two age groups (16–29 and 30–59). The older age group (60+) ranked RRFBs and detection-triggered LED signs as their top two most informative and effective WWD countermeasure choices, respectively, whereas the 16–29 and 30–59 age groups ranked RRFBs and the wigwag flashing beacons as their top two most informative and effective WWD countermeasure choices, respectively.

Also, the age group 30–59 showed a higher preference for the wigwag flashing beacons than the other two age groups, while the older age group (60+) showed mixed sensitivity to this WWD countermeasure among its participants. Furthermore, age groups 16–29 and 60+ ranked the detection-triggered blank-out signs in a similar fashion as their 3rd choice of being the most informative and effective WWD countermeasure, while the 30–59 age group ranked it as 4th choice.

Based on the nonparametric tests, red RRFBs was ranked as being significantly more effective than detection-triggered LED lights around “WRONG WAY” signs and detection-triggered blank-out signs that flash “WRONG WAY” at the 5% and 1% levels, respectively. Detection-triggered LED lights around “WRONG WAY” signs and wigwag flashing beacons were ranked as significantly more effective than detection-triggered blank-out signs that flash “WRONG WAY” at the 10% level and 1% levels, respectively.

Survey results also confirmed that the newly-developed signing and pavement marking standards for arterials near freeway off-ramps provide a significant improvement to mitigate wrong-way driving.

7 EVALUATION OF COUNTERMEASURES VIA A HUMAN FACTORS APPROACH USING DRIVING SIMULATION

This section summarizes the human factors approach using a driving simulator performed by Dr. Walter Boot of the Florida State University (FSU). The perspective taken frames drivers' decisions to enter the interstate at a given point as a cue-based decision. Road geometry, pavement markings, guide or warning signs, and the behavior of other traffic are all cues that drivers may consider when deciding which of available entry points is the correct one, and these cues may differ in their salience and informational value. For example, whereas seeing a yellow edge line on the right side of the road and a white edge line on the left would signal driving the wrong-way on an interstate ramp, this cue is likely less salient than a bright, retroreflective pavement marking showing an arrow pointing in the opposite direction. A cue-based approach allows for a flexible, generalizable way to categorize features of interchanges associated with a high risk of wrong-way entries and categorize features of current and proposed countermeasures.

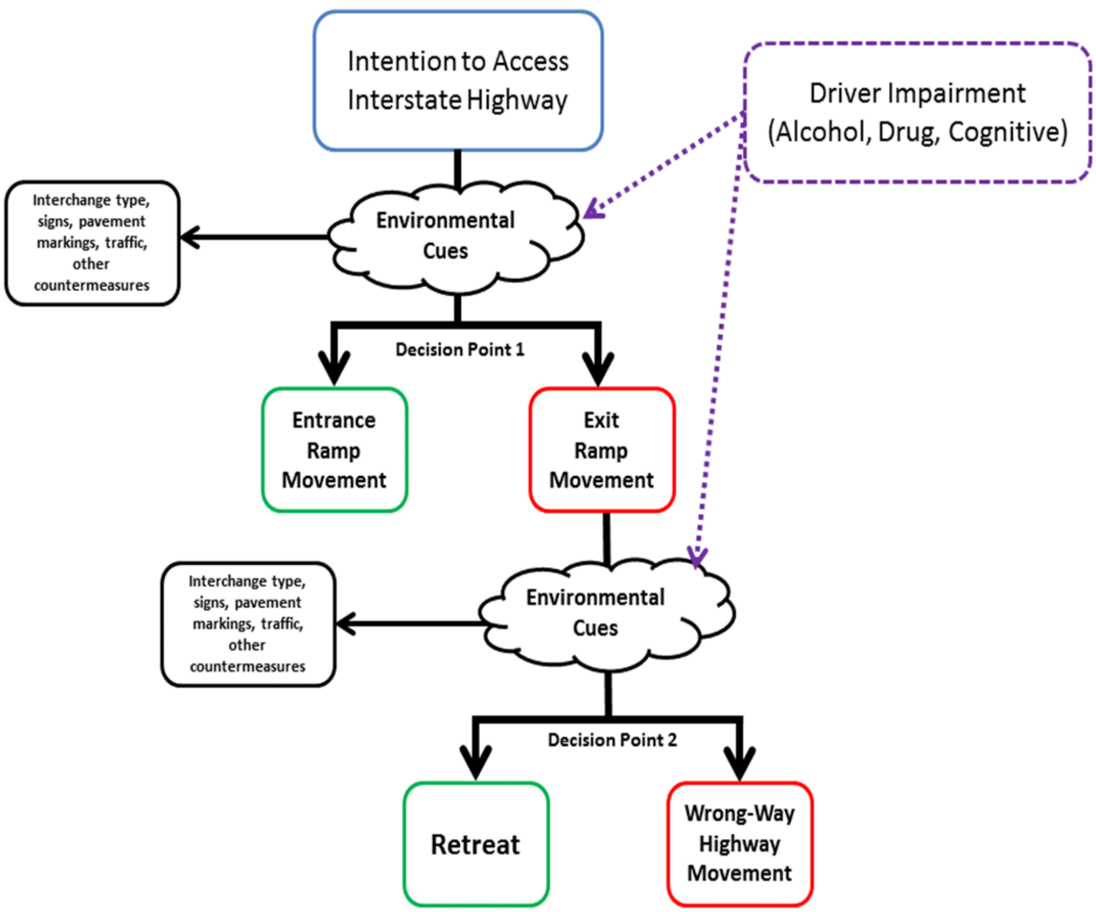


Figure 62: Cue-based Decision Model – Previous Projects Focused on First Decision Point in Model, Current Project Focuses on Second

The framework (Figure 62) also considers how characteristics of individual drivers, including impaired drivers, may interact with the cue environment. Impairment affects drivers' ability to make inferences based on the information around them, meaning that countermeasures effective in communicating their message to non-impaired drivers may not be effective for impaired drivers, potentially even increasing their confusion. One benefit of a cue-based approach is that it provides a framework for making predictions about which countermeasures are likely to be effective in reaching not only the typical unimpaired driver, but also the impaired or disoriented driver. For this study, countermeasures designed to intervene before a driver has entered an off-ramp (Decision Point 1) and after a driver is already driving the wrong-way on an off-ramp (Decision Point 2) were evaluated.

Multiple ramp study tests were performed using a driving simulator, as depicted in Figure 63.

Figure 63: NADS MiniSim Driving Simulator Setup at FSU Psychology Department – Countermeasure "WRONG WAY" Blank-out Depicted on Screen

7.1 Ramp Study 1

This simulator study exposed participants to "WRONG WAY" signs that were either static (standard) or dynamic (included flashing elements). Of primary interest was whether participants stopped/slowed earlier for dynamic signs compared to standard signs, and if so, whether one dynamic sign was more effective than others.

A total of 120 participants (M_{Age} = 20, SD_{Age} = 3.05) who were undergraduate students from FSU completed the experiment. All reported holding a valid driver's license. In total, 63 participated for course credit and 57 participated for a payment of $15/hour. Five reports of mild simulator sickness were noted during the task (slight discomfort, e.g., dizziness), and, as a result, these participants were excluded from analyses. One software error, one experimenter error, and two participants not following instructions resulted in 111 participants, unless otherwise noted.

A NADS MiniSim high-fidelity driving simulator developed by the National Advanced Driving Simulator lab at the University of Iowa was used for the study (Figure 63). The NADS MiniSim incorporates a dashboard with a virtual instrument cluster steering wheel, an accelerator and brake pedals, and three 42-in. displays that gives the driver a 180° horizontal and 50° vertical field of view of the simulated environment. Each display has a resolution of 1360 x 768 pixels and a refresh rate of 60 Hz.

7.1.1 Simulated Highway Off-Ramp (from Perspective of Wrong-way Driver)

A simulated environment modeled after a highway off-ramp (Figure 64) and the countermeasures "WRONG WAY" red RRFBs, wigwags, LEDs, and blank-outs and a standard "WRONG WAY" sign (Figures 66–70) were created by the University of Iowa to be driven in the NADS MiniSim. A nighttime scenario was developed given the preponderance of WWDs occurring late at night/early morning. To isolate the effect of particular countermeasures, this section of roadway was designed to provide no cues other than signage that a driver might be driving the wrong way (e.g., for a typical ramp, an outer lane marking on the right that is yellow would signify that the driver is going the wrong way on the off-ramp).

Figure 64: Simulated Environment as Seen from Start of Drive.
No countermeasures visible at this point.

Figure 65: "WRONG WAY" RRFBs

Figure 66: "WRONG WAY" Wigwags

Figure 67: "WRONG WAY" LEDs

Figure 68: "WRONG WAY" Blank-outs

Figure 69: Standard MUTCD R5-1a "WRONG WAY" signs

Within the simulated environment at 9,000 feet from the start of the drive, participants unexpectedly encountered a "WRONG WAY" sign, and the type of sign was experimentally manipulated (four dynamic and one standard).

7.1.2 Practice Task

Participants first completed a practice task within the same simulated environment of the experimental task for familiarization with the sensations of driving in a simulated environment, as well as to acclimate to the brake and gas pedals and the sensitivity of the steering wheel. In this practice task, participants were instructed to drive until they saw a set of barricades on the left, then come to a complete stop and place the vehicle into park. After doing this the first time, participants were told by an experimenter to repeat this process at the next set of barricades. After the second stop, the practice task was terminated.

7.1.3 Experimental Task

Participants were assigned to one of five scenarios in which the first sign encountered varied ("WRONG WAY" LED, "WRONG WAY" wigwag, "WRONG WAY" blank-out, "WRONG WAY" RRFB, "WRONG WAY" Standard). The second sign encountered by all participants who received a dynamic sign first was the standard "WRONG WAY" sign (MUTCD R5-1a); those who received the standard sign first did not receive a second sign.

At the start of the experiment, the lights were shut off, and the following instructions were given:

> Your goal in this task is to drive on the highway until the scenario terminates. You'll see a black screen and it will return to this screensaver, but at any moment if the road conditions seem unsafe, we ask that you come to a complete stop and place the vehicle in park, just as you did in the practice. At that point, if you could ring the bell, I will return with further instructions. We ask that you maintain a speed of 40 mph. If your speed reaches 45 mph, a police siren will go off to alert you.

If participants reported feeling unsafe, they received the following instructions:

> We now ask that you continue down the highway, but if at any point you notice that the road conditions seem unsafe, please come to a complete stop again and place the vehicle in park as you have just done. The scenario will terminate automatically when the task is complete. Please place the vehicle back in drive (using the paddle shifters) once I have closed this door.

Upon completion of the scenario, participants completed a Qualtrics demographics survey.

7.1.4 Results

Of primary interest was whether participants stopped in response to the first countermeasure they encountered, and if so, when and where they stopped.

An effective "WRONG WAY" countermeasure sign would cause a driver to slow or stop and turn around in advance of the sign; in this task, participants were instructed to stop the vehicle at the first sign that they felt they were in an unsafe situation. Thus, slowing/stopping behaviors across the different countermeasure conditions were compared.

It became clear in the data analysis that responses to the blank-out sign were very different compared to the other dynamic signs and that the dynamic signs excluding the blank-out sign (RRFB, LED, wigwag) all produced similar behaviors. Thus, in many of the analyses, dynamic sign conditions excluding the blank-out sign were collapsed. These analyses present the categories of standard, dynamic (excluding blank-out), and blank-out.

To quantify differences in slowing to the sign, three areas of interest (AIOs) were created: (1) one before the flashing began in the dynamic signs conditions, (2) an area after the onset of the trigger that activated dynamic signs, and (3) an area after the location of the sign (up to 100 ft after). These same AOIs were used for the standard sign condition. The first analysis calculated at what point during these three AOIs the participant reached his or her minimum speed to assess slowing in response to the sign (i.e., minimum speed was considered a response) and when this response occurred relative to the sign for each condition). Figure 70 represents these data.

Overall, all signs yielded comparable percentages of participants responding as a function of area of interest, with one notable exception: Many participants did not reach their minimum speed in response to the blank-out sign until after they had passed it. For the other dynamic signs and the standard sign, most participants responded in advance of the sign.

Efficacy of each sign was also evaluated by plotting survival curves depicting the proportion of participants in each group who were still driving (i.e., had not stopped or turned around) at each point in the scenario. Figure 71 represents this analysis (removing those who stopped well in advance of the trigger locations).

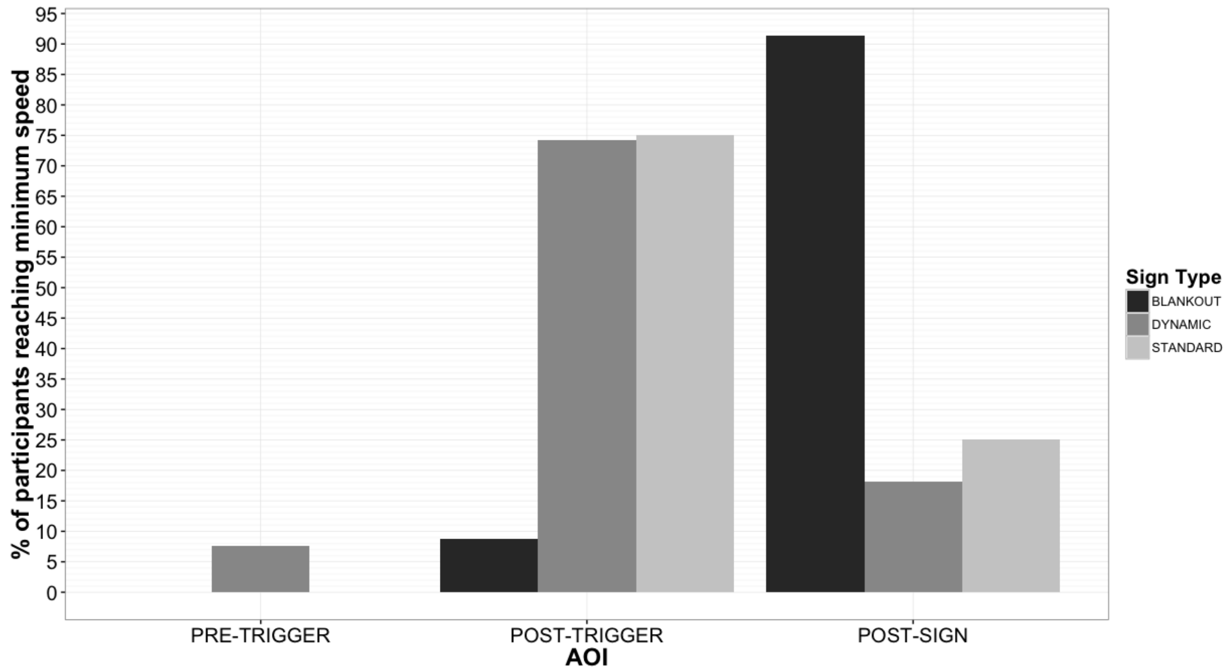


Figure 70: Percentage of Participants Reaching Minimum Speed as Function of Sign Type and Area of Interest

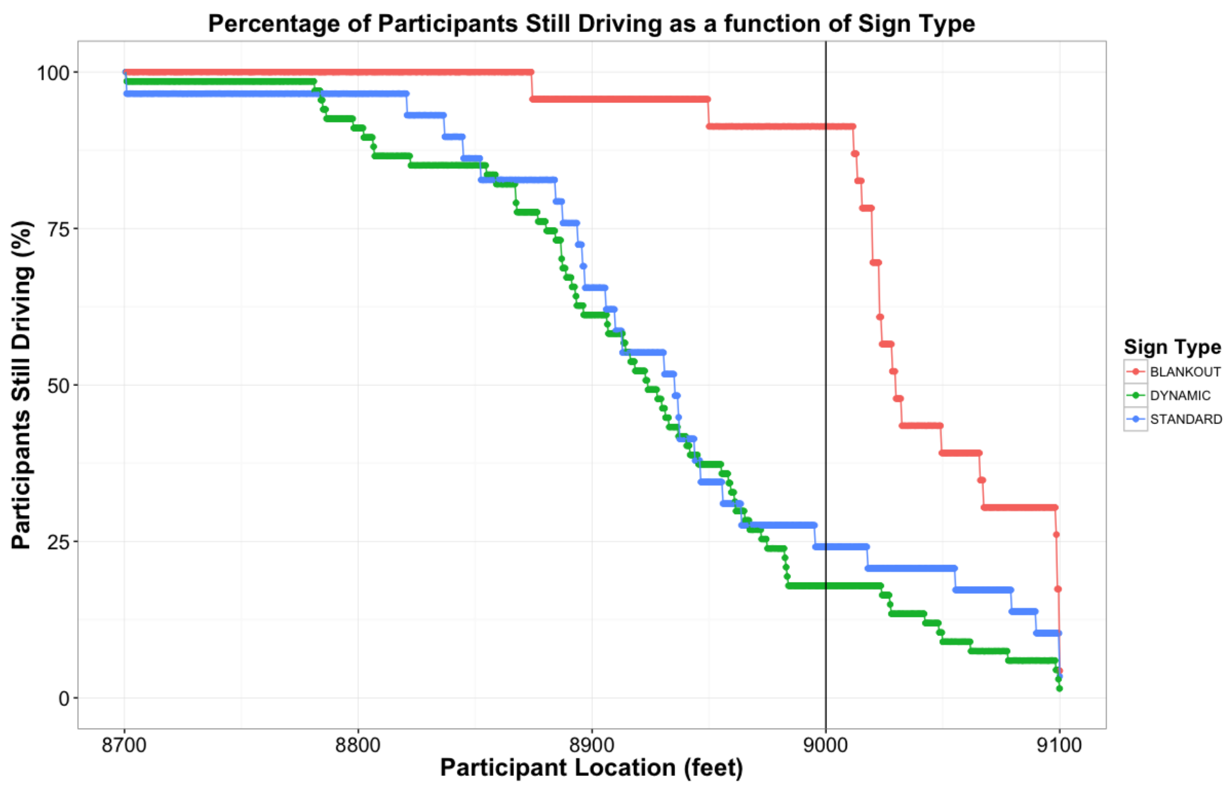


Figure 71: Survival Curve Analysis of Participants Still Driving, as Function of Sign Type and Location in Simulated Environment.
Vertical line displayed at 9,000 ft indicates location of countermeasure.

It is clear from this analysis that dynamic countermeasures (not including the blank-out sign) and the standard static sign were equally effective. A Fisher's Exact Test conducted on the proportion of participants who stopped before vs. past the countermeasure revealed no advantage with respect to stopping behavior.

7.2 Ramp Study 2

For this study, a total of 69 participants (M_{Age} = 20, SD_{Age} = 1.62) who were undergraduate students from FSU completed the experiment. In total, 31 participated for course credit, and 38 participated for a payment of $15/hour. Although recruitment materials listed holding a valid driver's license as a requirement for participation, one participant reported not having a driver's license. No reports of simulator sickness were noted during the task, although 4 participants reported slight discomfort (i.e., dizziness) temporarily after their drive. One data file was corrupted, so, as a result, all analyses included 68 participants unless otherwise noted.

Participants encountered a "WRONG WAY" RRFB sign, "WRONG WAY" wigwag sign, or a standard "WRONG WAY" sign. Driver reaction to this first countermeasure was of primary interest. However, were asked participants to continue to drive and pass other signs to collect pilot/exploratory data. It was anticipated that after the first "WRONG WAY" sign, participants would be extremely vigilant and would look for additional "WRONG WAY" messages, contaminating their responses to these signs.

To simulate the experience of drug/alcohol impairment, Fatal Vision Silver Label impairment goggles were used (http://fatalvision.com/fatal-vision-silver-label.html, Figure 72 and Figure 73). The level of distorted vision is marketed as similar to what is to be expected with a BAC level of 0.17–0.20. Participants were counterbalanced to one of two conditions wearing the simulated impairment goggles: (1) original simulated impairment goggles, and (2) simulated impairment goggles with a tint that blocks 35% of light. The addition of the tint did not seem to greatly influence behavior, so these two conditions were collapsed in the reported analyses.

Figure 72: Fatal Vision Silver Label Impairment Goggles with Tint Blocking 35% of Light Absorption

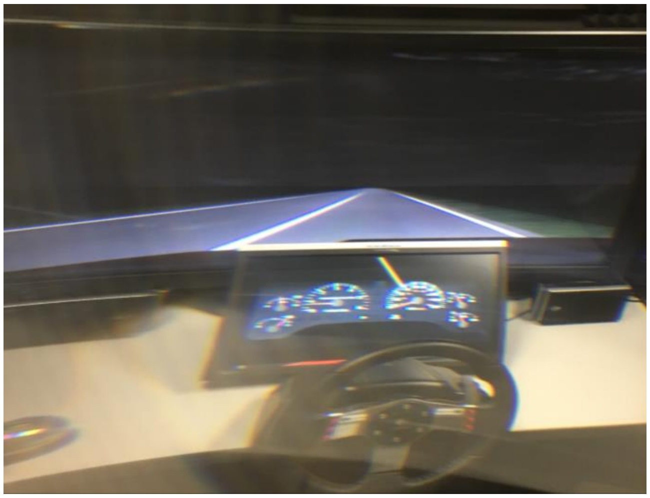


Figure 73: View of Simulated Environment through Fatal Vision Silver Label Impairment Goggles

7.3 Results

Ramp Study 2 found results similar to the first study: both static and dynamic signs caused participants to slow and stop equally well. A full report of findings is provided in Appendix E. This appendix also outlines the findings from two simulator studies on arterial countermeasures, both supporting the conclusion that a greater number and diversity of countermeasures can reduce confusion regarding proper highway entry points.

The model of wrong-way crashes (WWCs) predicted that a greater number of cues made available to drivers in and around off-ramps will decrease the likelihood of wrong-way entries (WWEs) and WWCs. In the simulator experiments reviewed, adding additional countermeasures, including arterial countermeasures, reduced confusion regarding highway entrance points. This was most evident in driver speed. When fewer countermeasures were present, drivers slowed near the off-ramp as if they were considering turning onto it. In the first experiment reported, there was also a trend for fewer WWE when arterial countermeasures were added to an interchange. Converging evidence from two previous studies suggests that arterial changes can make a difference, reducing confusion, and these changes are recommended to reduce WWEs.

In the two studies examining dynamic and static signs on a simulated off-ramp, participants rated dynamic signs containing flashing elements (blank-out, LED, RRFB, wigwag) as more effective at alerting them of WWD compared to a standard static wrong-way sign. However, when it came to behavioral evidence, there was little indication that dynamic "WRONG WAY" signs provided a better cue that drivers should stop compared to the static sign. In both experiments, for the most part, all countermeasures were equally effective. In Ramp Study 1, the large majority of participants stopped in advance of all "WRONG WAY" signs whether they were dynamic or static. The one exception was the blank-out sign. This study found the blank-out sign may be less effective; most participants stopped after the blank-out sign rather than before it. In Ramp Study 2, even under conditions of simulated impairment, most participants stopped either before each countermeasure or shortly after it (within 100 ft). Here again, there was little difference between static and dynamic signs.

Replacing a standard “WRONG WAY” sign with a blank-out sign may provide less information rather than more information because it provides no message until it is triggered. Depending on the speed of the wrong-way driver, there may not be enough time to extract the sign’s meaning. Based on these results, avoiding the use of “WRONG WAY” blank-out signs is recommended, as there did not seem to be a disadvantage with respect to other dynamic “WRONG WAY” signs (relative to a standard static sign). The researchers are hesitant to recommend against other dynamic off-ramp signs despite little evidence for a behavioral benefit in the reported simulator studies. First, participants rated these signs as more effective at alerting them of their WWD. Second, based on the attention literature, there is little reason to doubt that these signs are not more effective at capturing attention. Unless signs first capture attention, there is little hope for them to convey the appropriate message. Conditions to test this effect may not have been ideal in the simulator. This task required giving instructions to participants on how to respond and the nature of the task. Alerting drivers that they should stop if they feel unsafe may have encouraged them to be extra vigilant, enhancing the processing of countermeasures. It is certainly plausible that on the road, dynamic signs may be especially beneficial to drivers who are unaware of the potential of danger, believing that they have correctly entered an entrance ramp.

Benefits of dynamic countermeasures are consistent with recent operational field studies that have found that dynamic “WRONG WAY” signs featuring red LEDs were associated with a decrease in WWD driving events (Finley et al., 2016). Although no behavioral benefits were observed in the current study, it is important to consider these results in the context of the other analyses and evaluations of the larger project, and some of the limitations of simulator work and the current study design.

The full version of the human factors approach using driving simulation study (as submitted to FDOT in Deliverable 6 of this project) performed by Dr. Boot is provided in Appendix E.

8 SUMMARY OF EVALUATION RESULTS

This section presents the development of recommendations for future implementation of WWD countermeasures based on the analysis results and findings of sections 2, 4, 5, 6, and 7, as previously submitted to FDOT. Some of the material (figures, tables, charts, etc.) under this section is presented again in addition to their respective original sections to capture the underlying reasons in the development of the future implementation of recommended countermeasures out of the seven WWD countermeasures studied in this project, as depicted in Figures 74 and 75, are:

1. Newly-developed S&PM standards
2. Red RRFBs
3. Red flush-mount IIRPMs
4. Detection-triggered LED lights around “WRONG WAY” signs
5. Detection-triggered blank-out signs that flash “WRONG WAY”
6. Delineators along off-ramps
7. Wigwag flashing beacons

Figure 74: Newly-developed S&PM Standards – WWD Countermeasure #1

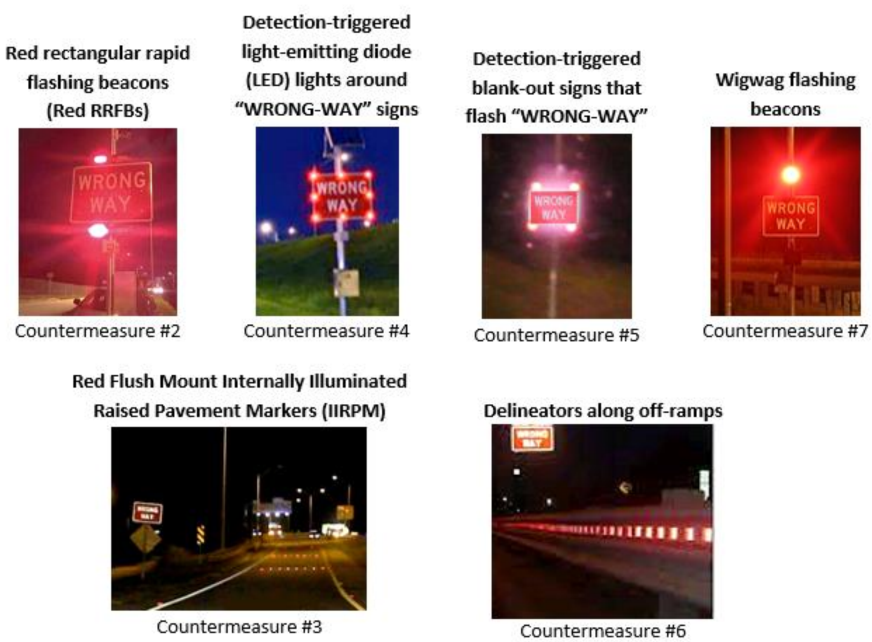


Figure 75: WWD Countermeasures #2–#7

The CUTR research team reviewed the data, evaluation results, and conclusions provided by each subcontractor, conducted a final comparison and evaluation of the identified countermeasures, and identified the top four recommended countermeasures for future widespread implementation by FDOT as summarized in the final section of this report.

8.1 Results from Sections 2 and 4 – Analysis of Literature Review, Existing Data, and Studies

Sections 2 and 4 of this report include a literature review conducted by Dr. Priyanka Alluri and a cost data summary by Hagen Consulting Services in direct synergy with PI Dr. Pei-Sung Lin. The literature review focused mainly on the existing WWD countermeasure studies conducted in Florida, specifically in the jurisdictions of Florida's Turnpike Enterprise and FDOT Districts 3 and 7. In addition to the literature review, cost data and the ability to alert wrong-way drivers and/or send real-time alerts to a TMC were reviewed. Table 29 summarizes this evaluation for each of the seven countermeasures. Countermeasure #1 is effective to prevent vehicles on arterial from entering the freeway off-ramp. Countermeasures #2, 4, 5, and 7 should be considered as freeway off-ramp countermeasure to deter WWD because of their capabilities to detect WWD and inform the incident to TMC.

Table 29: Summary Table for Cost and Alert Capability of Each WWD Countermeasure

Countermeasure	Cost[1]	Mitigate WWD or Alert Wrong-Way Driver?[2]	Send Real-time Alerts to TMC?[3]
#1 Newly-developed S&PM standards	Low	Yes	No
#2 Red RRFBs	High	Yes	Yes
#3 Red flush-mount IIRPMs	Low	Yes	No (separate detection communication system to send real-time alerts in development)
#4 Detection-triggered LED lights around "WRONG WAY" signs	Low	Yes	Yes
#5 Detection-triggered blank-out signs that flash "WRONG WAY"	High	Yes	Yes
#6 Delineators along off-ramps	Low	No	No
#7 Wigwag flashing beacons	High	Yes	Yes

[1] Cost includes initial installation, maintenance, and operation costs.
[2] Countermeasure effectiveness evaluated by its ability to mitigate WWD or alert wrong-way drivers to turn back on ramp prior to entering freeway.
[3] Assessment based on capability and accuracy to send real-time alerts.

8.2 Results from Section 5 – Field Testing and Evaluation of Identified WWD Countermeasures Using Task Groups

Section 5 included results from field testing and evaluation of the identified countermeasures through focus groups for the specific sites selected. Based on survey results from the focus group members, focus group discussions, and statistical data analysis, the top three WWD countermeasures are shown in Table 30.

Table 30: Top Three Countermeasures based on Expert Task/ Focus Group Discussions and Focus Group Surveys Input

Rank	Countermeasure
1	#2 – Red RRFBs
2	#5 – Detection-triggered blank-out signs that flash "WRONG WAY"
3	#7 – Wigwag flashing beacons

It should be noted that the ratings of the top two countermeasures were very close with no statistical difference. In addition, the expert task/focus group participants confirmed the effectiveness of Countermeasure #1 for mitigating WWD on arterials.

8.3 Results from Section 6 – Assessment and Comparison of Perceived Effectiveness of Identified WWD Countermeasures through Public Opinion Surveys

Section 6 summarizes the assessment and comparison of the perceived effectiveness of the identified WWD countermeasures obtained through a public opinion survey using pre-recorded field videos.

Table 31 summarizes the overall evaluation results based on average rankings of countermeasures on deterring WWD obtained through the survey and statistical analysis. After statistical analysis of the data, it was determined that the rankings of the red RRFBs and wigwag flashing beacons were not statistically different. Similar to the focus group results, survey participants also confirmed the effectiveness of Countermeasure #1 for mitigating WWD on arterials.

Table 31: Top Three Countermeasures Based on Survey Results

Rank	Countermeasure
1	#2 – Red RRFBs
2	#7 – Wigwag flashing beacons
3	#4 – Detection-triggered LED lights around "WRONG WAY" signs

8.4 Results from Section 7 – Analysis and Comparison of Effectiveness of Identified WWD Countermeasures via Human Factors Approach Using Driving Simulation

Section 7 summarized the analysis and comparison of the effectiveness of identified WWD countermeasures via a human factors approach using driving simulation. Figure 76 shows the driving simulator used for the analysis of this portion.

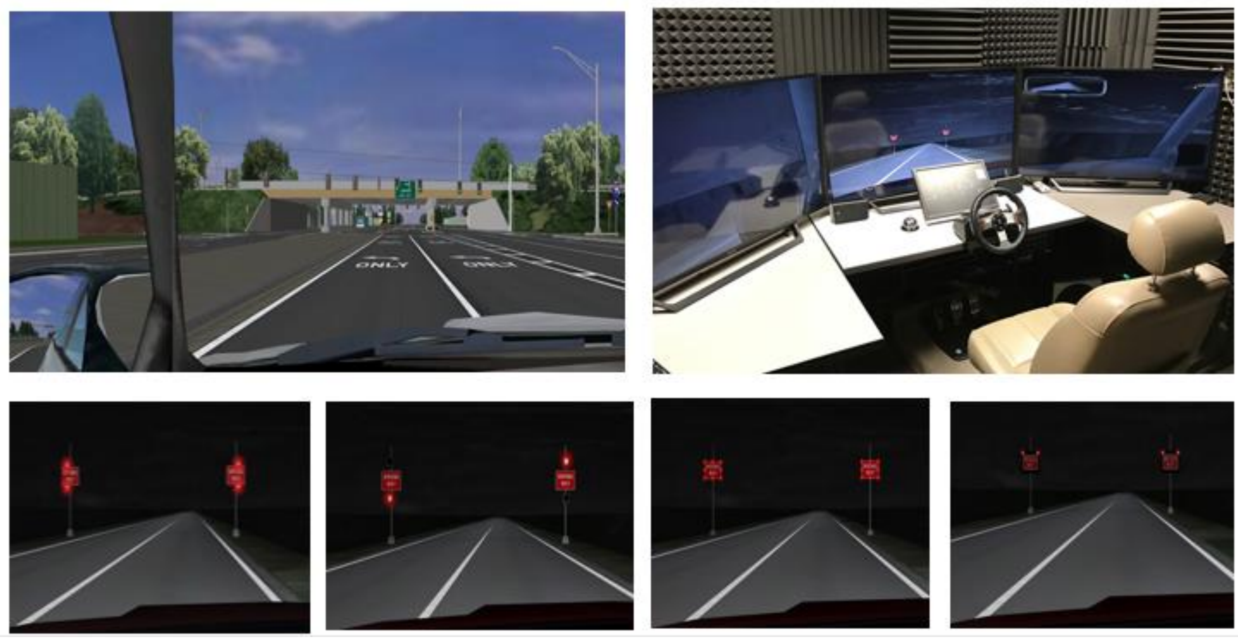


Figure 76: Driving Simulator Used for Human Factors Approach Analysis

Per the simulator results, the following conclusions were determined by the research team:

1. Countermeasure #1, newly-developed S&PM standards, should be implemented to reduce confusion regarding freeway entry points (confirming FDOT's conclusions since they already are the new S&PM standards).
2. The implementation of dynamic "WRONG WAY" signs including red RRFBs (Countermeasure #2), detection-triggered LED lights around "WRONG WAY" signs (Countermeasure #4), and wigwag flashing beacons (Countermeasure #7) should be considered to mitigate wrong-way crashes.
3. Detection-triggered blank-out signs that flash "WRONG WAY" (Countermeasure #5) that light up only when a driver is approaching may not effectively warn drivers in time that they are going the wrong-way and are not recommended.

Overall, the top three countermeasures (two tied at #3) are 1) red RRFBs, 2) wigwag flashing beacons, and 3) detection-triggered blank-out signs that flash "WRONG WAY" and detection-triggered LED lights around "WRONG WAY" signs.

9 CONCLUSIONS AND RECOMMENDED COUNTERMEASURES FOR FUTURE IMPLEMENTATION

Researchers concluded that a combination of cues help drivers pursue safe driving options; no particular sign or a lane marking but a combination of cues provide sensory inputs to drivers for making decisions. By analyzing all results, it was concluded that the top four countermeasures for freeway off-ramps are as depicted in Table 32.

Table 32: Top Four Countermeasures Recommended for Future Implementation

Rank	Countermeasure
1	#2 – Red RRFBs
2	#7 – Wigwag flashing beacons
3	#5 – Detection-triggered blank-out signs that flash "WRONG WAY"
3	#4 – Detection-triggered LED lights around "WRONG WAY" signs

The major conclusions and recommendations from this WWD research project are the following:

- Countermeasure #1, newly-developed S&PM standards, is confirmed as a very positive countermeasure on arterials to mitigate wrong-way entries onto freeway off-ramps.
- Countermeasure #2, red RRFBs, is the top countermeasure for mitigating WWD at freeway off-ramps and informing the TMC and is strongly recommended to be installed at off-ramps for future implementations.
- Countermeasure #7, wigwag flashing beacons, is the second best countermeasure for mitigating WWD at freeway off-ramps and informing the TMC.
- Countermeasure #5, detection-triggered blank-out signs that flash "WRONG WAY," is an effective countermeasure for mitigating WWD at freeway off-ramps and informing the TMC. However, if implemented, it is not recommended as a stand-alone device without other static "WRONG WAY" signs.
- Countermeasure #4, detection-triggered LED lights around "WRONG WAY" signs, is an effective countermeasure for mitigating WWD at freeway off-ramps and informing the TMC and has a relatively low cost.
- Countermeasure #3, red flush-mount IIRPMs, could be considered as a supplemental countermeasure for mitigating WWD at freeway off-ramps.
- Countermeasure #6, delineators along off-ramps, is the least effective countermeasure and is not recommended to be used for deterring WWD at freeway off-ramps.
- It is recommended to further examine countermeasures #2, #4, #5 and #7 to increase the length of WWD detection zones, so driver will obtain longer time of WWD warnings.
- It is recommended to further examine countermeasures #2, #4, #5 and #7 and adjust their detection zones to minimize false WWD detections.
- In addition to the countermeasures that were studied as a part of this research effort, it is essential that the other static wrong-way devices (wrong-way arrows, RPMs, static "WRONG WAY" signs, etc.) be present and in good condition on each ramp.

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APPENDIX A –
Driver Focus Group Survey Questionnaire

WWD Countermeasure Field Testing

Questions for a Focus Group

Countermeasure Number:___#1___ Name of Participant:______________________
E-mail address of Participant: ________________________

1. **Is this wrong-way driving (WWD) countermeasure you just experienced clear to you? Please describe what you know about this countermeasure based on your observation and understanding.**

2. **Could this WWD countermeasure help prevent you from turning onto a wrong way freeway off-ramp? Please provide reasons to support your answer.**

3. **Please rate how well this WWD countermeasure on an arterial near a freeway off-ramp directed you to correct driving direction when it was compared to 1) a small static no left-turn sign near a traffic signal head and 2) potentially misleading left-turn arrow pavement marking near the freeway off-ramp intersection; 10 being "extremely well", to 0 being "there is no difference". Your rating:_______**

Please see the back →

4. **<u>Describe</u> how effectively this WWD countermeasure you just experienced prevented you from driving onto a wrong-way freeway off-ramp? <u>Please also provide your rating</u> out of 10; 10 being "most effective" and 0 being "not effective at all". Your rating:_______**

5. **<u>Describe</u> the pros and cons of this WWD countermeasure you just experienced as a driver in detail.**

6. **<u>Please provide</u> any additional feedback you have for this countermeasure.**

WWD Countermeasure Field Testing

Questions for a Focus Group

Countermeasure Number:__________ Name of Participant:_____________________
E-mail address of Participant: __________________________________

1. Is this wrong-way driving (WWD) countermeasure you just experienced clear to you? Please describe what you know about this countermeasure based on your observation and understanding.

2. Could this WWD countermeasure help prevent you stop or discontinue wrong-way driving? Please provide reasons to support your answer.

3. Please rate how effectively this WWD countermeasure warned you of wrong-way driving when it was compared to standard static "WRONG WAY" signs installed at a freeway off-ramp; 10 being "extremely well", to 0 being "there is no difference". Your rating:_______

Please see the back →

4. **<u>Describe</u> how effectively this WWD countermeasure you just experienced warned you of or stopped your wrong-way driving? <u>Please also provide your rating</u> out of 10; 10 being "most effective" and 0 being "not effective at all". Your rating:_______**

5. **<u>Describe</u> the pros and cons of this WWD countermeasure you just experienced as a driver in detail.**

6. **<u>Please provide</u> any additional feedback you have for this countermeasure.**

APPENDIX B –
Driver Focus Group Survey Responses
&
Pros and Cons of Selected WWD Countermeasures

Driver Focus Group Survey Responses

Newly-Developed S&PM Standards

Q1. Is this WWD countermeasure you just experienced clear to you? Please describe what you know about this countermeasure based on your observation and understanding.

- Permanent Participant #1 – Yes. The new pavement markings tell drivers explicitly to go straight instead of driving the wrong-way.
- Permanent Participant #2 – Fairly clear, the straight arrow and shield combo helped me to know to go forward rather than turn left onto the off-ramp. Seemed that ramp had multiple signs to mitigate confusion.
- Local Participant #1 – This countermeasure was very clear to me. It is easy to understand and reinforces what the I-275 direction signs show.
- Local Participant #2 – The WWD countermeasure is the additional arrow on the pavement with an I-275 Southbound shield pavement marking before the turn to the off-ramp.
- Permanent Participant #3 – Yes, the improved pavement markings clearly point you to go straight rather than turn where you should not turn.
- Permanent Participant #4 – It is clear to me. I saw an I-275 southbound shield pavement marking with a straight arrow that points me to the right direction (straight, not turning).
- Local Participant #3 – Yes, the pavement marking is placed at a spot where drivers may get confused on where to turn. The colors are bright, and signage is easy to understand. The pavement marking is large enough to see from a distance as you approach the ramp.
- Permanent Participant #5 – This pavement marking combination clearly informs the driver that the interstate on ramp is straight ahead and not the first left (off-ramp). The markings and the message are clear.

Q2. Could this WWD countermeasure help mitigate you from turning onto a wrong-way freeway off-ramp? Please provide reasons to support your answer.

- Permanent Participant #1 – Yes, but if a driver is confused or not concentrating on the markings, he/she might easily miss them. It might not be effective in urban environments where there are too many distractions.
- Permanent Participant #2 – Yes, the straight arrows serve as a clear cue that a left turn (onto the off-ramp) turn would be inappropriate.
- Local Participant #1 – Yes, the “South” pavement marking states explicitly which direction it will be taking me. This eliminates doubt for a confused driver and reinforces what is already known for a driver who is familiar with the road.
- Local Participant #2 – If I was observant enough, it could mitigate me from turning into the wrong direction. If I am driving, my focus to find the correct way to travel will not be on the ground generally; I look up and around for some sign as to where I am supposed to turn into.
- Permanent Participant #3 – Yes, the message is very clear and simple.
- Permanent Participant #4 – Yes, it tells me the direction to I-275 southbound is straight. It is a very good improvement from the confusing left-turn pavement marking.

- Local Participant #3 – Yes, this countermeasure is probably the most effective for mitigating people from turning onto a wrong-way off-ramp. It lets drivers know to go straight and make a turn at the next light. It is a proactive measure to help mitigate the wrong action.
- Permanent Participant #5- Yes, the markings state to go straight in order to go on the on-ramp.

Q3. Please rate how well this WWD countermeasure on an arterial near a freeway off-ramp directed you to the correct driving direction when it was compared to 1) a small static "NO LEFT TURN" sign near a traffic signal head and 2) a potentially misleading left-turn arrow pavement marking near the freeway off-ramp intersection (with 10 being "extremely well" to 0 being "there is no difference").

- Permanent Participant #1 – (No reply)
- Permanent Participant #2 – (No reply)
- Local Participant #1 – (No reply)
- Local Participant #2 – I do not believe it is a huge attractor and not incredibly clear to see, but it could help if I am looking towards the ground.
- Permanent Participant #3 – The message is clear, simple, and placed right where needed.
- Permanent Participant #4 – (No reply)
- Local Participant #3 – (No reply)
- Permanent Participant #5 – (No reply)

Q4. Describe how effectively this WWD countermeasure you just experienced mitigated you from driving onto a wrong-way freeway off-ramp? Please provide your rating out of 10 (with 10 being "most effective" and 0 being "not effective at all").

- Permanent Participant #1 – This new pavement marking explicitly tells me to go straight and not make a left turn in the wrong-way direction.
- Permanent Participant #2 – I did not feel tempted to turn the wrong-way. I feel that if I missed any one cue (at least as a non-impaired driver) I would pick up on other cues (signs, pavement markings etc.)
- Local Participant #1 – (No reply)
- Local Participant #2 – In the case that it would help to know not to take that first turn (wrong-way) ramp, I believe it is effective. If another car is on the pavement covering that space, then I would have no idea.
- Permanent Participant #3 – Very clear and simple message with very good primacy.
- Permanent Participant #4 – Very clear to inform the driver to go straight.
- Local Participant #3 – This measure is effective because it is preventative. It clears confusion and assures drivers they are making the correct turns.
- Permanent Participant #5 – The driver needs to pay attention to the pavement markings for this measure to be effective.

Q5. Describe the pros and cons of this WWD countermeasure you just experienced as a driver in detail.

- Permanent Participant #1 – Pros: Since these are too many signs, markings on pavement are more effective. Drivers cannot miss these pavement markings. These are on the arterial, well ahead of the ramp. Drivers go slow here and have an opportunity to correct. Cons: They are prominent now. Not sure how effective they will be when the markings are worn out/faded.

- Permanent Participant #2 – Pro: The more cues, usually the better. Redundancy is probably an important part of mitigating wrong-way driving. Con: For very impaired drivers, I am not sure that even multiple static cues would have a big effect.
- Local Participant #1 – Pros: I-275 shield is a common logo that drivers will immediately recognize. Text direction and arrow (i.e., south) are effective and informing for driver. Great location, as drivers' eyes tend to focus on the road when driving. Cons: May need additional illumination-pavement reflectors.
- Local Participant #2 – Pro: Cheap to do. Con: It would not be the first thing I would look for if I am trying to find where to go.
- Permanent Participant #3 – Pro: Very clear and simple message. Con: If there is a vehicle in front of you, the message may be blocked.
- Permanent Participant #4 – Pro: It provides a very clear direction to move forward instead of turning. Con: I do not think there are any cons.
- Local Participant #3 – Pros: Large signage. Proactive/preventive. Clears confusion. Great placement on arterial. Cons: No lights. Does not say "WRONG-WAY." On ground, might miss/overlook.
- Permanent Participant #5 – Pros: Gets the attention of drivers to show them the right turn for the on-ramp. Cons: Pavement marking/static.

Q6. Please provide any additional feedback you have for this countermeasure.

- Permanent Participant #1 – It is good to reinforce wrong-way driving again on the ramp so that drivers who missed the pavement markings have a second chance.
- Permanent Participant #2 – I like this combination. It is not just where not to go, but where to go (guiding arrows). I think this component may sometimes be neglected.
- Local Participant #1 – (No reply)
- Local Participant #2 – (No reply)
- Permanent Participant #3 – Very good countermeasure. Needs to be repeated on the approach if spacing allows. Also, it is a supplement to the standard regulatory signs, not a replacement.
- Permanent Participant #4 – If possible, there should be one more set of I-275 shield pavement markings and straight arrows.
- Local Participant #3 – This countermeasure is very effective in mitigating wrong turns and should be used to complement other WWD measures.
- Permanent Participant #5 – It is a great complementary addition to a dynamic WWD countermeasure located on the actual off-ramp. This is a must in the design of these interchanges.

Red RRFBs

Q1. Is this WWD countermeasure you just experienced clear to you? Please describe what you know about this countermeasure based on your observation and understanding.

- Permanent Participant #1 – Yes, when I drive the wrong-way, the flashing beacons begin flashing.

- Permanent Participant #2 – Yes, it is clear. The flashing was very effective with respect to capturing attention, and the "WRONG-WAY" message familiar and clear. Based on this countermeasure, I would slow down for sure, and I would probably do so in enough time to extract the "WRONG-WAY" message from the signs.
- Local Participant #1 – Very clear. This countermeasure contained high-intensity RRFBs mounted on "WRONG WAY" signs. It does a great job at alerting the driver.
- Local Participant #2 – This countermeasure was the flashing red beacon placed below the "WRONG WAY" sign and moved side to side rather than a wig wag. It was very clear to me what the countermeasure is. It was easy to see and understand that I was traveling in the wrong direction.
- Permanent Participant #3 – Very clear flashing wig wag with the red RRFBs. The signs were also easy to read and had additional signs beyond this countermeasure.
- Permanent Participant #4 – It is very clear to me that I drove in the wrong direction. The intensity of red RRFB is strong and catches my attention. I understand the meaning of this countermeasure.
- Local Participant #3 – Yes, the flashing lights are very alarming and give a sense of emergency. As a driver, I knew something was wrong and I needed to turn around. The red lights meant "Stop, danger!"
- Permanent Participant #5 – Yes, the RRFBs cannot be mistaken. It delivers a very clear warning message. Once the driver looks up, they can see the "WRONG WAY" signs.

Q2. Could this WWD countermeasure help mitigate wrong-way driving? Please provide reasons to support your answer.

- Permanent Participant #1 – Yes, it is prominent, difficult to miss, red in color.
- Permanent Participant #2 – Yes, I think that most people would recognize some kind of error was made due to the message.
- Local Participant #1 – Yes, it is informative.
- Local Participant #2 – This countermeasure would help prevent me from traveling in the wrong direction because not only does it kick in immediately when I see the first "WRONG WAY" sign, but also I would only need to travel a short distance before I saw the flashing red lights.
- Permanent Participant #3 – Yes, the flashing red attracts attention to the sign. The sign is still legible, plus there were additional signs after those with RRFBs.
- Permanent Participant #4 – Yes, this countermeasure can definitely prevent me from driving to the wrong direction because it immediately catches my attention. The duration of flashing is long enough for me to read the sign.
- Local Participant #3 – Yes, like stated above, the RRFB gave off a sense of urgency. As soon as I saw the lights go off, the intensity of the flashes grabbed my attention and made me turn around. The radar detection went off early, so I could turn around before passing.
- Permanent Participant #5 – Definitely. Strong flashing beacons fully gets the drivers attention!

Q3. Please rate how effectively this WWD countermeasure warned you of wrong-way driving when compared to standard static "WRONG WAY" signs installed at a freeway off-ramp (with 10 being "extremely well" and 0 being "there is no difference").

- Permanent Participant #1 – (No reply)
- Permanent Participant #2 – (No reply)
- Local Participant #1 – (No reply)
- Local Participant #2 – It was effective in attracting my eyes to the "WRONG WAY" sign that I could potentially miss without any lights.
- Permanent Participant #3 – (No reply)
- Permanent Participant #4 – The red RRFB is very eye-catching. You know something is wrong then you see another pair of "WRONG WAY" signs, so you know you drove in wrong direction.
- Local Participant #3 – (No reply)
- Permanent Participant #5 – (No reply)

Q4. Describe how effectively this WWD countermeasure you just experienced warned you of or stopped your wrong-way driving? Please also provide your rating out of 10 (with 10 being "most effective" and 0 being "not effective at all").

- Permanent Participant #1 – Very effective. Its red flashing lights are hard to miss. The frequency of the flashing/pattern suggests that something is serious and requires attention, and "red" means "danger" or wrong.
- Permanent Participant #2 – The warning was very effective, the red flashing lights and clear message provide multiple cues that an error was being made.
- Local Participant #1 – This RRFB is fantastic for notifying and correcting a wrong-way driver's behavior. I believe it will benefit all drivers, including older adults and those with poor vision.
- Local Participant #2 –The flashing red lights are a universal sign to stop. If you see traffic lights flashing red, you stop. Seeing these, I would make the same connection.
- Permanent Participant #3 – Very effective! The wigwag red flash was very attention-getting.
- Permanent Participant #4 – It is very effective. The high intensity of the red RRFB definitely gives a strong warning of wrong-way driving.
- Local Participant #3 – The RRFB is radar activated, so the lights were flashing almost immediately after turning on the off-ramp. The flashes are so intense that it would be impossible to miss.
- Permanent Participant #5 – Very strong in getting driver's full attention.

Q5. Describe the pros and cons of this WWD countermeasure you just experienced as a driver in detail.

- Permanent Participant #1 – Pros: Red RRFBs are attention grabbing—red color, the flashing pattern. Cons: Might be easy to miss when driving fast and if they are not triggered immediately.
- Permanent Participant #2 – Pros: Salient, clear, and familiar message. Cons: Flashing may mask the lettering conveying the meaning of sign. This may be especially true for older drives.
- Local Participant #1 – Pros: Highly effective in grabbing attention. High-intensity lighting. Cons: Sensor could activate sooner; however, activation of RRFBs may be dependent on speed of vehicle.
- Local Participant #2 – Pros: It picks up the vehicle traveling the wrong direction quickly, and no matter what lane, it will still go off. Con: It might be slightly difficult to see the sign as effectively as what I saw with the wigwag movement. Not much, but slightly.

- Permanent Participant #3 – Pro: Wigwag flashing clearly says danger. Very clear message. Con: Cannot think of any. This was very effective and did not miss any vehicles.
- Permanent Participant #4 – Pro: Got my immediate attention. Long flashing duration. Very high intensity of red RRFB. Con: Cannot read the “WRONG WAY” sign that well.
- Local Participant #3 – Pros: Familiar “WRONG WAY” signs. Intense flashing red lights. Radar detection. Long intervals. Cons: Lights make sign hard to read.
- Permanent Participant #5 – Pros: Cannot be mistaken, these strong flashing beacons are very effective in getting the driver attention. Cons: Detection zone can be tweaked to give a longer response time.

Q6. Please provide any additional feedback you have for this countermeasure.

- Permanent Participant #1 – (No reply)
- Permanent Participant #2 – For this installation, I appreciated the redundant “WRONG WAY” signs after the flashing countermeasures.
- Local Participant #1 – (No reply)
- Local Participant #2 – (No reply)
- Permanent Participant #3 – This setup is very good. Having additional static signs after the countermeasure is really good.
- Permanent Participant #4 – It is a very effective WWD countermeasure.
- Local Participant #3 – In my opinion, this is the most effective countermeasure.
- Permanent Participant #5 – Probably one of the best countermeasures. Red light meant emergency. Wanted me want to turn around. Detects all vehicles from far away. Gets your attention. No problem reading “WRONG WAY” sign. Very bright, harder to read, but the next set of static signs clarify.

Red Flush-Mount IIRPMs

Q1. Is this WWD countermeasure you just experienced clear to you? Please describe what you know about this countermeasure based on your observation and understanding.

- Permanent Participant #1 – When you drive the wrong-way, the in-pavement markers flash red, telling me that I am driving the wrong-way. There are three rows of these in the pavement markers.
- Local Participant #4 – It blinks to warn you that you are going the wrong-way.
- Permanent Participant #2 – It was effective in terms of letting me know something was unusual or abnormal. I think it would definitely cause me as a driver to appraise the situation. I do not know if the measure by itself clearly conveys “wrong way,” but it would certainly make me look for signage about what may be going on.
- Permanent Participant #3 – Fits nicely to complement the standard treatments. Yes, this helps make the message clear.
- Local Participant #5 – The countermeasure is clear in my view. The embedded LEDs are bright and directly in my line of sight as a driver.
- Local Participant #6 – Yes, red is a color used to get vehicles to stop. In this case, it indicates vehicles are going the wrong-way.

- Permanent Participant #4 – It is not too clear to me when I drive through. I noticed something is different from the other ramp. It got my attention that maybe something is wrong.
- Permanent Participant #5 – It is clear that there is something wrong, with the blinking red lights. However, it is not clear if they are for WWD.
- Local Participant #7 – The WWD consists of three strips of flashing lights, meant to alert the driver of a wrong-way entrance to the highway.

Q2. Could this WWD countermeasure help mitigate wrong-way driving? Please provide reasons to support your answer.

- Permanent Participant #1 – Maybe. The in-pavement markers are not bright and not closely spaced. With street lights on, the markers are not prominently visible.
- Local Participant #4 – It could be, due to the flashing lights drawing your attention.
- Permanent Participant #2 – Yes, it would cause me to slow down and evaluate the situation and search for signs or markers.
- Permanent Participant #3 – Yes, as long as it was used with the standard treatments. It should not be considered as a replacement for the standard devices.
- Local Participant #5 – Yes, the bright red LEDs along with the static "WRONG WAY" signs and arrows are clear and instantly get my attention that I am driving in the wrong direction.
- Local Participant #6 – Yes, the IIRPM's (red) indicate "wrong-way."
- Permanent Participant #4 – It may stop me from continuing since something is different, but I am not 100% sure I know I drove the wrong-way.
- Permanent Participant #5 – It gets the attention of the driver with red blinkers. It can stop, but will all drivers understand they are a wrong-way countermeasure?
- Local Participant #7 – I believe this countermeasure is helpful at alerting the driver to be cautious, but it is not completely clear by itself that the driver should stop immediately. Personally, it reminded me of something you might see when approaching a pedestrian crossing.

Q3. Please rate how effectively this WWD countermeasure warned you of wrong-way driving when it was compared to standard static "WRONG WAY" signs installed at a freeway off-ramp (with 10 being "extremely well" and 0 being "there is no difference").

- Permanent Participant #2 – Again, I don't know if the countermeasure itself conveys "wrong-way" well, but it might slow a driver down enough to extract more information.
- Local Participant #6 – It is very clear that the countermeasure warns of wrong-way driving.
- Permanent Participant #5 – It is not clear if it is for WWD.

Q4. Describe how effectively this WWD countermeasure you just experienced warned you of or stopped your wrong-way driving? Please provide your rating out of 10 (with 10 being "most effective" and 0 being "not effective at all").

- Permanent Participant #1 – Quite effective compared to just the static "WRONG WAY" signs. Red flashers are effective in telling the drivers that something is wrong.

- Local Participant #4 – The lights are too far up the ramp; you are almost a quarter way up the ramp before you pay attention to them, especially if you are going fast. Once noticed, you know you are going the wrong-way.
- Permanent Participant #2 – This countermeasure itself serves as a good warning that something is amiss, but by itself does not necessarily convey the message that I should turn around.
- Permanent Participant #3 – It is a good supplement (probably a better word than complement) to the standard treatments. On this ramp, the wrong-way arrow treatment is in really good condition, and the signs are good, too.
- Local Participant #5 – The embedded LEDs' static "WRONG WAY" signs and arrow pavement markings are clear and directly in my line of sight and inform me of my wrong-way maneuver. This is very effective.
- Local Participant #6 – Very clear; the flashing lights get your attention and the red lines across the ramp form a visual barrier.
- Permanent Participant #4 – I do not think it is effective to warn me of wrong-way driving.
- Permanent Participant #5 – Not clear they are for WWD.
- Local Participant #7 - Not very effective at conveying wrong-way entrance. Got my attention, but did not seem a serious enough alert and was not clear what it meant. May distract attention away from more effective signs and arrows.

Q5. Describe the pros and cons of this WWD countermeasure you just experienced as a driver in detail.

- Permanent Participant #1 – Pros: Red color flashers. Cons: Not very visible because of street lights and other lights; they are sparse and can have more flashers in each line.
- Local Participant #4 – Pros: Lights draw attention, better than the arrow. Cons: Too far up the ramp.
- Permanent Participant #2 – Pros: Very attention grabbing/salient. Cons: Once it has your attention, the message is ambiguous.
- Permanent Participant #3 – Pros: It is in the roadway, not off to the side. Very good! Cons: On all the time vs. triggered (not that big a deal).
- Local Participant #5 – Pros: Bright LEDs and high reflectivity of signage are great at getting the driver's attention at night. Cons: Static signs could be larger and could use LEDs on sign panels; roadway lights take a little away from LED's full effectiveness.
- Local Participant #6 – Pros: Very visual at night. Three red lines form a visual barrier, alternating solid/flash give contrast and help in getting your attention.
- Permanent Participant #4 - Pros: It gets my attention to some degree. Cons: not quite sure what is wrong. It is not bright enough.
- Permanent Participant #5 – Pros: Gets your attention. Cons: Too much street lighting diminishes the effect. Not clear if for WWD.
- Local Participant #7 – Pros: The flashing lights catch your attention easily. When seeing the countermeasure, I became alert. Cons: The countermeasure does not get the wrong-way point across on its own; it came across as more of a "take caution" measure, like approaching a stop sign or pedestrian crossing.

Q6. Please provide any additional feedback you have for this countermeasure.

- Permanent Participant #1 – (No reply)
- Local Participant #4 – Might work better in conjunction with flashing arrow or flashing signs for earlier warning.
- Permanent Participant #2 – I think the same LEDs embedded in an arrow pavement marker would both capture attention and provide a less ambiguous message.
- Permanent Participant #3 – This is very good countermeasure that should be considered for all the ramps that have wrong-way crash issues. May consider for all ramps if cost is low. Would be nice to try flashing RPMs in the wrong-way arrow (simulator).
- Local Participant #5 – (No reply)
- Local Participant #6 – Generally, a very effective countermeasure for nighttime warning for drivers. The in-roadway device is right in the driver's eye, gives maximum effectiveness.
- Permanent Participant #5 – These should be installed in areas with not much lighting, since lighting diminishes their effect. Supplement these with radar detection dynamic LED light "WRONG WAY" signs (suggestion from FSU students). Can the red blinkers be in the "WRONG-WAY" arrow? Secondary static "WRONG WAY" signs.
- Local Participant #7 – I think the countermeasure would be more useful if it was in the shape of an arrow and was supplemented with extra signs. It does get your attention better than the existing arrow and signs, but it does not convey the wrong-way alert well. Note: These could potentially make the one-say signs less effective as it may take attention away from existing more effective means.

Detection-Triggered LED Lights around "WRONG WAY" signs

Q1. Is this WWD countermeasure you just experienced clear to you? Please describe what you know about this countermeasure based on your observation and understanding.

- Permanent Participant #1 – Yes. The LED lights around the sign start flashing when WWD is detected.
- Permanent Participant #2 – Somewhat. I could see an inattentive driver missing the message. It happens fairly quickly. First sign and second (flashing signs) are fairly close together. By the time the flashes pulled my attention/eyes, I was already past the sign, and after that there were no redundant cues to let me know the message I missed. The purpose of this countermeasure is to mitigate people from driving onto off-ramps. This is done by placing flashing "WRONG WAY" signs on the edge of the road.
- Local Participant #8 – The purpose of this countermeasure is to mitigate people from driving onto off-ramps. This is done by placing flashing "WRONG WAY" signs on the edge of the road.
- Permanent Participant #3 – Yes, It does accentuate the "wrong-way" message.
- Permanent Participant #4 – It is somewhat clear to me. It detects wrong-way driving and triggers LED flashing to warn wrong-way drivers.
- Local Participant #9 – As a driver, the countermeasure on the first round was not very clear. I knew something was wrong but I did not have much time to see the "WRONG-WAY" letters. Second and third round, I was able to notice that I was going on the wrong direction because the speed was not as fast as the first round.

- Permanent Participant #5 – The sign was clearly retroreflective so you could read “WRONG-WAY,” and once the radar detected the vehicle, the LEDs around the sign lit up. The LEDs are not super strong, but they draw some attention.
- Local Participant #10 – The WWD countermeasure was clear at speeds less than 30 mph. However, most of my attention was on the flashing red lights, which indicated some sort of warning. The “WRONG-WAY” was not as bright as compared to the flashing light, and I missed the actual message on the board at high speed (>30 mph).

Q2. Could this WWD countermeasure help mitigate wrong-way driving? Please provide reasons to support your answer.

- Permanent Participant #1 – Maybe, if I am playing attention to the road and sign. If I am inattentive or traveling at high speeds, I might miss the sign/lights.
- Permanent Participant #2 – Yes, it would provide some basic warning that something was wrong. However, additional cues past the flashing signs would support knowledge about what went wrong and how to correct the error.
- Local Participant #8 – Yes, having clear “WRONG WAY” signs is a very clear method that will catch the attention of the drivers who make incorrect turns onto ramp exits.
- Permanent Participant #3 – Probably not. Although it does emphasize the sign, it comes on too late if you are accelerating at a rapid rate. In my first run, especially since I was first, I thought it did not work. It came on just as I was passing the sign.
- Permanent Participant #4 – Yes. I believe it will help me to prevent wrong-way driving because of the flashing. It caught my attention first, and then I saw the “WRONG WAY” sign. However, the duration was pretty short after I saw flashing.
- Local Participant #9 – The countermeasure worked well to prevent or help me to notice I was going on the wrong direction. The lights were very intense; it helped me to notice that something was wrong.
- Permanent Participant #5 – Yes; however, the speed of the vehicle and detection zone plays an important role for the perception-reaction time of the driver. The LEDs draw some attention to the sign when lit up but are not super strong.
- Local Participant #10 – Yes, it could mitigate wrong-way driving, coupled with other measures such as “STOP” sign. It can mitigate wrong-way driving.

Q3. Please rate how effectively this WWD countermeasure warned you of wrong-way driving when it is compared to standard static “WRONG WAY” signs installed at a freeway off-ramp (with 10 being “extremely well” to 0 being “there is no difference”).

- Permanent Participant #1 – (No reply)
- Permanent Participant #2 – (No reply)
- Local Participant #8 - (No reply)
- Permanent Participant #3 – It would be better if a redundant assemble was further down the ramp.
- Permanent Participant #4 – (No reply)
- Local Participant #9 – (No reply)
- Permanent Participant #5 – (No reply)

- Local Participant #10 - (No reply)

Q4. Describe how effectively this WWD countermeasure you just experienced warned you of or stopped your wrong-way driving? Please provide your rating (10 being "most effective" and 0 being "not effective at all").

- Permanent Participant #1 – The lights surely grab your attention. But if you are traveling at high speeds, you might see the lights only for a second or so, and therefore might not realize what they are for.
- Permanent Participant #2 – It depended on speed. I was surprised by how late the flashing lights activate at higher speed. I can imagine an older or inebriated driver perhaps showing not much of a difference between signs with & without flashing LEDs.
- Local Participant #8 – If you are driving fast or driving distracted, you will not notice the signs. The LED lights on the border of the sign cover the letter "WRONG-WAY" in the sign, basically making the sign useless. With the LEDs off, letters are visible yet very hard to read.
- Permanent Participant #3 – If you are impaired or not looking for it, it could be missed, especially in a smaller vehicle accelerating hard.
- Permanent Participant #4 – It is somewhat effective to warn me and prevent me to continue. Because the duration is short to recognize the wrong-way, if I do not pay attention, I may have a very short time to recognize the "WRONG WAY" sign.
- Local Participant #9 – In general, it was effective because it helped me to notice that something was wrong. By the time I see the sign, as a driver, I will stop my wrong-way driving, but if the light lit up as soon as I made the right turn, it would be more effective.
- Permanent Participant #5 – The LEDs could be brighter, which will attract more attention, and the driver will be more likely to react to the countermeasure. Also, the detection zone was too close, which gives the driver about one second to observe and react to the sign while at the same time trying to understand what it is.
- Local Participant #10 – The signal warned me of a violation and was quite effective at warning me at low speeds, definitely better than the conventional signs.

Q5. Describe the pros and cons of this WWD countermeasure you just experienced as a driver in detail.

- Permanent Participant #1 – Pros: The red lights grab your attention. Cons: The text is too dull compared to the lights. Will miss the lights if travelling at high speeds.
- Permanent Participant #2 – Pro: It seems effective in alerting and grabbing attention Con: Once attention is captured, the driver may be past this sign too soon to get the message.
- Local Participant #8 – Pros: It worked effectively every time I passed through, caught my attention every time. Cons: The letters of the sign are not very visible while the LEDs are flashing.
- Permanent Participant #3 – Pro: It does accentuate the "WRONG WAY" sign nicely. Draws attention to the message. Con: Sensitive to vehicle size. Might be missed if vehicle is accelerating fast.
- Permanent Participant #4 – Pros: The LED flashing around the "WRONG WAY" sign could catch my attention. I could see/read the "WRONG WAY" sign after it started to flash. Cons: Two

"WRONG WAY" signs are too close (standard ones and the countermeasure). The time from LED flashing to passing the LED "WRONG WAY" sign is short.

- Local Participant #9 – This countermeasure, in general, is very accurate to mitigate wrong-way driving. The lights are very intense, and the distance of these signs to the street is also very accurate or clear to be observed. Con: On the other hand, I think it could work better if the driver had more time to look at the sign, so that he/she could be able to read the sign.
- Permanent Participant #5 – Pros: LEDs, when lit, draw attention to the sign. Cons: LEDs are brighter, and a short detection zone may cause driver miss/not observe the sign. Faster vehicles will have about one second to process all the information the sign is trying to send, which is very hard to achieve.
- Local Participant #10 – Pros: Catches attention immediately. Cons: "WRONG-WAY" letters not as bright as compared to the flashing lights and hard to read. Attention was mostly on the right side sign only.

Q6. Please provide any additional feedback you have for this countermeasure.

- Permanent Participant #1 – Have another set of lights a few feet downstream that trigger at the same time as the first set of lights. This will make sure that the drivers do not miss it.
- Permanent Participant #2 – For older drivers or individuals with poorer vision, flashing may actually mask the text. Changes in optical media (with age) scatters light, older drivers may be at a disadvantage (though would be unlikely to be driving at night, when this would be the biggest problem). This countermeasure may be made more effective by fleshing from further out (greater distance) plus additionally, high salience signs after the LED ones.
- Local Participant #8 – While the LED was flashing, I looked at the sign but could not read the words. By the time LEDs shut off, I looked back at the road to concentrate on my driving.
- Permanent Participant #3 – Redundancy, especially another pair of signs further down the ramp activated by radio would help.
- Permanent Participant #4 – When the speed of a vehicle is high, the time to recognize the "WRONG WAY" sign is pretty short. To be more effective, the detection zone needs to be longer. The detection zone is too short.
- Local Participant #9 – In my opinion, this is a great tool to prevent crashes; however, it could be more efficient if the sign could be bigger in size, so that it could be easier to notice it. The time it starts lighting up should be as soon as the driver makes the right turn toward the wrong direction. The letter of this sign should be brighter.
- Permanent Participant #5 – Longer reaction time/a larger detection distance might really help this sign/countermeasure and attracts the driver's attention more effectively.
- Local Participant #10 – A third sign placement could definitely help in WWD countermeasure.

Detection-Triggered Blank-out Signs That Flash "WRONG WAY"

Q1. Is this WWD countermeasure you just experienced clear to you? Please describe what you know about this countermeasure based on your observation and understanding.

- Permanent Participant #1 – Yes! When I drive in the wrong direction, the blank-out signs flashed "WRONG WAY," alerting me.

- Permanent Participant #2 – Yes, the message was very clear, attention capturing. “WRONG-WAY” meaning effectively converged and was very attention-capturing.
- Permanent Participant #3 – Yes, very clear wrong-way message. Very nice that it is dark until needed. Attention getting!
- Local Participant #5 – This countermeasure was very clear to me as a driver. The large illuminated sign got my attention right away to inform me I was traveling in the wrong direction. In addition, the static “WRONG WAY” sign overhead is highly reflective.
- Local Participant #11 - Yes, it was very clear I was going the wrong-way. The red reflectors and the sudden flashing sign stood out to me.
- Local Participant #6 – Yes, it reinforced the “WRONG WAY” signs already in place.
- Permanent Participant #4 – Yes, it was very clear to me since it shows the wrong-way message when my vehicle reached a midpoint of the off ramp. It got my attention.
- Permanent Participant #5 – Yes, the countermeasure is clear warning for a WWD event. The measure detects a WWD vehicle and a blank-out sign lights up.
- Local Participant #12 – Very clear message: pay attention, you are driving in the wrong direction, stop and turn around as soon as possible.
- Local Participant #13 – It was clear to notice something was wrong, when the countermeasure turned on. But reading the message would depend on how fast you are going and where you are looking at.

Q2. Could this WWD countermeasure help mitigate wrong-way driving? Please provide reasons to support your answer.

- Permanent Participant #1 – Yes! The signs are prominent. The red flashing cannot be missed by wrong-way drivers. The big “WRONG WAY” sign overhead is hard to miss.
- Permanent Participant #2 – Yes, I would discontinue driving or search for additional cues in the environment. I will likely realize the error. Seemed to activate with enough time for the message to be understood even at higher speeds.
- Permanent Participant #3 – Very likely, it gets your attention and is very bright, but not too bright where glare would be a concern. The sign is still very legible.
- Local Participant #5 - Yes, the sign is clearly legible with flashing lights that clearly let me know of the improper driving direction along with the dual “WRONG-WAY” arrows and red RPMs.
- Local Participant #11 – Yes, it is very effective and I believe the message is clear.
- Local Participant #6 – Yes, the sign was coming on (illumination) as I approached and was a “change” from static signs; it gets your attention.
- Permanent Participant #4 – Yes, I think when I see this blank-out wrong-way message, I will realize I drove in the wrong direction. It showed me the wrong-way message.
- Permanent Participant #5 – Definitely. The message it delivers is clear and is effective from dark to light-up “WRONG WAY” sign flashing.
- Local Participant #12 – Yes, but only if the font size was larger, and the detection is much sooner. At 50 mph, it barely captured my attention. By the time I was parallel to it was when it lit up. Circle LEDs on corner could also be bigger. (NOTE: My vision is not 100% great, even with glasses, -11 both eyes).

- Local Participant #13 – Yes, it could. It would definitely capture attention, particularly during the nighttime, because it is very bright and colorful, so it would trigger a certain type of reaction.

Q3. Please rate how effectively this WWD countermeasure warned you of wrong-way driving when it was compared to standard static “WRONG WAY” signs installed at a freeway off-ramp (10 being “extremely well” to 0 being “there is no difference”).

- Permanent Participant #1 – (No reply)
- Permanent Participant #2 – If the first sign did not capture my attention, this one would.
- Permanent Participant #3 – (No reply)
- Local Participant #5 – (No reply)
- Local Participant #11 – (No reply)
- Local Participant #6 – (No reply)
- Permanent Participant #4 – (No reply)
- Permanent Participant #5 – (No reply)
- Local Participant #12 – (No reply)
- Local Participant #13 – (No reply)

Q4. Describe how effectively this WWD countermeasure you just experienced warned you of or stopped your wrong-way driving? Please also provide your rating out of 10 (with 10 being “most effective” and 0 being “not effective at all”).

- Permanent Participant #1 – Very effective. It is the combination of treatments that is most effective—1) the big overhead “WRONG WAY” sign, 2) the red pavement markers, and 3) the blank- out sign.
- Permanent Participant #2 – Both visually sound and clear meaning. Compared to Miami site, flashing did not seem to mask the sign lettering.
- Permanent Participant #3 – Very good countermeasure. Gets your attention- nicely bright with flashers in the corners, too.
- Local Participant #5 – As I was driving, the sudden illuminated “WRONG WAY” sign with flashers provided a clear message that I was driving in the wrong direction, therefore forcing me to turn around and correct the wrong-way direction.
- Local Participant #11 – (No reply)
- Local Participant #6 – The illumination of the sign as you approach alerts you while you are moving of the wrong-way. This should be a clear straight forward countermeasure.
- Permanent Participant #4 – I believe it is effective, the wrong-way message is clear to me. The sign is easy to read. It is bright.
- Permanent Participant #5 – This is effective since it detects and then lights up fully as a “WRONG WAY” sign, getting a lot of attention and making the driver look.
- Local Participant #12 – At a high speed, the font was hard to read. The circle LED motion pattern worked well, although the circles could be larger. The red color was indicative I was doing something wrong. Perhaps since it is an LED sign, the sign can alternate between “WRONG-WAY” and “TURN AROUND.”
- Local Participant #13 – (No reply)

Q5. Describe the pros and cons of this WWD countermeasure you just experienced as a driver in detail.

- Permanent Participant #1 – Pros: It is hard to miss. It worked even when the driver was far away from the sign. Cons: None.
- Permanent Participant #2 – Pros: This is a message that people know, it is familiar, and easy to process. Harnessed natural reflex to attend to abrupt onset. Cons: Perhaps large sign/font might be necessary for older or impaired drivers.
- Permanent Participant #3 – Pros: Dark until needed—surprise factor. Cons: One side had been knocked down, could be bigger.
- Local Participant #5 – Pros: Very bright and clear, straightforward and effective, reflectivity of static signs and RPMs were very bright. Cons: Response time could use a little adjustment to trigger the sign to come on sooner. Slower speed to effect the response time.
- Local Participant #11 – Pros: Very clear, red reflectors on ground and sudden flashing signs are effective. Cons: I was already passing the sign by the time I got to react to it. The other "WRONG WAY" signs could have more lighting around them, hard to see at night.
- Local Participant #6 – Pros: Illumination is a change from static, reinforces wrong-way messages. Should be clear to drivers. Cons: Possibly more effective if placed over the lane; a few of the trials seemed to have a slow response, maybe came on too late. During one run, it did not come on, so I stayed in the far right lane, and it cut over at the last minute. Calibration of detection to correct slow/small vehicle issues.
- Permanent Participant #4 – Pros: It detects the wrong-way vehicle and shows the message clearly. Cons: Slow speed does not trigger the blank-out wrong-way message. If the sign message is bigger, it will be much better (size).
- Permanent Participant #5 – Pros: Very effective and gets attention of driver. Message very clear. It is very visible. Video does not do it justice. Cons: Detection zone can be longer so driver does not pass the sign quickly depending on speed.
- Local Participant #12 – Pros: Flashing pattern of circles. Bright. Red color for background. Cons: Small font. Small circles. Slow onset of trigger. Too far up ramp.
- Local Participant #13 – Pros: It will capture attention no matter how fast and where you are looking at. It is bright enough. Cons: If your visual field focused on the corner of the road, it might be difficult to catch what it is saying. Felt it is a bit small.

Q6. Please provide any additional feedback you have for this countermeasure.

- Permanent Participant #1 – (No reply)
- Permanent Participant #2 – What I have frequently thought about is more command-like messages. For example, "TURN AROUND"—this would eliminates the extra cognitive step of translating information that something is wrong into what to do with the knowledge.
- Permanent Participant #3 – D3 has done a lot here. I really like the oversized overhead "WRONG WAY" sign on the gantry and the wrong-way arrows (great condition). This countermeasure is a very nice addition to the package.
- Local Participant #5 – I think a mixture of the in-pavement lights along with the illuminated "WRONG WAY" signs would make it very effective.

- Local Participant #11 – I put a “9” rating because I did not see the sign light up when I passed it the first time (for questions 3 and 4).
- Local Participant #6 – Calibration of detection slow/small vehicle issues.
- Permanent Participant #4 – I like it; we should consider the countermeasure. Speed and car size. Look into calibration.
- Permanent Participant #5 – RRFBs are probably best. Can have a second set to make sure driver can see the measure and take action. Blank-out possibly first, and then static signs. The red circles at the corners can be longer. Possible improvement LED lights combo. Better than “WRONG WAY” sign with LED flashing around. Calibration – size and speed of car. Static, blank-out, and static.
- Local Participant #12 – Alternative message if possible between “WRONG-WAY” and “TURN AROUND.” Siren, if possible to draw attention to the location. Could appear sooner in ramp before static signs.
- Local Participant #13 – When I drove slowly via the second lane, it did not get turned on. It has to be on both sides of the road. Could be better to install sooner (closer) point.

Delineators along Off-ramps

Q1. Is this WWD countermeasure you just experienced clear to you? Please describe what you know about this countermeasure based on your observation and understanding.

- Permanent Participant #1 – Not very. When I drove the wrong-way, the red-strip on the concrete barrier on the right illuminated a little. There are two “WRONG WAY” signs that are at a lower light than usual signs.
- Permanent Participant #2 – This particular countermeasure in isolation does to provide a clear message. Although red is typically associated with “STOP,” here it could be interpreted as just a warning that a barrier is to the right.
- Local Participant #1 – Not very clear. In-lane delineators are present but are small—about the same width of a pavement line—making it difficult to notice. It may be more effective if its size was increased.
- Local Participant #14 – Besides four “WRONG WAY” signs, with two on each side, there are red reflectors on the right-side concrete wall and a few red reflectors on the ground.
- Local Participant #2 – No. The countermeasure was not explained to me beforehand, but I assumed the countermeasure was the reflective along the delineators because it was the only other thing along the road that I saw, not including the “WRONG WAY” signs.
- Permanent Participant #3 – It was clear to me as a traffic engineer that more red is bad, but it really did not blow me away. I was somewhat underwhelmed.
- Permanent Participant #4 – It is not clear to me. I did not see any specific wrong-way message to warn me. I saw delineators that seemed to indicate the curve of the ramp.
- Local Participant #3 – No. The delineators are not a clear indicator of wrong-way driving. The reflective markers look like they are just lining the wall and showing the driver wall barriers. I would not correlate delineators with wrong-way driving signage. There is no messaging or lighting, so this could be easily missed.

- Permanent Participant #5 – Not really. The delineators look like they can be any type of a red-strip that can even highlight that there is a ramp-wall there and to warn against colliding into it.

Q2. Could this WWD countermeasure help mitigate wrong-way driving? Please provide reasons to support your answer.

- Permanent Participant #1 – No. It does not tell a driver that he/she is driving in the wrong-way, the red color is not prominent, and the strip is reflecting white color when you are close.
- Permanent Participant #2 – I do not think that this message in isolation provides a clear stop message, and it may not be interpreted as something being wrong. Reflective material may just be assumed to be there for visibility purposes.
- Local Participant #1 – No. Its presence is not very obvious to the ordinary driver, and even if he/she notices, they may not associate it with wrong-way movements. I think it would cause more confusion, because the average driver does not know what it means.
- Local Participant #14 – Yes, it could do that if my mind is focusing on driving. It may not, however, do that otherwise because it is not eye-catching enough. In fact, the reflectors on the wall do not reflect well.
- Local Participant #2 – I do not believe this countermeasure would prevent me from not driving in the wrong direction. Not knowing what is was beforehand, I thought it could just be a precaution for the barrier itself so that I would not hit it.
- Permanent Participant #3 – Probably not – it is subtle; add a little more red. Also, it was off to the side rather than in your face.
- Permanent Participant #4 – I do not think this WWD countermeasure will help prevent me to stop or discontinue wrong-way driving because I did not see the wrong-way driving warning message. The delineators were not effective in warning me.
- Local Participant #3 – No. Nothing about this countermeasure tells a driver that he/she is going the wrong-way. The signage is on the border of the right-hand side of the road. Drivers will not look at the wall while they are driving.
- Permanent Participant #5 – Probably not. The delineators are static and do not really emphasize that the driver is wrong-way driving.

Q3. Please rate how effectively this WWD countermeasure warned you of wrong-way driving when it was compared to standard static "WRONG WAY" signs installed at a freeway off-ramp (with 10 being "extremely well" to 0 being "there is no difference").

- Permanent Participant #1 – (No reply)
- Permanent Participant #2 – At this installation, the other countermeasures (signs) were very salient, reflectors could not compete with these other messages. Not much added value.
- Local Participant #1 – (No reply)
- Local Participant #14 – (No reply)
- Local Participant #2 – I saw it with the "WRONG WAY" sign, but I understood the sign and not the countermeasure. I knew I was going the wrong-way from the signs only.
- Permanent Participant #3 – (No reply)
- Permanent Participant #4 – Not effective at all.
- Local Participant #3 – (No reply)

- Permanent Participant #5 – (No reply)

Q4. Describe how effectively this WWD countermeasure you just experienced warned you of or stopped your wrong-way driving? Please also provide your rating out of 10 (with 10 being "most effective" and 0 being "not effective at all").

- Permanent Participant #1 – Not effective. Because it does not tell that you are driving in wrong-way, the red strip is not prominent, and the strip is also quite short.
- Permanent Participant #2 – It did not provide a clear warning. Message was ambiguous. Going around the curve, both the red and white sites were partially visible, making the "red" message even less visible/clear.
- Local Participant #1 – I do not associate countermeasure #5 with wrong-way driving at all. However, it did seem to alert me, making me drive slower to try and understand the nearby surroundings. Because I associated "red" (reflectors) with stopping, it would encourage me to stop or at least slow down.
- Local Participant #14 – (No reply)
- Local Participant #2 – (No reply)
- Permanent Participant #3 – Provided additional red, but nothing more. Not a bad supplement to standard treatments, but not dynamic enough to make a big difference.
- Permanent Participant #4 – It is not effective at all.
- Local Participant #3 – This is not very effective because the message is not clear. It looks like a reflective barrier so people do not drive into the wall. You have to drive all the way down the ramp before processing the delineators.
- Permanent Participant #5 – Not effective, not clear if WWD is the issue that this countermeasure is warning for.

Q5. Describe the pros and cons of this WWD countermeasure you just experienced as a driver in detail.

- Permanent Participant #1 – Pros: The "WRONG WAY" sign is after the red strip. Cons: It does not explicitly tell that the driver is driving wrong-way, the red color in the strip is not prominent, the strip is short, and the strip almost looked like a design.
- Permanent Participant #2 – Pros: Some may interpret red reflectors as a means to stop. Cons: I do not think most will, and I do not think the message will be effective for impaired drivers. Not salient. Even if it captures attention, once attention is there, meaning is absent.
- Local Participant #1 – Countermeasure #5 is not effective to use by itself; however ,I think when paired in conjunction with more obvious WWD signage, such as flashing signs, it would help notify the wrong-way driver. Pros: It is cost-effective to install (reflectors) Cons: Easy to overlook, especially when accelerating fast up ramp, it is small in appearance, and it is an unfamiliar roadway infrastructure which may confuse more than inform.
- Local Participant #14 – The red reflectors on the right wall could work better if they are on the left side. The few reflectors on the ground on the left side are not red. There should be more reflectors on the ground on both sides.
- Local Participant #2 – Pros: When I was traveling along the ramp, I did look towards it while I was rounding the curve, so I believe the placement was effective. Cons: It is not an obvious warning as compared to the "WRONG WAY" signs.

- Permanent Participant #3 – Pros: More red reflectors. Cons: Not enough punch to it. It would have been more effective to have this on the other side (the outside of the curve) so that the red would be in your face more.
- Permanent Participant #4 – Pros: Red delineators may provide some warning or get drivers' attention. Cons: It is not clear to provide warning message.
- Local Participant #3 – Pros: Reflectivity is red, barriers extend through entire ramp. Cons: Not alerting, hard to see, on the wall, no text/message, and reflective barrier.
- Permanent Participant #5 – Pros: Cheaper to install probably. Cons: Not clear which message it carries, not very visible, not effective, and static.

Q6. Please provide any additional feedback you have for this countermeasure.

- Permanent Participant #1 – (No reply)
- Permanent Participant #2 – (No reply)
- Local Participant #1 – This countermeasure would be best when implemented with other WWD signage. Because of its minimalistic appearance, perhaps it could function better on small roads, where there is less traffic or slower speed limits, in conjunction with "WRONG WAY" signs.
- Local Participant #14 – A light pole blocks part of a "WRONG WAY" sign.
- Local Participant #2 – (No reply)
- Permanent Participant #3 – Underwhelmed. Would be much better on the other side of the ramp, or even better on both. Also, the other devices (edge line RPMs and wrong-way arrows) are not in good shape. Needs maintenance work.
- Permanent Participant #4 – It provides good warning for curve of the ramp, but not the warning for wrong-way driving.
- Local Participant #3 – This countermeasure could be used to complement other countermeasures, but it is not clear or effective enough to warn the wrong-way driving and have enough time to correct the mistake.
- Permanent Participant #5 – This is not a very effective WWD countermeasure compared to others experienced. Messages are not clear. Small delineators—can they be larger, on both sides of roadway? Used with other countermeasures? Drunk driver can be focused in front of them, not to side.

Wigwag Flashing Beacons

Q1. Is this wrong-way driving WWD countermeasure you just experienced clear to you? Please describe what you know about this countermeasure based on your observation and understanding.

- Permanent Participant #1 – Yes, very clear. The red lights on top and bottom of the "WRONG WAY" sign start blinking when I drive in the wrong-way.
- Permanent Participant #2 – Yes, meaning was fairly clear, the message easy to comprehend.
- Local Participant #1 – Yes. It clearly informed me that I was driving in the wrong direction.
- Local Participant #14 – Yes. The red-flashing beacons' lights brought my attention to the "WRONG WAY" signs on both sides.
- Local Participant #2 – I knew what to expect from this countermeasure. I understood the flashing red beacon meant I was driving in the wrong direction.

- Permanent Participant #3 – Yes, the flashing wigwag light grabs your attention and makes you want to stop.
- Permanent Participant #4 – Yes. It is clear to me. When I pass through the detection zone, my vehicle triggered the sensor. I can see flashing beacons on both of the “WRONG WAY” signs. It indicates that I drive in the wrong direction.
- Local Participant #3 – Yes. The wigwag combination messaging was very clear. The sudden flashing lights were very sudden and alerting. The “WRONG WAY” sign was familiar and more alarming with the flashing lights. This countermeasure is great because the sign is easy to ready and the red lights definitely let the driver know to turn around.
- Permanent Participant #5 – Yes, the countermeasure is clearly a WWD one, since the wigwag beacons are on a “WRONG WAY” sign. It is visible and easy to understand.

Q2. Could this WWD countermeasure help mitigate wrong-way driving? Please provide reasons to support your answer.

- Permanent Participant #1 – Yes! The lights on the top and bottom of the “WRONG WAY” sign cannot be missed. The “WRONG WAY” signs are lower and within cone of vision.
- Permanent Participant #2 – Yes, even if the message did not come through, the red bell lights, similar to stop lights/railroad lights would cause me to slow down, seek additional information, and be cautious.
- Local Participant #1 – Yes. The flashing beacons when mounted on the “WRONG WAY” sign make it very obvious that I am headed in the wrong direction, and to turn around immediately. It is effective in telling me to stop/turn around.
- Local Participant #14 – Yes. The three “WRONG WAY” signs before the beacons do not reflect much light due to the width of the off-ramp, but the red beacons are adequate to catch my eyes.
- Local Participant #2 – This WWD countermeasure would prevent me from continuing driving the wrong-way. It was obvious when I saw it and it is a universal sign to stop.
- Permanent Participant #3 – Yes, the wigwag red is a clear danger indication.
- Permanent Participant #4 – Yes. It will help me to stop or discontinue wrong-way driving because I can see the wrong-way message. The flashing beacon suddenly starts to flash, which will catch my attention.
- Local Participant #3 – Yes. This countermeasure clearly alerts the driver that they have made a mistake. When the lights suddenly flash, they are very bright and illuminate the sign.
- Permanent Participant #5 – (No reply)

Q3. Please rate how effectively this WWD countermeasure warned you of wrong-way driving when it was compared to standard static “WRONG WAY” signs installed at a freeway off-ramp (with 10 being “extremely well” to 0 being “there is no difference”).

- Permanent Participant #1 – (No reply)
- Permanent Participant #2 – Adds a lot compared to standard signs.
- Local Participant #1 – (No reply)
- Local Participant #14 – (No reply)
- Local Participant #2 – It helped illuminate the wrong-way.

- Permanent Participant #3 – (No reply)
- Permanent Participant #4 – (No reply)
- Local Participant #3 – (No reply)
- Permanent Participant #5 – Effective but compared to RRFBs, the intensity can be higher to get more attention.

Q4. Describe how effectively this WWD countermeasure you just experienced warned you of or stopped your wrong-way driving? Please also provide your rating out of 10 (with 10 being "most effective" and 0 being "not effective at all").

- Permanent Participant #1 – The signs and the lights are prominent and clearly visible. They got my attention. It is hard to miss. The street light on top of the "WRONG WAY" sign made the sign visible.
- Permanent Participant #2 – Red flashing lights clearly indicated something was wrong. Message at the center of flashing lights clear, effectively captured attention and conveyed message once attention got there.
- Local Participant #1 – This was effective because of the flashing lights.
- Local Participant #14 – I would give a 10 if the red beacons are triggered every time.
- Local Participant #2 – It is effective in the interpretation of the sign as well as seeing it and such.
- Permanent Participant #3 – Very effective red flasher warns of danger. Loop failure in inside lane prevented triggering lights. Other lanes seemed to work well.
- Permanent Participant #4 – I believe it is very effective to me since this WWD countermeasure sends a clear message.
- Local Participant #3 – I rated the countermeasure a 7 because it is very effective, but the placement of the countermeasure could use improvement. The sign only flashed for about four rounds before I passed it. The signs should be placed closer to the off-ramp exit, so the drivers can be alerted sooner.
- Permanent Participant #5 – Message clear that this is a WWD countermeasure and draws attention of driver.

Q5. Describe the pros and cons of this WWD countermeasure you just experienced as a driver in detail.

- Permanent Participant #1 – Pros: The sign is prominent, could be mistaken for a railway crossing, hard to miss, the red lights are bright, lights turn on well in advance and you have enough time to react. Cons: Cons: The wigwag could be quicker like RRFBs.
- Permanent Participant #2 – Pros: Salient, clear message. Cons: They activate a very narrow part of the road, meaning the signs are really close to vehicle, hard to read. May require head movement, not just eye movement.
- Local Participant #1 – Pros: Illuminating lights alert the driver immediately, effectively communicates to driver of wrong-way driving, and easy on the eyes (steady flashing). Cons: Wigwag beacon is placed within close exiting proximity of off-ramp, and roadway geometry is definitely a large factor in the placement of this device.
- Local Participant #14 – The loops that trigger the red beacons are too close to the lights. The distance may not give enough time for drivers to react.

- Local Participant #2 – Pros: It is effective in understanding you are traveling the wrong direction, although the sign is in a last measure instance. Cons: You have to travel a distance before seeing you are not traveling correctly. In addition, there are some flaws such as the lag and it not kicking in in certain instances.
- Permanent Participant #3 – Pros: Wigwag flash is attention-getting and dynamic. Very strong countermeasure. Cons: Loop detectors failed, caused some non-actuations.
- Permanent Participant #4 – Pros: It clearly sends the wrong-way message to warn drivers. Cons: It seemed not reliable. I drove four times but my vehicle was not detected two of those times. The inside and outside loop detectors may have problems, the intensity of the wig-way flashing beacons is not strong, and the duration is a little shorter.
- Local Participant #3 – Pros: "WRONG WAY" text, flashing light, and radar detection. Cons: Placement too far, had to drive all the way down.
- Permanent Participant #5 – Pros: Dynamic sign, beacons draw attention to "WRONG WAY" sign, and gives enough time upon detection to react. Cons: Intensity can be higher to draw more attention to the warning delivered.

Q6. Please provide any additional feedback you have for this countermeasure.

- Permanent Participant #1 – The "WRONG WAY" sign itself could be more retroreflective.
- Permanent Participant #2 – Wish they were earlier up the ramps and activated a bit earlier. This could give more time to read message and notice the flashing.
- Local Participant #1 – (No reply)
- Local Participant #14 – Static "WRONG WAY" signs on wide off-ramps are not effective. More red reflectors on the ground may be necessary.
- Local Participant #2 – (No reply)
- Permanent Participant #3 – Perhaps we should have this earlier in the sequence. It grabs your attention, and then has the static signs drive home the wrong-way message. Loop reliability is an issue.
- Permanent Participant #4 – This countermeasure should be placed at a location closer to the off-ramp intersection to warn drivers. The current one is placed far from the intersection.
- Local Participant #3 – The countermeasure on the left hand side was hard to see because it was placed at the turning curve, almost in a blind spot.
- Permanent Participant #5 – RRFBs might be superior in capturing the attention of the wrong-way driver. Reminded of everything (danger, stop, railroad crossing)! This is good. Reaction time/detection time, close to exit, reminded of railroad crossing and those with eye conditions are able to read "WRONG WAY" sign; a light away from sign is good. Clear message, measured too far back in the ramp, and can be longer flashing.

Pros and Cons of Selected WWD Countermeasures

Newly-Developed S&PM Standards

Pros

- Pavement markings tell drivers explicitly to go straight instead of turning into the wrong-way (Permanent Participant #1, Permanent Participant #2, Permanent Participant #4, Permanent Participant #5).
  - Very clear and simple message (Permanent Participant #3).
  - Gets the attention of driver to show them the right turn for the on-ramp (Permanent Participant #5).
- Pavement markings are more effective, since there are already too many [static] signs (Permanent Participant #1).
- Are obvious – drivers can't easily miss the pavement markings (Permanent Participant #1)
- Located on arterial, well ahead of off-ramp, where drivers go slow and have an opportunity to correct [their behaviors] (Permanent Participant #1).
- Eliminates doubt for any confused drivers and reinforces what is already known for those who are familiar (Local Participant #1).
- Interstate shield is great as it is a common logo that drivers will immediately recognize (Local Participant #1); the colors are bright and logo is large enough to see from a distance (Local Participant #3).
- Great location, as drivers' eyes tend to focus on the road when driving (Local Participant #1, Local Participant #3).
- Proactive preventive in stopping wrong-way driving (Local Participant #3).
  - Provides positive guidance in direction through use of arrows; It's not just where NOT to go, but where to go. I think this component is sometimes neglected (Permanent Participant #2).
- Cost-efficient (Local Participant #2).
- Very good countermeasure and supplement to standard regulatory signs, but should not act as a replacement (Permanent Participant #3).
- Very good improvement from previous left-turn pavement marking (Permanent Participant #4).
- Great addition to a dynamic WWD countermeasure located on the actual off-ramp (Permanent Participant #5).

Cons

- If driver is confused or not paying attention, can easily miss them (Permanent Participant #1).
- On ground; drivers might miss or overlook (Local Participant #3).
  - If I am driving, my focus to find the correct way to travel will not be on the ground. Generally, I look up and around for some sign as to where I am supposed to turn (Local Participant #2).
- Pavement marking may be blocked if there is a vehicle in front (Permanent Participant #3).
- May not be effective in urban environment where there are too many distractions (Permanent Participant #1).

- Unsure of how effective they will be when markings are worn out or faded (Permanent Participant #1).
- For very impaired/demented drivers, multiple static cues may not have a big effect (Permanent Participant #2).
- No lights (Local Participant #3); may need supplementation of additional illumination, such as pavement reflectors (Local Participant #1).
- Pavement marking/static (Permanent Participant #5).

Additional Comments

- Multiple signs to prevent confusion.
    - The more cues, usually the better. Redundancy is probably an important part of mitigating wrong-way driving (Permanent Participant #2).
    - If possible, we should have one more set of I-275 shield pavement marking and straight arrow (Permanent Participant #4).

Red RRFBs

Pros:

- Prominent, difficult to miss, in red color … frequency of flashing pattern suggests something is "serious and requires attention," while red means "danger" or wrong [way] (Permanent Participant #1, Permanent Participant #3).
    - Red lights meant "emergency," wanting me to turn around (Permanent Participant #5).
- Attention-grabbing (Permanent Participant #1).
    - Flashing was very effective with respect to capturing attention (Permanent Participant #2).
    - Very high intensity of red RRFB (Permanent Participant #4, Local Participant #3, Local Participant #1, Permanent Participant #5); Strong flashing beacons cannot be mistaken and very effective in fully getting the driver's attention (Permanent Participant #5).
- Wrong-way warning is very effective, message is familiar, clear and provided multiple cues that an error was being made (Permanent Participant #4, Permanent Participant #2).
- Picks up movement of vehicle traveling in wrong direction quickly (Local Participant #2).
- Long flashing duration (Permanent Participant #4, Local Participant #3).
- Radar detection (Local Participant #3).
- Familiar with "WRONG WAY" signs (Local Participant #3).

Cons:

- Easy to miss when driving fast and aren't triggered immediately (Permanent Participant #1).
- Flashing may mask the lettering, conveying the meaning of sign. May be especially true for older drivers (Permanent Participant #2).
    - More difficult to see the sign effectively [when compared with Wigwag beacon] (Local Participant #2).
    - Cannot read "WRONG WAY" sign that well (Permanent Participant #4); lights make sign hard to read (Local Participant #3).
    - Very bright, making it harder to read, but the next set of static signs helps clarify (Permanent Participant #5).

- Sensors could activate sooner; however, activation of RRFBs may be dependent on speed of vehicle (Local Participant #1).
- Detection zone can be tweaked to give a longer response time (Permanent Participant #5).

Additional Comments:

- Good setup. Having additional static signs after the RRFB is also really good (Permanent Participant #3).

Red Flush-Mount IIRPMs

Pros:

- Red-colored flashers (Permanent Participant #1).
  - Quite effective compared to just static “WRONG WAY” signs; are effective in telling drivers that something is wrong (Permanent Participant #1).
- Lights draw attention and are better than the [wrong-way] arrow (Local Participant #4).
  - Great at getting drivers’ attention at night (Local Participant #5, Local Participant #7).
  - Very attention grabbing/salient; serves as a good warning that something is amiss (Permanent Participant #2).
  - Gets attention, to some degree (Permanent Participant #4, Permanent Participant #5).
- Very visual at night; three red lines across the ramp form a visual barrier and alternating solid/flash give contrast and help in getting attention (Local Participant #6).
- On the roadway, not off to the side (Permanent Participant #3).
  - Roadway device is right in the driver’s eye, giving maximum effectiveness (Local Participant #6).

Cons:

- Not bright and not very visible because of street lights and other lights (Permanent Participant #1).
  - Roadway lights take a little away from LED’s full effectiveness (Local Participant #5); too much street lightning diminishes their effect (Permanent Participant #5); urban lights may lessen intensity of IIPM’s (Local Participant #6).
  - Not bright enough (Permanent Participant #4).
- They are sparse; could have more flashers in each line (Permanent Participant #1).
- Markers are too far up the ramp (Local Participant #4).
- Message is ambiguous, and doesn’t necessarily convey the message that I should turn around (Permanent Participant #2).
  - Concern – Will all drivers understand it? (Local Participant #6).
  - Not clear enough – May stop me from continuing because something is different, but I am not 100% sure that I know I drove the wrong way” (Permanent Participant #4).
  - Not clear if the blinking red lights are for wrong-way driving (Permanent Participant #5).
- Markers are on all of the time vs. triggered, but not that big of a deal (Permanent Participant #3).
- No impact in daylight conditions (Local Participant #6).

- Does not get wrong-way point across on its own; seemed more of a "take caution" measure, such as in approaching a stop sign or a pedestrian crossing (Local Participant #7).

Additional Comments:

- Supplement these with radar detection dynamic LED light WW signs (Permanent Participant #5 notes).
    - Might work better in conjunction with flashing arrow or flashing signs for earlier warning (Local Participant #4).
- The same LED embedded in an arrow-shaped pavement marker would both capture attention and provide a less ambiguous message (Permanent Participant #2, Local Participant #7).
- Use as supplement (Local Participant #7).
    - Pair with secondary "WRONG WAY" sign (Permanent Participant #5's notes)
    - Should be used as a supplement WITH the standard treatments, and should NOT be considered as a replacement for the standard devices (Permanent Participant #3).
- May consider for all ramps if cost is low (Permanent Participant #3).
- Should be installed in areas with not much lighting, since lighting diminishes their effect (Permanent Participant #5).

Detection-Triggered LED Lights around "WRONG WAY" signs

Pros:

- LEDs, when lit, draw attention to the sign (Permanent Participant #5).
    - Red lights grab attention (Permanent Participant #1, Local Participant #10); seems effective in alerting and grabbing attention (Permanent Participant #2, Permanent Participant #4).
- Worked effectively and caught attention every time (Local Participant #8).
- Accentuate the "WRONG WAY" sign nicely; draws attention to the message (Permanent Participant #3, Permanent Participant #4).
- Accurate to prevent wrong-way-drivers; lights are intense and distance of the signs to the street are accurate or clear to be observed (Local Participant #9).

Cons:

- Will miss the lights if traveling at high speeds (Permanent Participant #1).
    - The driver may pass the sign too soon, before getting the message (Permanent Participant #2).
    - It could work better if the driver had more time to look at the sign so he/she will be able to read it (Local Participant #9).
    - Easily missed if driver was impaired or distracted/not looking for it and accelerating fast (Permanent Participant #3).
- The letters of the sign aren't very visible while the LEDs are flashing (Local Participant #8, Local Participant #10).
    - Text is too dull compared to LED lights (Permanent Participant #1); Letters are hard to read (Local Participant #10).
- Sign should be bigger in size so it's easier to notice; letters should be brighter (Local Participant #9).

    - LEDs can be brighter (Permanent Participant #5).
- Flashing may actually mask the text, specifically in older drivers or individuals with poor vision; may be at a disadvantage (Permanent Participant #2).
- Sensitive to vehicle size (Permanent Participant #3).
- The standard "WRONG WAY" sign and countermeasure are too close to one another (Permanent Participant #4).
- The time from LED flashing to passing to LED "WRONG WAY" sign is too short (Permanent Participant #4).
- Short detection zone may cause driver to miss/not observe the sign (Permanent Participant #5).
    - Faster vehicles will have ~1 second to process all the information the sign is trying to send, which is very hard to achieve (Permanent Participant #5).
- Attention was mostly on the right side only (Local Participant #10).

Additional Comments:

- Suggestion: Have another set of lights a few feet downstream that trigger at the same time as the first set of lights. This ensures that drivers don't miss it. (Permanent Participant #1).
- LED lights on the border of the sign cover the letters "WRONG-WAY" on the sign, basically making the sign useless. With the LEDs off, letters are visible, yet hard to read. (Local Participant #8).
- Would be better if a redundant assembly was further down the ramp (Permanent Participant #3).
- Detection zone needs to be longer for countermeasure to be more effective (Permanent Participant #4).
    - Light should be activated as soon as driver makes right turn in wrong direction (Local Participant #9).

Detection-Triggered Blank-out Signs That Flash "WRONG WAY"

Pros:

- Hard to miss (Permanent Participant #1).
    - Very visible (Permanent Participant #5).
- Worked even if driver is far away from the sign (Permanent Participant #1).
- This is the message that people know. It is easy to process, and harnessed natural reflex to attend to abrupt onset (Permanent Participant #2).
- Dark until needed – surprise factor (Permanent Participant #3).
- Very bright and clear, straightforward and effective – [the combination of] reflectivity of static signs and RPM's were very bright (Local Participant #5, Local Participant #12).
- Illumination is a change from static [signs]; reinforces "wrong-way" messages; should be clear to drivers (Local Participant #6).
- Detects the wrong-way vehicle and shows the message clearly (Permanent Participant #4, Permanent Participant #5).
- Captures attention no matter how fast and where you're looking at (Local Participant #13).

Cons:

- Perhaps a larger sign/font might be necessary for older or impaired drivers (Permanent Participant #2, Local Participant #12, and Local Participant #13).
    - If the sign's message is bigger, it will be much better (Permanent Participant #4).
- One side had been knocked down (Permanent Participant #3).
- Could be brighter (Permanent Participant #3).
- Response time could use a little adjustment to trigger the sign to come on sooner; slower speed seems to effect the response time (Local Participant #5).
    - Already passing the sign by the time I got to read it (Local Participant #11).
    - Slow onset of trigger (Local Participant #12).
- Possibly more effective if placed over the lane (Local Participant #6).
- Calibration of detection – slow/small vehicle issues; slower speeds do not trigger the blank-out wrong-way message (Local Participant #6, Permanent Participant #4, Permanent Participant #5).
    - A few of the trials seemed to have a slow response – maybe came on too late, while one of the trial runs, it didn't come on at all (Local Participant #6, Local Participant #13).
- Sign lights up 2–3 seconds – can be longer (Permanent Participant #5).
- Red circles can be larger (Permanent Participant #5; small circles (Local Participant #12).
- Too far up ramp (Local Participant #12); better to install at sooner/closer point (Local Participant #13).
- If your visual field focused on the center of the road, it might be difficult to catch what it is saying (Local Participant #13).

Additional Comments:

- The combination of treatments with this countermeasure made it most effective: the big overhead "WRONG WAY" sign, the red pavement markers, and the blank-out sign (Permanent Participant #1, Permanent Participant #3).
- When compared to Miami site (Countermeasure 4), flashing did not seem to mask the sign letters (Permanent Participant #2).
- Command-like messages: For example, [a "WRONG WAY" sign, followed by] a "TURN AROUND" sign – this eliminates the extra cognitive step of translating information that something is wrong and into what to do with that knowledge (Permanent Participant #2, Local Participant #12).
- Provide siren if possible to draw attention to sign location (Local Participant #12).
- Mixture of "in-pavement" lights along with the illuminated "WRONG WAY" signs would make it very effective (Local Participant #5).
- Suggested combination: static sign, blank out sign, static sign (Permanent Participant #5).

Delineators along Off-ramps

Pros:

- The "WRONG WAY" sign is after the red strip (Permanent Participant #1).
- Red delineators may provide some warning or get driver's attention (Permanent Participant #4).
    - Some may interpret red reflectors as a means to stop (Permanent Participant #2).
- Cost-effective to install (Local Participant #1, Permanent Participant #5).

- Placement is effective (Local Participant #2).
  - Barriers extend through the entire ramp (Local Participant #3).
- The addition of more red reflectors [on the roadway] (Permanent Participant #3); reflectivity is red (Local Participant #3).

Cons:

- Does not explicitly tell that the driver is driving the wrong-way (Permanent Participant #1).
  - Not an obvious warning if compared to "WRONG WAY" signs (Local Participant #2).
  - Not enough punch to it (Permanent Participant #3).
  - Not a clear warning message (Permanent Participant #4, Permanent Participant #5); no text or message provided (Local Participant #3).
- Red color in the strip is not prominent, is short, and almost looked like [normal roadway] design (Permanent Participant #1).
  - Not very visible and not effective (Permanent Participant #5); hard to see and not alerting (Local Participant #3).
  - Small and minimalistic in appearance, is easy to look over, especially when accelerating quickly up ramp (Local Participant #1).
- Static (Permanent Participant #5).
- Not salient; even if it captures attention, once attention is there, the meaning is absent (Permanent Participant #2).
- Most drivers will likely not stop and the message will not be effective for impaired drivers (Permanent Participant #2).
  - Drunk driver can be focused on front of them, not to the side (Permanent Participant #5).
- An unfamiliar roadway infrastructure may confuse more than inform (Local Participant #1).
- Not effective to use by itself, but if paired in conjunction with more obvious WWD signage, such as flashing signs, it would help to notify the driver (Local Participant #1, Local Participant #3).
- Reflectors on the left side of the ground are not red (Local Participant #14).
- Would be much better on the other side of the ramp (Permanent Participant #3).

Additional Comments:

- Would work better of delineators were also on both sides, as well as more reflectors on the ground, on both sides (Local Participant #14, Permanent Participant #3).
- A light pole blocks part of a "WRONG WAY" sign (Local Participant #14).
- Other devices (edge line RPMs and wrong-way arrows) need maintenance work (Permanent Participant #3).

Wigwag Flashing Beacons

Pros:

- The sign is prominent and hard to miss (Permanent Participant #1).
  - Effective in understanding you are traveling in wrong direction (Local Participant #2).
- The red lights are bright (Permanent Participant #1).
  - Illuminating lights alert the driver immediately (Local Participant #1).

- Wigwag flash is attention-getting and dynamic; very strong countermeasure (Permanent Participant #3).
  - Dynamic sign; beacons draw attention to "WRONG WAY" sign (Permanent Participant #5).
- Gives enough time upon detection to react (Permanent Participant #5).
- Clearly sends the wrong-way message to warn drivers (Permanent Participant #4).
- Steady flashing pattern is easy on the eyes (Local Participant #1).
  - Those with eye conditions will be able to read the "WRONG WAY" sign [easier]; lights [further] away from sign is good (Permanent Participant #5 notes).
- Lights turn on well in advance, giving you enough time to react (Permanent Participant #1).
- Could be mistaken for railway crossing (Permanent Participant #1).
  - Driver can be reminded of danger, stop, RR crossing – this is good (Permanent Participant #5 notes).
- Salient, clear message; effectively captured attention and conveyed message (Permanent Participant #2, Local Participant #1).
- Wrong-way text, flashing light, radar detection (Local Participant #3).

Cons:

- The wigwag flashing could be quicker, like RRFBs (Permanent Participant #1).
- The "WRONG WAY" sign itself could be more retro-reflective (Permanent Participant #1).
- They activate at a very narrow part of the road, meaning the signs are really close to vehicle, making it hard to read (Permanent Participant #2).
- May require head movement, not just eye movement (Permanent Participant #2).
- Wigwag beacon is placed within close exiting proximity of off-ramp; countermeasure is very close to the interstate exit (Local Participant #1, Local Participant #3).
  - Driver has to travel a distance before seeing that he/she isn't traveling correctly (Local Participant #2, Local Participant #3).
- Roadway geometry (off-ramp is curved and at an incline) plays a large factor in the placement of this device (Local Participant #1).
  - Countermeasure on the left hand side was hard to see because it was placed at the turning curve (Local Participant #3).
- Loops that trigger the red beacons are too close to the lights; distance may not give enough time for drivers to react (Local Participant #14).
- Loop detectors failed, causing some non-actuations (Permanent Participant #3).
  - Some flaws present: lag in activation time and/or not activating at all (Local Participant #2).
  - Did not seem reliable; drove four times but vehicle was only detected twice. Inside and outside look detectors may have problems (Permanent Participant #4).
- Intensity of wigwag flashing beacon is not strong (Permanent Participant #4).
- Current duration is a little shorter (Permanent Participant #4); can be longer flashing (Permanent Participant #5 notes).
- Intensity can be higher to draw more attention to the warning delivered (Permanent Participant #5).

Additional Comments:

- Wish they were closer towards the entrance of the ramps and activated a bit earlier, giving more time to read the message and notice the flashing (Permanent Participant #2).
    - Perhaps have countermeasure earlier in the sequence; it grabs your attention, and then has the static signs to remind the wrong-way message (Permanent Participant #3).
    - Should be placed at location closer to the off-ramp intersection to warn drivers. The current one is placed far from the intersection (Permanent Participant #4).
- Static "WRONG WAY" signs on wide off-ramps are not effective – they do not reflect much light—so more reflectors on the ground may be necessary (Local Participant #14).

APPENDIX C –
Public Opinion Survey

Public Opinion Survey

1. For the signing and pavement marking countermeasure in Figure 2 below (Countermeasure #1), to what degree does this countermeasure improve upon the previous condition to warn or prevent wrong-way driving? (Please circle your answer)

	
Figure 1. Previous condition.	Figure 2. Current condition.

   a. Significant improvement
   b. Moderate improvement
   c. Minor improvement

Please continue on next page →

2. Please rank the effectiveness of the following four countermeasures at off-ramps from the most effective to the least effective where 1: Most effective, 2: the 2nd most effective, 3: the 3rd most effective, and 4: the least effective.

Countermeasure #2

Countermeasure #4

Countermeasure #5

Countermeasure #7

3. Please compare Countermeasure #3 and Countermeasure #5 below. Which do you think is more effective? Please circle your choice.


a. Countermeasure #3


b. Countermeasure #6

4. A. Of your choice from question 2 and question 3, which is more effective?
a) Choice from question 2
b) Choice from question 3

B. Do you think it would be beneficial to supplement your choices from question 2 and question 3 together?
a) Yes
b) No

If your answer is No, please skip 4C.

C. If yes, to what degree will the supplementation have on overall effectiveness?

a) Significant improvement

b) Moderate improvement

c) Minor improvement

5. Please rank the effectiveness of all six countermeasures from the most effective to the least effective where 1: most effective, 2: the 2nd most effective, 3: the 3rd most effective, 4: the 4th more effective, 5: the 5th most effective, and 6: the least effective.

☐  Countermeasure #2	☐  Countermeasure #4
☐  Countermeasure #5	☐  Countermeasure #7
☐  Countermeasure #3	☐  Countermeasure #6

Please continue on next page →

Participant's Demographics (Please circle your choice)

City/State: ___________________

Gender:
a) Male
b) Female

Age:
a) 16-29
b) 30-59
c) 60+

Race:
a) African American
b) Asian
c) Caucasian
d) Latina/o
e) Other

APPENDIX D –
Detailed Survey Results

Table D-1. Question 1

Question 1 Answer	Total
Minor improvement	33
Moderate improvement	68
Significant improvement	145
(blank)	4
Grand Total	**250**

Table D-2.1. Question 2

Countermeasure #2

Rank	Total
1	80
2	67
3	54
4	45
(blank)	4
Grand Total	**250**

Table D-2.2. Question 2

Countermeasure #4

Rank	Total
1	55
2	59
3	69
4	59
(blank)	8
Grand Total	**250**

Table D-2.3. Question 2

Countermeasure #5

Rank	Total
1	36
2	53
3	81
4	73
(blank)	7
Grand Total	**250**

Table D-2.4. Question 2

Countermeasure #7

Rank	Total
1	79
2	63
3	37
4	64
(blank)	7
Grand Total	**250**

Table D-3. Question 3

Question 3 Answer	Total
Countermeasure #3	175
Countermeasure #6	62
(blank)	13
Grand Total	**250**

Table D-4.1. Question 4A

Question 4A Answer	Total
Choice from question 2	177
Choice from question 3	63
(blank)	10
Grand Total	**250**

Table D-4.2 Question 4B

Question 4B Answer	Total
No	25
Yes	218
(blank)	7
Grand Total	**250**

Table D-4.3 Question 4C

Question 4C Answer	Total
Minor improvement	6
Moderate improvement	51
Significant improvement	159
(blank)	34
Grand Total	**250**

Table D-5.1. Question 5

Countermeasure #2

Rank	Total
1	63
2	50
3	49
4	43
5	24
6	11
(blank)	10
Grand Total	**250**

Table D-5.2. Question 5

Countermeasure #5

Rank	Total
1	24
2	49
3	62
4	63
5	30
6	13
(blank)	9
Grand Total	**250**

Table D-5.3. Question 5

Countermeasure #3

Rank	Total
1	28
2	29
3	23
4	25
5	89
6	46
(blank)	10
Grand Total	**250**

Table D-5.4. Question 5

Countermeasure #4

Rank	Total
1	51
2	47
3	60
4	51
5	21
6	10
(blank)	10
Grand Total	**250**

Table D-5.5. Question 5

Countermeasure #7

Rank	Total
1	67
2	50
3	32
4	45
5	32
6	13
(blank)	11
Grand Total	**250**

Table D-5.6. Question 5

Countermeasure #6

Rank	Total
1	9
2	15
3	13
4	12
5	42
6	149
(blank)	10
Grand Total	**250**

Table D-6. City and State

City and State of Participant	Total
Balbino, Rio	1
Brandon, FL	8
Clearwater, FL	2
Crystal River, FL	1
Davenport, FL	1
Daytona Beach, FL	1
Detroit, MI	1
Dunedin, FL	2
Ecuador	1
Florida	4
Ft. Lauderdale, FL	1
Gibsonton, FL	1
Land O' Lakes, FL	4
Lutz, FL	10
Miami, FL	4
Miramar	1
Naples, FL	2
New Port Richey, FL	3
North Carolina	1
Norway	1
Odessa, FL	1
Orlando, FL	3
Palm Beach, FL	1
Palm Harbor, FL	1
Parkland, FL	1
Plant City, FL	1
Riverview, FL	5
Ruskin, FL	1
San Antonio, FL	1
Sarasota, FL	1
Seminole, FL	1
Spring Hill, FL	1
St. Petersburg, FL	2
Tampa, FL	156
Tarpon Springs, FL	1
Temple Terrace, FL	5
Thonotosassa, FL	2
Trinity, FL	1
Valrico, FL	1
Wesley Chapel, FL	13
Zephyrhills, FL	1
Grand Total	**250**

Table D-7. Gender

Gender of participant	Total
Female	127
Male	123
Grand Total	**250**

Table D-8. Age

Age of participant	Total
16-29	83
30-59	84
60 and over	83
Grand Total	**250**

Table D-9. Race

Race of participant	Total
African American	43
Asian	21
Caucasian	114
Latina/o	50
Other	15
(blank)	7
Grand Total	**250**

APPENDIX E –
Human Factors Study of Wrong-Way Countermeasures

ABSTRACT
Although infrequent, when wrong-way crashes (WWCs) do occur, they are much more deadly, compared to other types of highway crashes. Two approaches must be taken to reduce WWCs. First, the area around off-ramps must provide the perceptual cues necessary for drivers to distinguish them from entrance ramps. However, due to confusion, inattention, or impairment, some drivers may still make wrong-way entries (WWEs) and enter an off-ramp in spite of multiple salient cues. The second required approach is to alert drivers when a WWE has occurred (i.e., warn them that they are currently on an off-ramp) and discourage them from continuing forward. This requires salient, attention-grabbing cues for alerting purposes and a clear message to convey the nature of the error once attention has been captured.

Herein, we report evidence related to the effectiveness of countermeasures to mitigate WWEs and also to mitigate continued driving on an off-ramp once a WWE has occurred. We reviewed two previously-completed driving simulator studies funded by FDOT and the Center for Accessibility and Safety for an Aging Population (ASAP) that demonstrate that increased arterial countermeasures (including highway pavement shield markings and changes to lane markers) can reduce confusion regarding appropriate highway entrance points. We then report two new studies that placed drivers (within a simulation) on a ramp and asked them to proceed forward until they felt unsafe. As they drove, participants either encountered static or dynamic "WRONG WAY" signs flanking the ramp.

Dynamic signs featured flashing elements to capture attention. Drivers reported that dynamic signs were effective at alerting them of WWD and more effective than static "WRONG WAY" signs. However, in both studies, driver behavior did not differ as a function of whether the sign was static or dynamic with one exception: the blank-out "WRONG WAY" sign was much *less* effective at slowing/stopping drivers. This is likely due to the sign providing no advanced warning or information until it is triggered by a wrong-way driver. For all other conditions (including the standard static "WRONG WAY" sign), drivers either stopped before or shortly after the "WRONG WAY" sign.

The current data, considered in conjunction with our proposed model of WWCs and guidelines of good human factors, cause us to reach the following recommendations: **1) Arterial wrong-way countermeasures should be implemented to reduce confusion regarding highway entry points.** These countermeasures include forward rather than left-turn pavement arrows in advance of an off-ramp, highway pavement shields, larger and additional signage around off-ramps, and the addition of a "NO LEFT TURN" sign in advance of off-ramps. **2) The implementation of dynamic "WRONG WAY" signs should be considered to mitigate WWCs.** A great deal of attention research suggests that dynamic/flashing elements effectively capture attention. However, these dynamic cues should be implemented around a Wrong-Way message that is continuously present. **3) "WRONG-WAY" blank-out signs that onset only when a driver is approaching may not effectively warn drivers in time that they are going the wrong-way and are not recommended.**

1. INTRODUCTION

Although crashes caused by WWD represent only between 1% and 3% of all crashes on high-speed divided highways (NTSB, 2012), WWD crashes have been estimated to have a fatality rate 12 (Copelan, 1989) to as much as 27 times (Vaswani, 1973) that of other types of highway crashes. Research on wrong-way crashes in the United States has spanned over 50 years and has yielded information about the characteristics of wrong-way movements and crashes, the characteristics of drivers involved in wrong-way crashes, and the effectiveness of countermeasures designed to mitigate or correct wrong-way movements. Several broad and consistent conclusions about wrong-way drivers and crashes can be drawn from this large and expanding body of past work. First, driver impairment is consistently identified as a major contributing factor. Studies of crash records report that alcohol-impaired drivers account for between 50 and 70 percent of wrong-way-crash-involved drivers (Copelan, 1989; Lew, 1971; Scifres & Loutzenheiser, 1975; Tamburri & Theobald, 1965; Vaswani, 1977a, 1977b; Zhou et al., 2012; Zhou et al., 2014), which is higher than the rate of reported alcohol involvement across all fatal crashes (NHTSA, 2015). Second, older drivers, particularly those over age 70, are significantly overrepresented among wrong-way drivers relative to their numbers in the general population of licensed drivers (e.g. Braam, 2006; Scaramuzza & Cavegn, 2007; Tamburri & Theobald, 1965). Third, clear and conspicuous signs and pavement markings at freeway interchanges have been effective in reducing driver uncertainty and confusion, leading to a reduction in wrong-way entries at interchanges (e.g., Copelan, 1989; Tamburri & Theobald, 1965; Rinde, 1978).

Taken together, the common findings from WWD studies point to a multifaceted approach as the most effective strategy for addressing the problem of WWD: addressing the conditions that give rise to wrong-way driving incidents and developing better systems for reacting to wrong-way drivers when incidents do occur. Nationwide, significant progress has been made in reducing the incidence of alcohol-impaired driving over the past several decades through the combined effect of reducing the legal blood alcohol limit, administrative license suspension laws, harsher penalties for underage drinking, and increased public awareness of the problem of alcohol-impaired driving (e.g., Rogers & Shoenig, 1994; Wagenaar & Maldonado-Molina, 2007). Efforts are underway nationwide to educate aging drivers about the effects of age-related changes in vision and cognitive ability on driving performance, as well as to develop better means of predicting which older drivers can continue to drive safety and which should no longer be licensed. Finally, improvements to highway signs at and around interchanges have led some researchers to conclude that wrong-way driving by unimpaired drivers due to confusion alone has been effectively eliminated (Copelan, 1989).

Despite the progress that has been made, the incidence of wrong-way crashes has remained relatively stable, accounting for around 3% of all fatal crashes on divided highways each year (NTSB, 2012). This suggests that further progress requires refinement of existing WWD countermeasures and the development of new countermeasure strategies. Because interchanges are estimated to be the wrong-way entry point in about half of all wrong-way driving incidents on controlled-access divided highways, improvements to signs, pavement markings, and road geometry at highway entrance and off-ramps have been a common target for interventions (e.g., Parsonson & Marks, 1979; Rinde, 1978).

When existing countermeasures fail to deter a wrong-way freeway ramp entry, the next priority should be alerting the wrong-way driver to his/her error. However, given that a wrong-way driver is many times more likely than other drivers to be impaired, either due to consumption of an impairing substance or a medical condition, the challenge of designing countermeasures that quickly and clearly communicate their message without the risk of causing further confusion requires consideration of the capabilities of the impaired driver. What sensory and cognitive abilities are most likely to be impaired and to what degree? What features of a sign or other countermeasure are most likely to be salient and effectively capture the attention of an impaired driver?

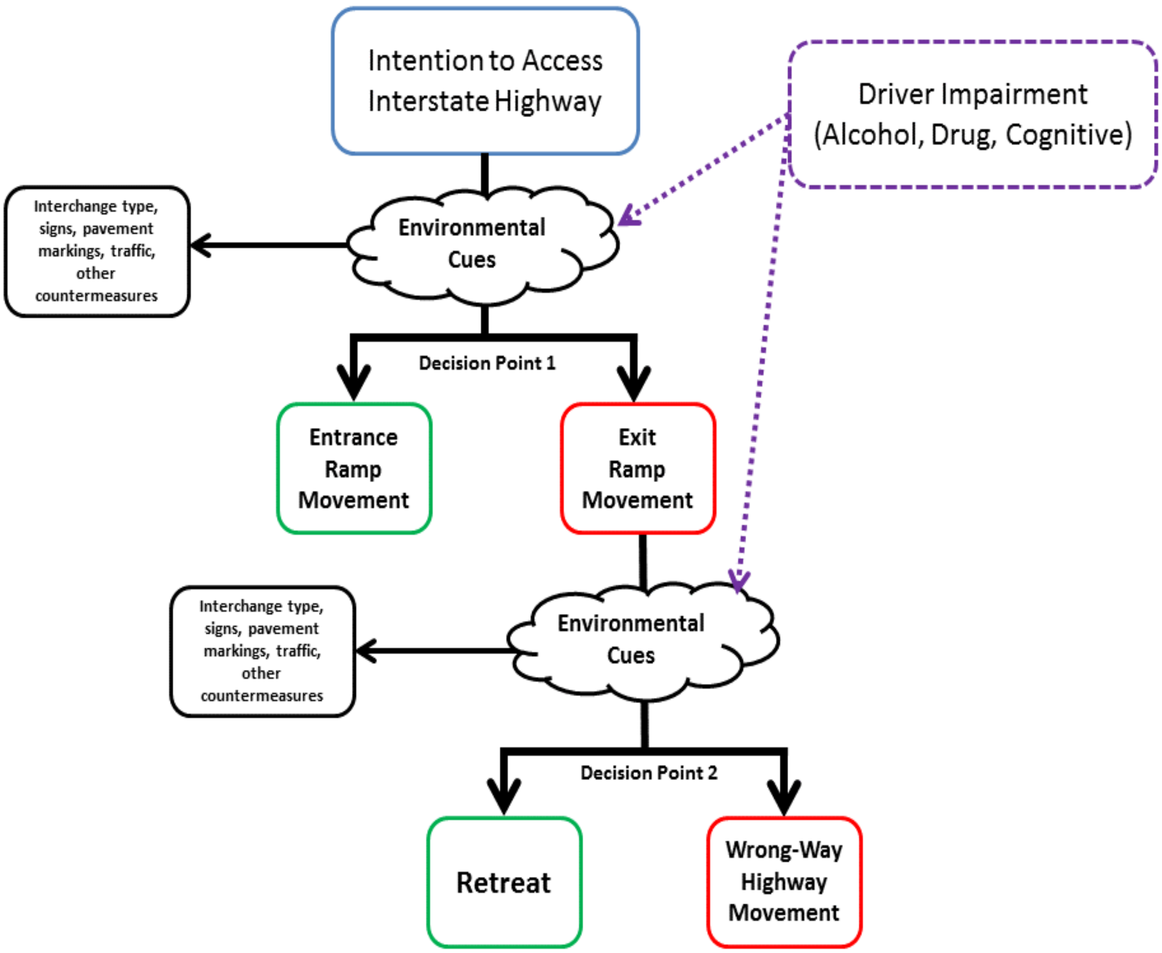

Figure E.1.1. Cue-based decision model.
Previous projects focused on first decision point in model, current project focuses on second.

Cue-decision Framework of Wrong-Way Entries and Crashes
The perspective we take frames drivers' decisions to enter the interstate at a given point as a cue-based decision. Road geometry, pavement markings, guide or warning signs, and the behavior of other traffic are all cues that drivers may consider when deciding which of available entry points is the correct one, and these cues may differ in their salience and informational value. For example, while seeing a yellow edge line on the right side of the road and a white edge line on the left would signal that one is driving

the wrong-way on an interstate ramp, this cue is likely less salient than a bright, retroreflective pavement marking showing an arrow pointing in the opposite direction. A cue-based approach allows for a flexible, generalizable way to categorize features of interchanges associated with a high risk of wrong-way entries and categorize features of current and proposed countermeasures.

Our framework also considers how characteristics of individual drivers, including impaired drivers, may interact with the cue environment. Impairment affects drivers' ability to make inferences based on the information around them, meaning that countermeasures effective in communicating their message to non-impaired drivers may not be effective for impaired drivers, potentially even increasing their confusion. One benefit of our cue-based approach is that it provides a framework for making predictions about which countermeasures are likely to be effective in reaching not only the typical unimpaired driver, but also the impaired or disoriented driver. In this report, we evaluate countermeasures designed to intervene before a driver has entered an off-ramp (Decision Point 1) and after a driver is already driving the wrong-way on an off-ramp (Decision Point 2).

Abrupt Onsets

Once a driver has entered an off-ramp, it is crucial to alert the driver an error has been made and draw their attention to a message that will explain the nature of the error. Countermeasures of interest studied here have been rated by human factors researchers, as part of the overall FDOT project, as the most likely to capture attention and be effective at conveying the appropriate message. Each is a variant of the standard "WRONG WAY" sign (MUTCD R5-1a). One features red beacons that flash in a wigwag pattern, one is supplemented by red rectangular rapid flash beacons (RRFBs), one features flashing LEDs around the border of the sign, and one is a blank-out sign that appears suddenly once triggered. These countermeasures aim to take advantage of the unique sensitivity of the human visual system to abrupt luminance onsets (e.g., Boot et al., 2005; Schreij et al., 2008; Theeuwes et al.,1998). These studies find that abrupt onsets have a high probability of capturing attention and drawing the eyes. Many studies have also found that the capture of attention by abrupt onsets is automatic and involuntary, and that abrupt onsets can override volitional control of attention.

Report Overview

This report contains data and recommendations based on driving simulator studies that have explored countermeasures to help drivers make better decisions at Decision Point 1 and Decision Point 2 of the proposed model (Figure E.1.1). The first two experiments have been previously funded by the Florida Department of Transportation and the Center for Accessibility and Safety for an Aging Population (ASAP). These studies tested the effect of arterial countermeasures with the aim of reducing Wrong-Way Entries and reducing confusion regarding appropriate highway entry points. The current report also includes the results of two new simulator studies conducted at Florida State University for the current project. Within the driving simulator, participants were positioned on a roadway which was ambiguous as to whether this section of roadway represented an exit or entrance ramp. Participants were instructed to drive forward, but to stop their vehicle if at any point, they felt the driving situation was unsafe. During this drive, participants either encountered a standard static "WRONG WAY" sign (MUTCD R5-1a) or "WRONG WAY" signs that featured abrupt luminance onsets ("WRONG WAY" RRFB, "WRONG WAY" Wigwag, "WRONG WAY" LED, "WRONG WAY" blank-out). It was predicted that these dynamic signs would provide an advantage over the standard static sign and that participants would be more likely to brake in response to them and brake further in advance of the sign. Participants also rated the effectiveness of dynamic signs with respect to alerting them and discouraging wrong-way driving, and rated these signs in comparison to standard signs.

2. DECISION POINT 1

Two recently-completed experiments provide evidence that increased arterial countermeasures can reduce confusion regarding correct highway entry points. Full reports of these studies can be found elsewhere (Boot et al., 2015; Boot et al., 2016). In both of these studies, drivers were given directions to get onto the highway using an entrance ramp on the left. To reach this ramp, they had to pass an off-ramp on the left, and the countermeasures around this off-ramp were manipulated. In one condition, the minimum signs and pavement markings recommended by the MUTCD were implemented. In the second condition, enhanced countermeasures were implemented. The most salient changes were pavement shields in the left-turn lanes in advance of the off-ramp indicating the highway number with forward arrows (instead of left-turn arrows). These conditions are depicted in Figures E.2.1 and E.2.2.

Figure E.2.1. Driving Simulator Scenario in Standard Countermeasure Condition, with Off-Ramp on Left

Figure E.2.3. Driving Simulator Scenario in Enhanced Countermeasure Condition, with Off-Ramp on Left

In the first study, younger and older drivers participated (with older drivers driving daytime scenarios and younger drivers driving nighttime scenarios, consistent with when WWCs tend to occur for each age group). Half of the younger group also participated under conditions of simulated impairment in which their vision was distorted and their cognitive resources were depleted with a secondary task. In total, this study included 120 participants. Overall, fewer WWEs occurred in the enhanced countermeasure condition compared to the standard countermeasure condition (0 vs. 4, $p = .06$). In general, WWEs were rare, but the driving simulator offers the opportunity to explore more subtle measures of driver confusion. For example, a driver considering entering an off-ramp will likely slow in advance of the ramp in anticipation of making a turn. In advance of the off-ramp participants reached lower minimum speeds in the standard condition compared to the enhanced condition ($M = 31$ vs. 36 MPH, $p < .01$). This provides behavioral evidence for confusion. Lane deviation and braking profile were also consistent with less confusion in the enhanced condition. In a separate study, only older adults were tested. A total of 30 participants experienced the standard condition, and 30 experienced the enhanced condition. In this case, there was little statistical support for enhanced countermeasures to reduce WWEs (1 in the enhanced condition, 0 in the standard), but a similar pattern was observed with respect to speed in advance of the off-ramp. In advance of the off-ramp participants reached lower minimum speeds in the standard condition compared to the enhanced condition ($M = 20$ vs. 28 MPH, $p < .05$). Both experiments provide support for the fact that arterial countermeasures can reduce confusion regarding highway entry points, and the implementation of these countermeasures is recommended.

3. RAMP STUDY 1

This simulator study exposed participants to “WRONG WAY” signs that were either static (standard) or dynamic (included flashing elements). Of primary interest is whether participants stop/slow earlier for dynamic signs compared to standard signs, and if so, whether one dynamic sign is more effective than others.

Participants
A total of 120 participants (M_{Age} = 20, SD_{Age} = 3.05), undergraduate students from FSU completed the experiment. All reported holding a valid driver's license. In total, 63 participated for course credit and 57 participated for a payment of $15/hour. Five reports of mild simulator sickness were provided during the task (slight discomfort, e.g. dizziness), and as a result, these participants were excluded from analyses. One software error, one experimenter error, and two participants not following instructions resulted in all analyses including a total of 111 participants unless otherwise noted.

Materials

Driving Simulator
A NADS MiniSim high-fidelity driving simulator developed by the National Advanced Driving Simulator lab at the University of Iowa was used for the study (Figure E.3.1). The NADS MiniSim incorporates a dashboard with a virtual instrument cluster, steering wheel, accelerator and brake pedals, and three 42-in. displays that gives the driver a 180° horizontal and 50° vertical field of view of the simulated environment. Each display has a resolution of 1360 x 768 pixels and a refresh rate of 60 Hz.

Figure E.3.1. NADS MiniSim Driving Simulator Setup at FSU's Psychology Department
Countermeasure "WRONG WAY" blank-out depicted on screen.

Simulated Highway Off-Ramp (from the Perspective of a Wrong-Way Driver)
A simulated environment modeled after a highway off-ramp (Figure E.3.2), as well as countermeasures "WRONG WAY" RRFB, "WRONG WAY" wigwag, "WRONG WAY" LED, "WRONG WAY" blank-out, and the standard "WRONG WAY" sign—MUTCD R5-1a (Figures E.3.3, E.3.4, E.3.5, E.3.6, and E.3.7, respectively) were created by the University of Iowa to be driven in the NADS MiniSim. A nighttime scenario was developed given the preponderance of WWCs occurring late at night/early morning. To isolate the effect

of particular countermeasures, this section of roadway was designed to provide no cues other than signage that a driver might be driving the wrong-way (e.g., for a typical ramp, if the outer lane marking on the right is yellow, this would signify that the driver is going the wrong-way on an off-ramp).

Figure E.3.2. Simulated Environment as Seen from Start of Drive
No countermeasures visible at this point.

Figure E.3.3. Depiction of Countermeasure "WRONG WAY" RRFB

Figure E.3.4. Depiction of Countermeasure “WRONG WAY” Wigwag

Figure E.3.5. Depiction of Countermeasure “WRONG WAY” LED

Figure E.3.6. Depiction of Countermeasure “WRONG WAY” Blank-out

Figure E.3.7. Depiction of Standard MUTCD R5-1a “WRONG WAY” Sign

Within the simulated environment at 9,000 feet from the start of the drive participants unexpectedly encountered a “WRONG WAY” sign and the type of sign was experimentally manipulated (four dynamic and one standard).

The dynamic signs varied in the number and size of their lighted beacons, and in the frequency of their flash. Countermeasure “WRONG WAY” RRFB flashed at a rate of 25 ms in the pattern shown in Figure E.3.8, and countermeasure “WRONG WAY” wigwag flashed at a rate of 250 ms in the pattern shown in Figure E.3.9. Countermeasure “WRONG WAY” LED flashed at a rate of 430 ms, as did the countermeasure “WRONG WAY” blank-out (Figures E.3.10 and E.3.11). Timings and flash sequences were derived from videos taken of these countermeasures in the field.

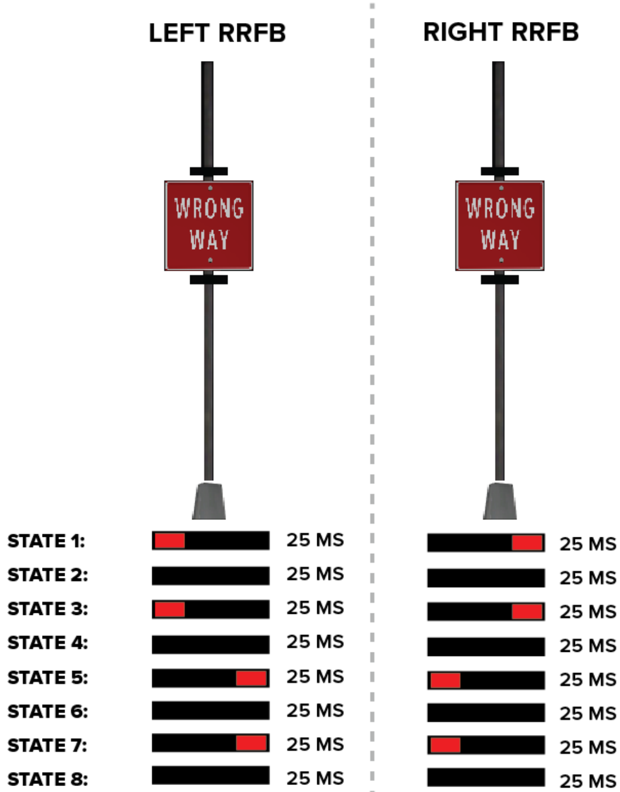

Figure E.3.8. Depiction of Flash Pattern for Countermeasure "WRONG WAY" RRFB

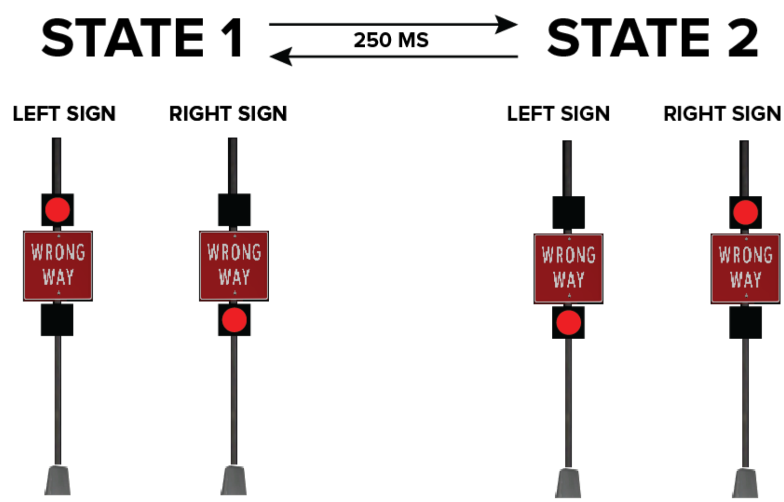

Figure E.3.9. Depiction of Flash Pattern for Countermeasure "WRONG WAY" Wigwag

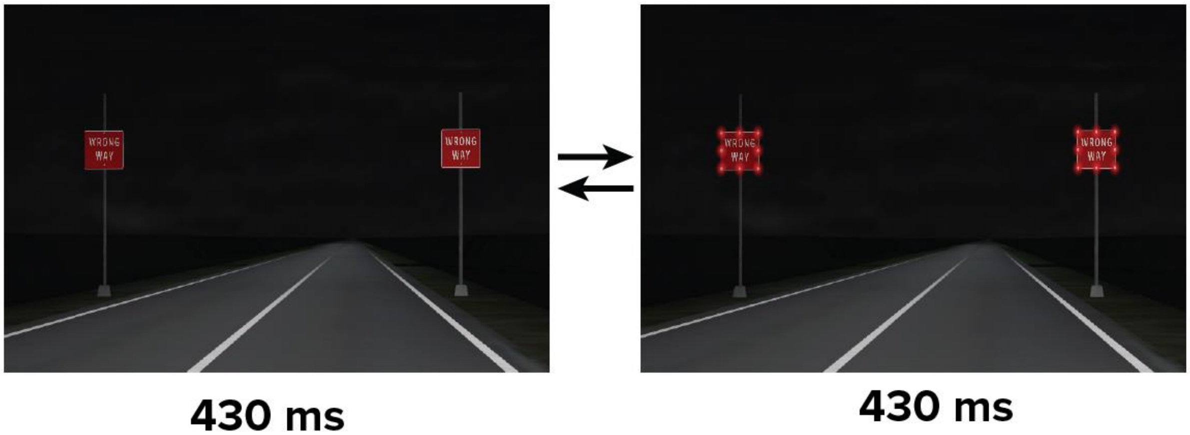

Figure E.3.10. Depiction of Flash Pattern for Countermeasure "WRONG WAY" LED

Figure E.3.11. Depiction of Flash Pattern for Countermeasure "WRONG WAY" Blank-out

To trigger flashing responses in the countermeasures in a fashion reminiscent to how these signals are activated in the field, location triggers were placed in the simulated environment, 200 feet before each sign. Once participants passed this trigger the dynamic signs began to flash.

Driver reaction to this first countermeasure was of primary interest. However, at 9,000 feet past this first dynamic signal, a standard "WRONG WAY" sign was shown. Two thousand feet past this second countermeasure, the scenario terminated. Participants who viewed a dynamic sign were later given a survey regarding their perceived effectiveness of this sign at alerting them to their wrong-way driving. The static sign at the end of the scenario served as a way for participants to compare the dynamic sign they encountered to a more typical static sign.

Procedure

Practice Task

Participants first completed a practice task within the same simulated environment of the experimental task for familiarization with the sensations of driving in a simulated environment, as well as to acclimate to the brake and gas pedals, and the sensitivity of the steering wheel. In this practice task, participants were instructed to drive until they saw a set of barricades on the left, then come to a complete stop and place the vehicle into park. After doing this the first time, participants were told by an experimenter to repeat this process at the next set of barricades. After the second stop, the practice task was terminated.

Experimental Task

Participants were assigned to one of five scenarios in which the first sign encountered varied (e.g., "WRONG WAY" LED, "WRONG WAY" wigwag, "WRONG WAY" blank-out, "WRONG WAY" RRFB, "WRONG WAY" standard). The second sign encountered by all participants who received a dynamic sign first was the standard "WRONG WAY" sign—MUTCD R5-1a; those who received the standard sign first did not receive a second sign.

At the start of the experiment, the lights were shut off, and the following instructions were given:

> Your goal in this task is to drive on the highway until the scenario terminates -you'll see a black screen and it will return to this screensaver, but at any moment if the road conditions seem unsafe, we ask that you come to a complete stop, and place the vehicle in park, just as you did in the practice. At that point if you could ring the bell, I will return with further instructions. We ask that you maintain a speed of 40 mph. If your speed reaches 45 mph, a police siren will go off to alert you.

If participants reported feeling unsafe, they received the following instructions:

> We now ask that you continue down the highway, but if at any point you notice that the road conditions seem unsafe, please come to a complete stop again and place the vehicle in park as you have just done. The scenario will terminate automatically when the task is complete. Please place the vehicle back in drive (using the paddle shifters) once I have closed this door.

Upon completion of the scenario, participants completed a Qualtrics demographics survey.

RESULTS

Of primary interest is whether participants stopped in response to the first countermeasure they encountered, and if so, when and where they stopped.

Responses by Area of Interest

An effective wrong-way countermeasure sign would cause a driver to slow or stop and turn around in advance of the sign, and in this task participants were instructed to stop the vehicle at the first sign that they felt they were in an unsafe situation. Thus, we compared slowing/stopping behaviors across the different countermeasure conditions.

It became clear in our data analysis that responses to the blank-out sign were very different compared to the other dynamic signs, and that the dynamic signs excluding the blank-out sign (RRFB, LED, wigwag) all produced similar behaviors. So, in many of our analyses, we collapsed across the dynamic sign conditions excluding the blank-out sign. These analyses present the categories of Standard, Dynamic (excluding Blank-out) and Blank-out.

To quantify differences in slowing to the sign, we created three areas of interest (AOIs): (1) one before the flashing began in the dynamic signs conditions, (2) an area after the onset of the trigger that activated dynamic signs, and (3) an area after the location of the sign (up to 100 ft after). These same AOIs were used for the standard sign condition. In our first analysis, we calculated at what point during these three AOIs the participant reached his or her minimum speed to assess slowing in response to the sign (i.e., minimum speed was considered a response and we analyzed when this response occurred relative to the sign for each condition). Figure E.3.12 represents these data.

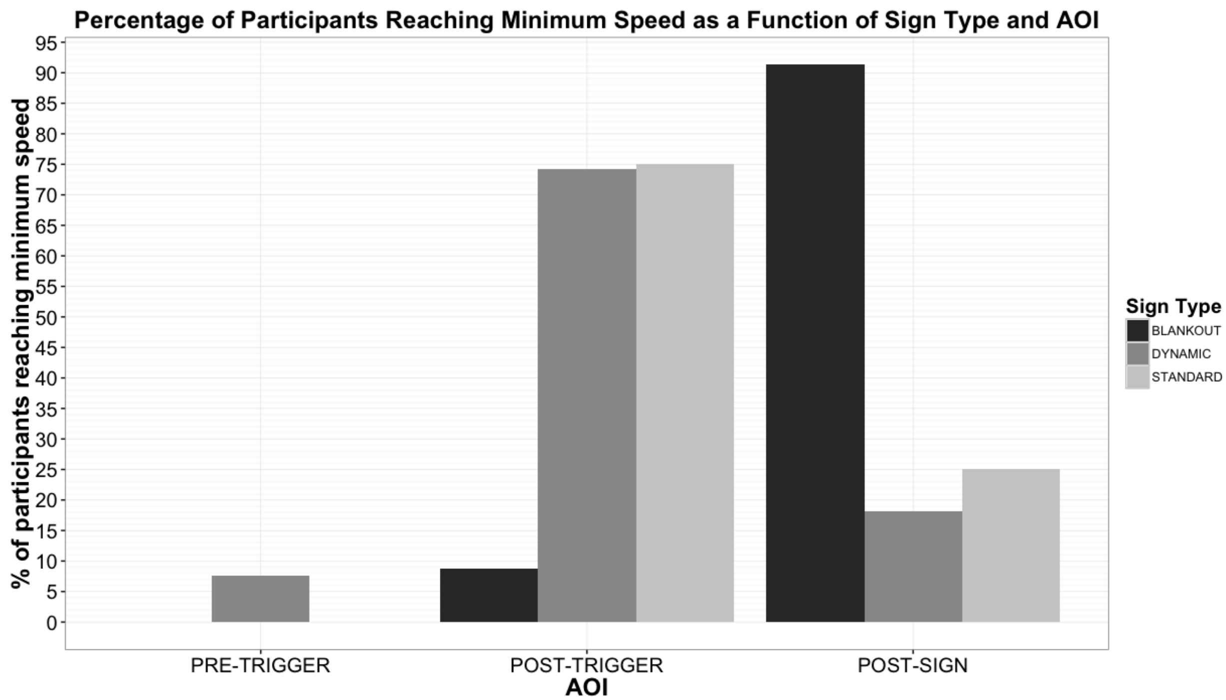

Figure E.3.12. Percentage of Participants Reaching Minimum Speed as a Function of Sign Type and Area of Interest

Overall, all signs yielded comparable percentages of participants responding as a function of area of interest, with one notable exception: many participants did not reach their minimum speed in response to the Blank-out sign until after they had passed it. For the other dynamic signs and the standard sign, most participants responded in advance of the sign.

We can also evaluate the efficacy of each sign by plotting survival curves depicting the proportion of participants in each group who were still driving (i.e., had not stopped or turned around) at each point in the scenario. Figure E.3.13 represents this analysis (removing those who stopped well in advance of the trigger locations).

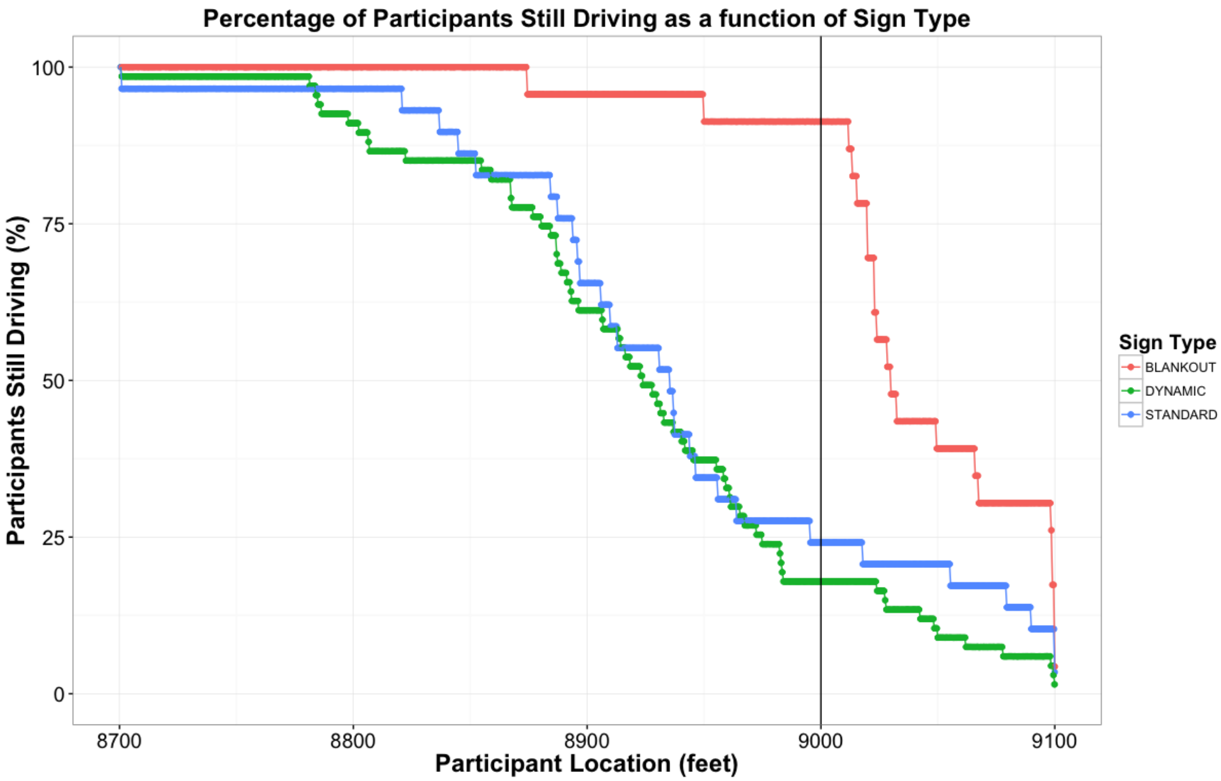

Figure E.3.13. Survival Curve Analysis of Participants Still Driving, as Function of Sign Type and Location in Simulated Environment. ***Vertical line displayed at 9000 ft indicates location of countermeasure.***

It is clear from this analysis that dynamic countermeasures (not including the blank-out sign) and the standard static sign were equally effective. A Fisher's Exact Test conducted on the proportion of participants who stopped before vs. past the countermeasure revealed no advantage with respect to stopping behavior (*p = .575; see Table E.3.1*).

Table E.3.1. Number of Participants who Discontinued Driving Forward in Area before Countermeasure and 100 ft Past Countermeasure

	Pre-Countermeasure	Post-Countermeasure	Total
Blank-out sign	2 (9%)	21 (91%)	23
Standard sign	21 (75%)	7 (25%)	28
Dynamic signs (LED, RRFB, Wigwag)	54 (82%)	12 (18%)	66

To compare stopping behavior between the blank-out sign and standard sign, a Fisher's Exact Test was conducted on the proportion of participants who stopped before vs. past the countermeasure. This revealed an advantage for the standard sign ($p < .001$). There was also an advantage for the other dynamic signs compared to the blank-out sign ($p < .001$). In sum, data suggest that the static and dynamic signs were equally effective, but that the blank-out sign was overall less effective.

Response Distance (to Complete Stop)

Participants were asked to come to a complete stop whenever they felt unsafe. For the purposes of this analysis, we were interested in exploring how many feet (beginning 300 ft before the sign location) it takes for a participant to come to a speed of less than 1 mph (Table E.3.2). Higher values represent less of an impact of the sign. Note that this may not capture participants who discontinued by turning around without stopping. Using a two-tailed, unpaired *t*-test, the difference in stopping distance between standard and dynamic (excluding Blank-out) signs was not found to be statistically significant ($t(90) = .84$, $p = .40$). Table E.3.3 breaks down the dynamic sign stopping distances as a function of countermeasure.

Table E.3.2. Distance until Participants Reached Speed of Less than or Equal to 1 mph before Countermeasure (for Participants Who Did So)

Condition	N	Mean (ft)	SD
Standard sign	21	221.8	54.3
Dynamic sign	71	237.1	78.1

To evaluate the efficacy of individual countermeasures on stopping distance, a univariate ANOVA, with a between-subjects factor for the first sign encountered was conducted, and a significant main effect of sign type ($F(4,87) = 10.07$, $p < .001$) emerged. Follow-up pairwise comparisons (adjusted for multiple comparisons with Scheffé's method) found that all dynamic countermeasures, save for the Blank-out sign, were not significantly different from each other (all p's > .985), or from the standard sign (all p's > .975), but were significantly different from the Blank-out countermeasure (all p's < .001).

Table E.3.3. Distance until Participants Reached Speed of Less Than or Equal to 1 mph Before Countermeasure (for Participants Who Did So) as Function of Sign Type

Countermeasure Type	N	Mean (ft)	SD
Standard	21	221.8	54.3
LED	20	208.3	76.5
Wigwag	20	212.3	64.7
RRFB	16	220.8	68.8
Blank-out	15	325.8	31.4

Based on this approach, we are not picking up on participants that did not follow directions (i.e., come to a complete stop), so subsequent analyses, will explore detecting a change in brake response.

Response Distance (Based on Brake Response)

The present analysis sought to explore potential differences in the distance at which participants applied force to the brake pedal, as a function of the type of sign to which they were exposed.

The present unpaired, two-tailed *t*-test analysis explored the distance at which the brake force of the participant was greater than 3% of the maximum force (max force = 180 lbs; 3% is ~10 lbs of pressure). This analysis revealed no significant difference between Standard and dynamic countermeasures ($t(100) = .84$, $p = .40$; see Table E.3.4). Table E.3.5 breaks down the brake distances as a function of countermeasure.

Table E.3.4. Distance Until Participants Applied 3% of Max Braking Force (~10 lbs)

Condition	N	Mean (ft)	SD
Standard sign	24	116.5	83.9
Dynamic sign	78	133.7	88.9

To evaluate the efficacy of individual countermeasures on braking distance, a univariate ANOVA, with a between-subjects factor for the sign encountered was run, and a significant main effect of sign type ($F(4,97) = 13.51$, $p < .001$) emerged. Follow-up pairwise comparisons (adjusted for multiple comparisons with Scheffé's method) found that all dynamic countermeasures, save for the Blank-out sign, were not significantly different from each other (all p's > .839), or from the standard sign (all p's > .801), but were significantly different from the Blank-out countermeasure (all p's < .001).

Table E.3.5.Distance Until Participants Applied 3% of Max Braking Force (~10 lbs), as Function of Sign Type

Countermeasure Type	N	Mean (ft)	SD
Standard	24	116.5	83.9
Wigwag	21	89.1	76.7
LED	20	98.3	70.5
RRFB	18	116.6	75.0
Blank-out	19	236.4	40.2

Secondary Measure of Feeling Unsafe (Turning Around)

A small number of participants interpreted our instructions to mean that they should turn around if they felt unsafe. Three participants did so, and all were in the dynamic condition. Using Fisher's Exact Test, this difference between static and dynamic signs was not statistically significant (neither with Chi Square with Yates correction: X^2 $(1, N = 111) = 0.098$, $p = 0.75$; not without Yates correction: X^2 $(1, N = 111) = 0.991$, $p = 0.32$).

Survey Results

Participants who were exposed to both types of countermeasures (static and dynamic) were asked to rate: 1) how effectively the dynamic WWD countermeasure they saw warned of wrong-way driving **compared to a standard, static sign** (which they viewed after encountering the dynamic sign), and to 2) rate how effectively the dynamic WWD countermeasure warned them of or stopped their wrong-way driving. Question 1 was answered on a 0 to 10 scale, with 0 being "there is no difference" between dynamic signs and the static sign and 10 being "extremely well" compared to the static sign, and Question 2 was rated on a scale from 0 to 10, with 0 being "not effective at all" and 10 being "most effective." In a review of the data, and before viewing condition assignment, it was suspected that one participant reverse coded their responses (rating 0 for both questions related to dynamic signs). This participant was excluded from the reported analyses. Participants also rated the effectiveness of the static sign with respect to warning them of or stopping their wrong-way driving.

In comparison to the standard "WRONG WAY" sign, on average, participants rated dynamic signs as providing a more effective warning (M = 7.65, SE = .26) on a scale from 0 to 10. Ratings were entered into an ANOVA with dynamic countermeasure type (blank-out, LED, RRFB, wigwag) as a between participant factor. This analysis revealed no difference between dynamic countermeasures (F(3, 78) = 2.09, p = .11, $\eta 2$ = .07, Figure E.3.14 white bars). When rating the overall effectiveness of dynamic signs with respect to warning of and stopping their wrong-way driving, participants again rated dynamic countermeasures highly (M = 8.47, SE = .24) on a scale from 0 to 10. However, ratings did not differ as a function of dynamic sign type (F(3, 78) = 0.35, p = .79, $\eta 2$ = .01, Figure E.3.14 black bars). When answering this same question about the static countermeasure they saw, effectiveness ratings were lower (M = 6.34, SE = .30), and this difference compared to the dynamic sign conditions was significant (F(1, 78) = 49.93, p < .001 $\eta 2$ = .39). Although, overall, there was no differences among the dynamic conditions, these signs overall were rated as being more effective at alerting drivers of wrong-way driving compared to static "WRONG WAY" signs.

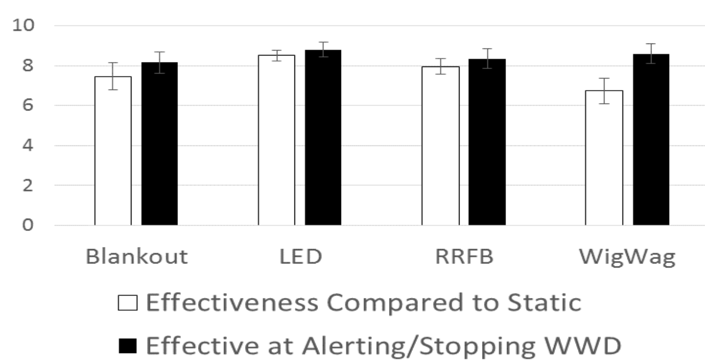

Figure E.3.14. Effectiveness Ratings of Various Dynamic "WRONG WAY" sign Countermeasures on Call of 0 to 10. ***Error bars represent +/- SEM.***

Summary of Ramp Study 1

Although dynamic signs were rated as more effective at conveying their message and stopping wrong-way driving compared to the standard static "WRONG WAY" sign, few behavioral differences emerged between sign conditions. The standard sign stopped participants as well as dynamic signs, with one exception: the blank-out sign did not effectively stop participants. This is likely due to the blank-out sign providing no information about wrong-way driving until it was activated when participants were 200 ft away. The next study examined the effect of two dynamic signs (RRFB, wigwag) under conditions of simulated impairment.

4. RAMP STUDY 2

Participants

A total of 69 participants (M_{Age} = 20, SD_{Age} = 1.62)—undergraduate students from FSU—completed the experiment. Thirty-one individuals participated for course credit, and 38 participated for a payment of $15/hour. Although recruitment materials listed holding a valid driver's license as a requirement for participation, one participant reported not having a driver's license. No reports of simulator sickness were provided during the task, although 4 participants reported slight discomfort (i.e., dizziness) temporarily after their drive. One data file was corrupted, so as a result all analyses included 68 participants unless otherwise noted.

Materials

Materials and procedures were very similar to RAMP STUDY 1.

Participants encountered a "WRONG WAY" RRFB sign, "WRONG WAY" wigwag sign, or a standard "WRONG WAY" sign. Driver reaction to this first countermeasure was of primary interest. However, we asked participants to continue to drive and pass other signs in order to collect pilot/exploratory data. It was anticipated that after the first "WRONG WAY" sign participants would be extremely vigilant and looking for additional wrong-way messages, contaminating their responses to these signs.

Simulated Impairment Goggles

To simulate the experience of drug/alcohol impairment, Fatal Vision Silver Label impairment goggles were used (http://fatalvision.com/fatal-vision-silver-label.html, Figure E.4.1 and Figure E.4.2). The level of distorted vision is marketed as similar to what is to be expected with a BAC level of 0.17 - 0.20. Participants were counterbalanced to one of two conditions wearing the simulated impairment goggles: (1) original simulated impairment goggles and (2) simulated impairment goggles with a tint that blocks 35% of light. The addition of the tint did not seem to greatly influence behavior, so these two conditions were collapsed together in the reported analyses.

Figure E.4.1. Fatal Vision Silver Label Impairment Goggles, with Tint Blocking 35% of Light Absorption

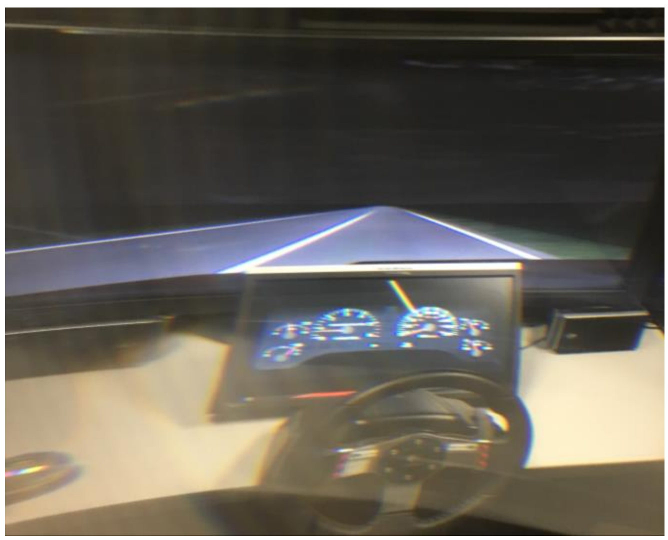

Figure E.4.2. View of Simulated Environment through Fatal Vision Silver Label Impairment Goggles

Procedure

Practice Task

Participants first completed a practice task within the same simulated environment of the experimental task for familiarization with the sensations of driving in a simulated environment, as well as to acclimate to the brake and gas pedals, and the sensitivity of the steering wheel. In this practice task participants were instructed to drive while wearing the impairment goggles until they saw a set of barricades on the left, then come to a complete stop and place the vehicle in park. After doing this the first time, participants were told by an experimenter to repeat this process at the next set of barricades. After the second stop the practice task was terminated.

Experimental Task

Participants were randomly assigned to scenarios in which the first sign encountered was dynamic or static/standard and one of two impairment conditions (impairment without tint, and impairment with tint). In the dynamic condition, participants either first encountered the "WRONG WAY" wigwag countermeasure or the "WRONG WAY" RRFB countermeasure. In the static condition, the first sign encounter by participants was the standard "WRONG WAY" sign.

At the start of the experiment, the lights were shut off, participants were reminded to wear the impairment goggles, and the following instructions were given:

> Your goal in this task is to drive on the highway until the scenario terminates (black screen and returns to screensaver), but at any moment if you feel unsafe, we ask that you come to a complete stop, and place the vehicle in park, just as you did in the practice. At that point if you could ring the bell, I will return with further instructions. We ask that you maintain a speed of 40 mph. If your speed reaches 45 mph, a police siren will go off to alert you.

If participants reported feeling unsafe, they received the following instructions:

> Thank you for coming to a complete stop. Did you have any issues with the brakes or placing the vehicle in park? [participant responds] We now ask that you continue down the highway, but if at any point you notice that you feel unsafe, please come to a complete stop again and place the vehicle in park as you have just done. The scenario will terminate automatically when the task is complete. Please place the vehicle back in drive (using the paddle shifters) once I have closed this door.

Upon completion of the scenario, participants completed a Qualtrics demographics survey.

5. RESULTS

In general, response to the "WRONG WAY" wigwag and the "WRONG WAY" RRFB were similar, so in most analyses we collapse data into a "standard" and "dynamic" countermeasure condition. Similar responses were also observed with and without additional tint, so these conditions were collapsed. Of primary interest was whether participants stopped in response to the first countermeasure they encountered, and if so, when and where they stopped.

Responses by Area of Interest

An effective wrong-way countermeasure sign would cause a driver to slow or stop and turn around in advance of the sign, and in this task participants were instructed to stop the vehicle at the first sign that they felt they were in an unsafe situation. Thus, we compared slowing/stopping behaviors across the different countermeasure conditions. To quantify differences in responding, we used the same AOIs as Ramp Study 1. Figure E.5.3 represents these data.

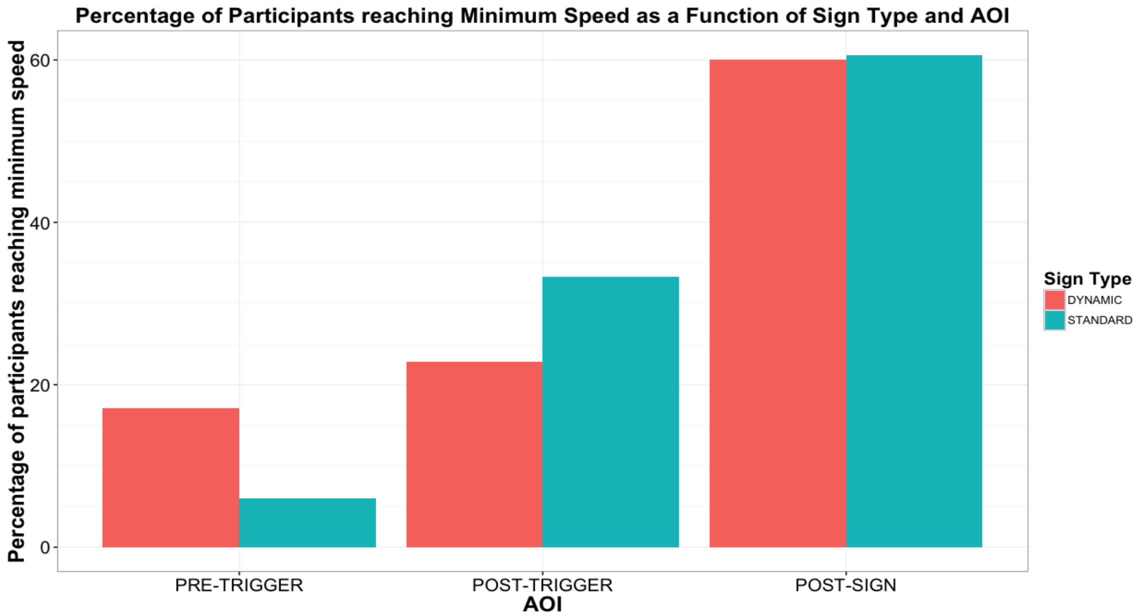

Figure E.5.3. Percentage of Participants Reaching Minimum Speed as Function of Sign Type and Area of Interest

Overall, both sign types of signs yielded comparable numbers of participants responding as a function of area of interest, except for the case of the pre-trigger AOI where there were more respondents in the dynamic condition than the standard condition. One important point to note is that that within the pre-trigger AOI, both signs had a roughly similar appearance (since the dynamic signs were not flashing). Any difference at this point between conditions is due to chance alone.

We also evaluated the sign efficacy by plotting survival curves depicting the proportion of participants in each group who were still driving (i.e., have not stopped or turned around) at each point in the scenario. Figure E.5.4 represents this analysis (removing those who stopped well in advance of the trigger locations). Note that the sign occurred at a distance of 9,000 ft, and the trigger for the dynamic countermeasures occurred at 8,800 ft.

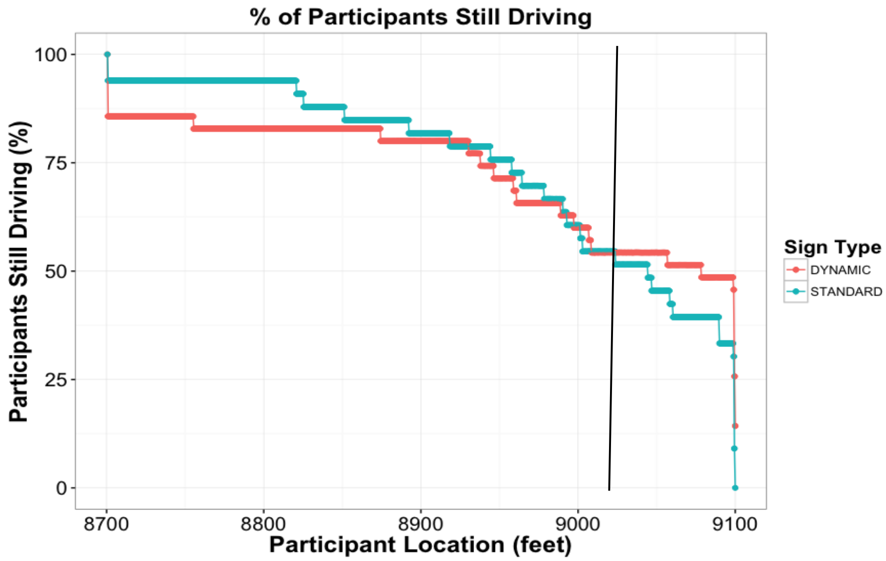

Figure E.5.4. Survival Curve Analysis of Participants Who Were Still Driving, as a Function of Sign Type and Location in Simulated Environment. ***Note that large majority of participants in both conditions discontinued driving forward within 100 ft of countermeasure, regardless of whether it was static or dynamic. Position of countermeasure indicated with solid black line.***

Results suggest that the static sign was as effective at stopping participants as the dynamic signs. A chi-square test with Yates correction compared the proportion of participants who stopped before vs. after the sign and found no difference between conditions, X^2 (1, N = 61) = 0.034, p = 0.85 (without Yates correction, considered to be strict, X^2 (1, N = 61) = 0.208, p = 0.65).

Response Distance (to Complete Stop)

In this task, participants were asked to come to a complete stop whenever the felt unsafe. For the purposes of this analysis, we were interested in exploring how many feet (beginning 300 ft before the sign location) it takes for a participant to come to a speed of less than 1 mph (Table E.5.1). Note that this may not capture participants who discontinued by turning around without stopping, or participants who stopped after the countermeasure instead of before it.

Table E.5.1. Distance Until Participants Reached Speed of Less than or Equal to 1 mph Before Countermeasure for Participants Who Did So

Condition	N	Mean (feet)	SD
Dynamic signs	8 (23%)	277.9	59.5
Standard signs	11 (33%)	285.5	62.7

An unpaired two-tailed t-test revealed no difference between Standard and dynamic sign conditions (t(17) = 0.27, p = 0.79).

To explore differences in stopping behavior across the two types of dynamic signs, an unpaired, two-tailed *t*-test analysis would be ideal, but since the RRFB condition only had 1 participant, it could not be calculated. The means and standard deviations are shown in Table E.5.2 below instead.

Table E.5.2. Distance until Participants Reached Speed of Less than or Equal to 1 mph for Participants Who Did So

Condition	N	Mean (ft)	SD
RRFB	1 (3%)	296.6	-
Wigwag	7 (19%)	275.2	63.7

Based on this approach, we are not picking up on participants that did not follow directions (i.e., come to a complete stop), so subsequent analyses will explore detecting a change in brake response.

Response Distance (Based on Brake Response)

The present analysis sought to explore potential differences in the distance at which participants applied force to the brake pedal, as a function of the type of sign to which they were exposed.

The present unpaired, two-tailed t-test analysis explored the distance at which the brake force of the participant was greater than 3% of the maximum force (max force = 180 lbs; 3% is ~10 lbs of pressure). This analysis revealed a significant difference between standard and dynamic countermeasures ($t(32) = 2.2349$, $p = 0.0325$), in that standard countermeasure unexpectedly resulted in earlier braking responses by 67 feet (Table E.5.3).

Table E.5.3.Distance Until Participants Applied 3% of Max Braking Force (~10 lbs)

Condition	N	Mean (ft)	SD
Dynamic signs	18 (51%)	222.2	94.9
Standard sign	16 (48%)	155.0	78.3

To explore differences in brake response behavior across the two types of dynamic signs, an unpaired, two-tailed t-test analysis was run. This analysis revealed significant differences between the two types of countermeasures in terms of their efficacy in encouraging stopping behaviors ($t(16) = 2.2104$, $p = 0.042$), in the direction of the “WRONG WAY” wigwag encouraging earlier braking by 94.7 (Table E.5.4).

Table E.5.4. Distance Until Participants Applied 3% of Max Braking Force (~10 lbs)

Condition	N	Mean (ft)	SD
RRFB	6 (19%)	285.3	80.6
Wigwag	12 (32%)	190.6	87.9

Secondary Measure of Feeling Unsafe (Turning Around)
In addition to the analyses presented, a subgroup of participants (*N*=13; 8 who received a dynamic sign first, 5 who received a standard sign first) interpreted the instructions regarding feeling unsafe and coming to a complete stop as indicating they should turn around (although this was never stated in the instructions for the task). Using Fisher's Exact Test, this difference was not statistically significant (p = .54).

Table E.5.5. Number of Participants Turning Around in Each Condition

	Turned Around	Did Not Turn Around	Total
Dynamic signs	8	27	35
Standard signs	5	28	33
Total	13	55	68

Summary of Ramp Study 2

Under conditions of simulated impairment, little difference was observed between dynamic and static signs. Out of the two dynamic signs, some evidence for earlier braking was observed for the "WRONG WAY" wigwag sign compared to the RRFB "WRONG WAY" sign.

6. DISCUSSION & RECOMMENDATIONS

Our model of WWCs predicts that a greater number of cues made available to drivers in and around off-ramps will decrease the likelihood of WWE and WWCs. In recent simulator experiments reviewed here, adding additional countermeasures, including arterial countermeasures, reduced confusion regarding highway entrance points. This was most evident in driver speed. When fewer countermeasures were present, drivers slowed near the off-ramp as if they were considering turning onto it. In the first experiment reported, there was also a trend for fewer WWE when arterial countermeasures were added to an interchange. **Converging evidence from two previous studies suggests that arterial changes can make a difference, reducing confusion, and we recommend these changes to reduce WWEs.**

In the two studies examining dynamic and static signs on a simulated off-ramp, participants rated dynamic signs containing flashing elements (blank-out, LED, RRFB, wigwag) as more effective at alerting them of wrong-way driving compared to a standard static "WRONG WAY" sign. However, when it came to behavioral evidence, there was little indication that dynamic "WRONG WAY" signs provided a better cue that drivers should stop compared to the static sign. In both experiments, for the most part, all countermeasures were equally effective. In Ramp Study 1, the large majority of participants stopped in advance of all "WRONG WAY" signs whether they were dynamic or static. The one exception was the blank-out sign. Our study found the blank-out sign may be less effective; most participants stopped after the blank-out sign rather than before it. In Ramp Study 2, even under conditions of simulated impairment, most participants stopped either before each countermeasure or shortly after it (within 100 ft). Here again, there was little difference between static and dynamic signs. Replacing a standard

“WRONG WAY” sign with a blank-out sign may provide less information rather than more information because it provides no message until it is triggered. Depending on the speed of the wrong-way driver, there may not be enough time to extract the sign’s meaning. **Based on these results, we recommend avoiding the use of the “WRONG WAY” blank-out sign.** There did not seem to be a disadvantage with respect to other dynamic “WRONG WAY” signs (relative to a standard static sign). **We are hesitant to recommend against other dynamic off-ramp signs despite little evidence for a behavioral benefit in the reported simulator studies.** First, participants rated these signs as more effective at alerting them of their wrong-way driving. Second, based on the attention literature, there is little reason to doubt that these signs are not more effective at capturing attention. Unless signs first capture attention, there is little hope for them to convey the appropriate message. Conditions to test this effect may not have been ideal in the simulator. In our task, we were required to give instructions to our participants on how to respond and the nature of the task. By alerting drivers that they should stop if they feel unsafe, we may have encouraged participants to be extra vigilant, enhancing the processing of countermeasures. It is certainly plausible that on the road, dynamic signs may be especially beneficial to drivers who are unaware of the potential of danger, believing that they have correctly entered an entrance ramp.

Benefits of dynamic countermeasures are consistent with recent operational field studies that have found that dynamic “WRONG WAY” signs featuring red LEDs were associated with a decrease in wrong-way driving events (Finley et al., 2016). Although no behavioral benefits were observed in the current study, it is important to consider these results in the context of the other analyses and evaluations of the larger project, and some of the limitations of simulator work and the current study design.

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